

NON-STRUCTURAL MASONRY WALLS STRENGTHENED WITH GFRP LAMINATES

E.D. Bastidas*, L.F. Molina *, L. Yamin **, A. Sarria ***, J.P. Ortega ****

ABSTRACT

One of the major construction systems in Colombia, and in general throughout Latin America, consists of multistory moment resisting reinforced concrete (RC) frames filled with unreinforced masonry (URM) walls. These non-structural masonry walls are conventionally built using clay tiles. Due to the high seismic activity in Colombia, this kind of masonry wall is prone to damage. One of the alternatives being explored in Colombia to prevent the failure or lessen the damages in clay tile URM walls is to strengthen them with Glass Fiber Reinforced Polymer (GFRP) laminates. This paper presents promising results of experimental tests conducted on twenty-six wallettes of 9x70x70 cm and 9x120x120 cm, which were strengthened with different layouts of GFRP laminates. In addition, a full-scale wall was tested to validate the technology. The paper discusses the effect of GFRP laminates on the failure mechanisms, capacity and ductility parameters as well as on the overall reduction of earthquake damage for clay tile URM walls.

KEYWORDS

- GFRP Laminates, • Non-Structural Masonry, • Clay Tiles, • URM Walls and Wallettes,
- Diagonal Tension, • Glass Fiber Sheet, • Epoxy Resin.

INTRODUCTION

One of the major construction systems in Colombia, and in general throughout Latin America, consists of multistory moment resisting reinforced concrete (RC) frames filled with unreinforced masonry (URM) walls. These infill walls do not have a structural function and are conventionally built using clay tiles and type M or S mortar. The walls are not in full contact with the surrounding RC structural elements and the gap widths are not uniform.

Upon completion of the wall, the surface is covered with plaster. Due to the high seismic activity in Colombia, this kind of masonry wall is prone to damage. As a matter of fact, post-earthquake observations of the earthquake in Armenia, Colombia, in January of 1999, indicated that failure of clay tile URM walls accounted for a large percentage of the overall losses in the affected civil infrastructure. One of the alternatives being explored in Colombia to prevent shear failure in clay tile URM walls is to strengthen them with fiber reinforced

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polymer (FRP) laminates. Available literature shows that FRP systems can remarkably increase the structural performance of masonry elements (Silva 2001; Tumialan 2001). However, no research is available on walls built with clay tiles that exhibit a more brittle behavior. Walls built with this kind of units can fail due to fracture of corners (see Figure 1a) or shear failure (see Figure 1b). This article presents the results of an experimental program conducted on wallettes of 70x70 cm. and 120x120 cm., which were strengthened with different layouts of GFRP laminates. In addition, a full-scale wall was tested to validate the technology. The results indicated that FRP reinforcement can efficiently improve the shear strength and deformation capacity of URM walls built with clay tiles.



(a) Fracture of corners



(b) Shear failure

Figure 1. Failure in walls built with clay tiles

FIBER REINFORCED POLYMERS (FRP) LAMINATES

FRP material systems, composed of fibers embedded in a polymeric matrix, exhibit several properties, which make them suitable for their use as structural reinforcing elements. FRP composites are characterized by excellent tensile strength in the direction of the fibers and by negligible strength in the direction transverse to the fibers. FRP composites are corrosion resistant and are expected to perform better than other construction materials in terms of weathering behavior. FRP laminates are formed by manual lay-up onto the surface of the member being strengthened. The FRP matrix consists of a polymer, or resin, used as a binder for the reinforcing fibers. The matrix has two main functions: to enable the load to be transferred among fibers and, to protect the fibers from environmental effects. In a composite material, the fibers have the role of the load-bearing constituent. Fibers give the composite high tensile strength and rigidity along their longitudinal direction. For structural applications three types of reinforcing fibers: carbon, aramid and glass are commonly used, which are used for the fabrication of Carbon FRP (CFRP), Aramid FRP (AFRP) and Glass FRP (GFRP) laminates, respectively. Table 1 presents some of the characteristics and properties of these laminates. In this investigation, due to their lowest cost with respect to the other fibers, GFRP laminates were selected to strengthen the non-structural masonry specimens.

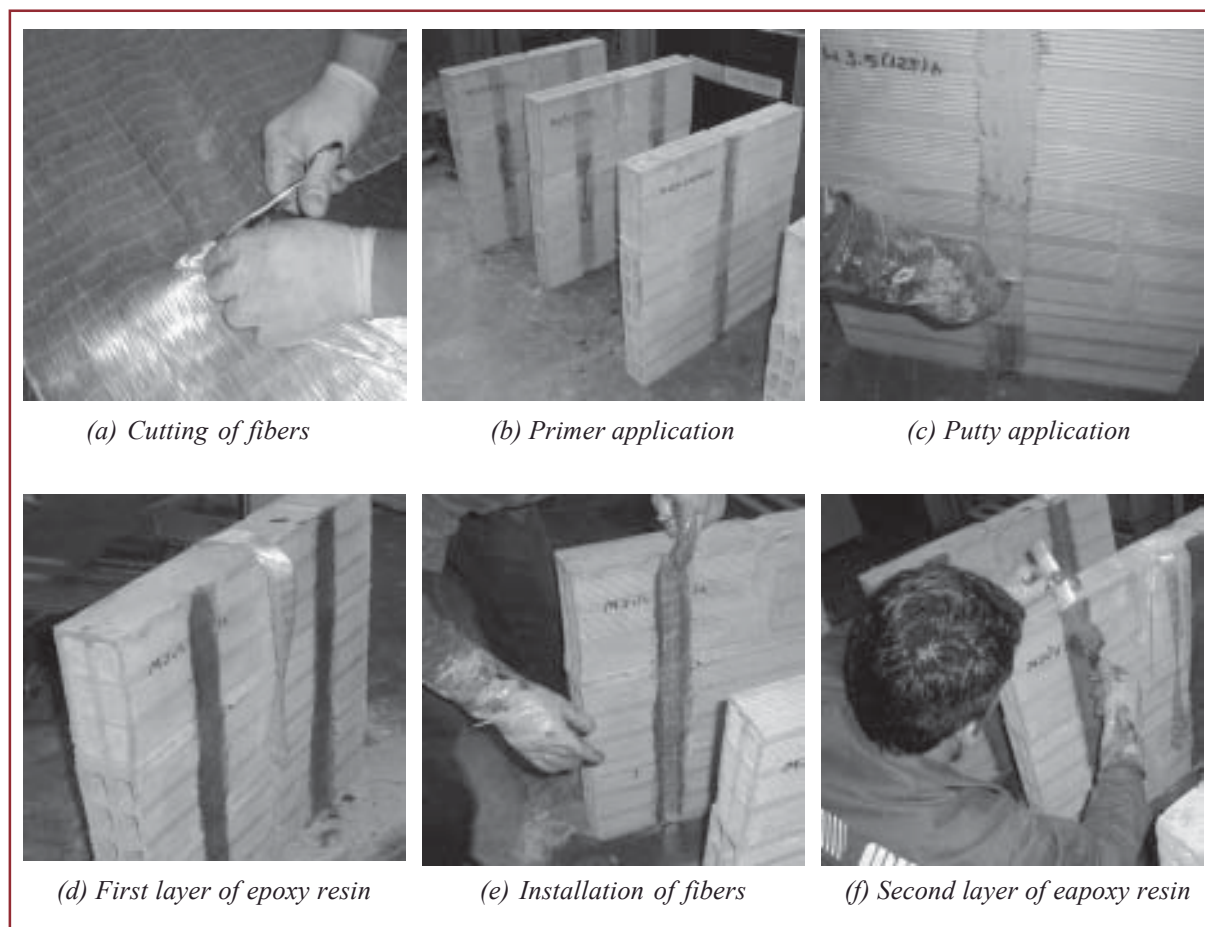
Table 1. Characteristics and Properties of FRP Laminates

Material	Density (g/m ³)	Thickness (mm)	Design Strength (MPa)	Modulus of Elasticity (GPa)	Maximum Strain (%)
GFRP	900	0.35	1520	72.4	2.10
AFRP	600	0.279	2000	120	1.67
CFRP	300	0.165	3800	227	1.67

The method for the strengthening of the URM wallettes is graphically described in Figure 2 and it can be summarized as follows:

- The glass fiber sheets are cut to the specified width and length.
- A layer of primer resin is applied to the surface to fill microcavities in the surface.
- Putty filler is applied, the primary purpose of using putty is to level the uneven surfaces present on the wall surface and to provide smooth and uniform surface to adhere the fibers.
- A layer of epoxy resin is applied to the surface using a roller to bond the fibers. Following this, the fibers are adhered to the wall surface.
- Once the fiber sheet is placed, it is pressed down using a “bubble roller” to eliminate entrapped air between the epoxy resin and fibers.
- Finally, a second layer of epoxy resin is applied to impregnate the fibers, which, after hardening, enables the newly formed laminate to become an integral part of the strengthened member.

Figure 2. *Installation of GFRP Laminates*



EXPERIMENTAL PROGRAM

As part of this investigation, laboratory tests were conducted on masonry wallettes and one full-scale wall. The specimens were built with non-structural clay tile units and strengthened with different layouts of GFRP laminates. The

in-plane tests were both static and cyclic. The non-structural clay tile units were 9 cm. wide, 23 cm. high and 33 cm. long, with a gross area of 207 cm² and a net area 97 cm². The compressive strength of the masonry units was 3.4 MPa. The clay tile units in the corners, where the load was applied, were filled with mortar

to prevent local failures (i.e. crushing) at the supports.

Testing of Wallettes of 70 x 70 cm.

The wallettes were tested in diagonal tension (see Figure 3), using different strengthening configurations: vertical, horizontal and a combination of both. Table 2 summarizes the main characteristics of these wallettes.



Figure 3. GFRP Strengthened wallettes subjected to diagonal tension.

Figure 4 shows a typical shear stress-shear strain curve for both URM wallettes and GFRP strengthened wallettes. An increase in both shear strength and shear deformation capacity was clearly obtained for the GFRP strengthened wallettes when compared to the control specimens.

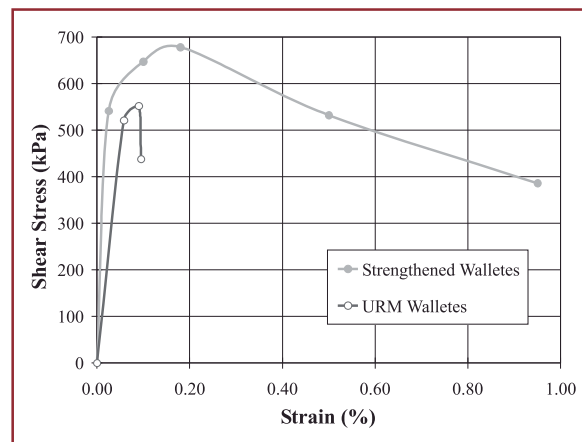


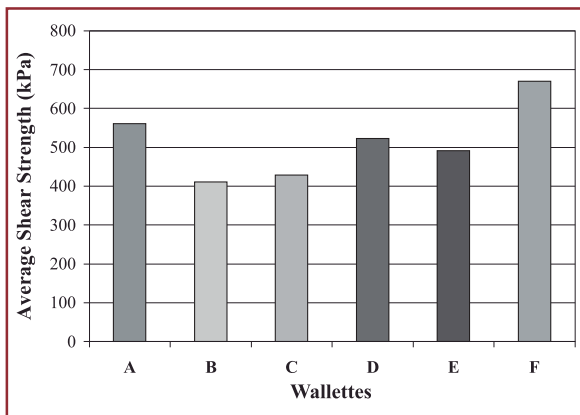
Figure 4. Typical shear stress vs. shear strain curve (Wallettes of 70x70 cm.)

Table 2. Characteristics of wallettes of 70x70 cm.

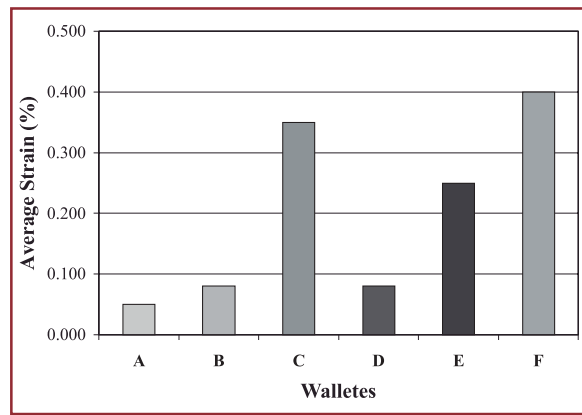
Reinforcement Scheme						
Wallette	A	B	C	D	E	F
Mortar Average Strength (MPa)	M 18	S 13	S 13	S 13	M 18	M 18
Reinforcement Width (cm)	-	-	2.5	3.0	2.5	3.5
Reinforcement Front Side	-	-	2 strips	2 strips	2 strips	1 strips
Reinforcement Back Side	-	-	-	-	-	1 strips
Number of Wallettes	2	2	2	2	2	2
Horizontal Spacing (cm)	-	-	-	33	23	-
Vertical Spacing (cm)	-	-	23	-	-	-

Figure 5 presents the average shear strength and maximum average shear strain obtained from the tests performed on the different specimens. The shear strength for control wallettes A and B ranged between 561 kPa and 411 kPa for mortars type M and S, respectively, according to NSR-98 Classification, Title D. Type C wallettes with double horizontal GFRP strips placed on the mortar joints, on just one wallette side, showed a small increase in shear strength of approximately 4% as compared with the corresponding control specimen. Type D wallettes with double vertical reinforcement on alternate mortar joints on one side showed a

shear strength increase of 27% with respect to the corresponding control specimen. Conversely, Type E wallettes with vertical GFRP reinforcement off the joints did not show any increase with regard to the corresponding control specimen. Type F wallettes exhibited an increase of 19% with respect to the corresponding control, having the largest value of shear strength amongst the group of tested wallettes. The strengthened wallettes had also a significant higher deformation capacity than the non-strengthened specimens. The exception was the Type D, where local failures in the support zone of the specimens were detected.




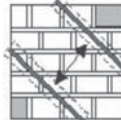
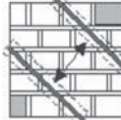
(a) Average Shear Strength



(b) Maximum Average Shear Strain

Figure 5. Test results for wallettes of 70x70 cm

Table 3. Characteristics of wallettes of 120x120 cm.

Reinforcement Scheme			
Wallette	G	H	I
Mortar Average Strength (MPa)	M 18	M 18	M 18
Reinforcement Width (cm)	-	1.5	2.0
Reinforcement Front Side	-	2 strips	2 strips
Reinforcement Back Side	-	2 strips	2 strips
Number of Wallettes	2	4	4
Diagonal Spacing (cm)	-	56	56

Testing of wallettes of 120 x 120 cm.

Six wallettes of 120x120 cm., with different strengthening configurations, were tested in diagonal tension. Table 3 presents the main characteristics of the wallettes.

Figure 6 presents typical shear stress vs. shear strain curves for both URM wallettes and GFRP strengthened wallettes. An increase in both shear strength and shear deformation capacity was also observed, as in the case of the wallettes of 70x70 cm.

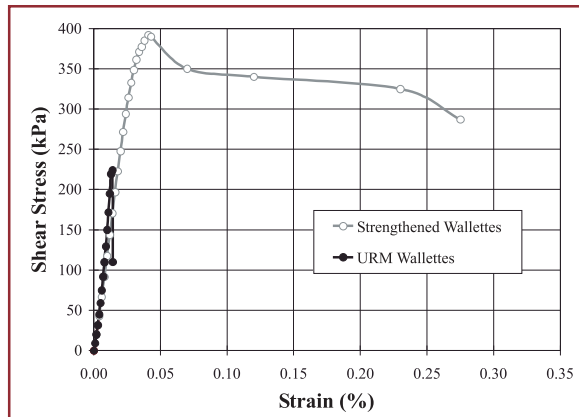
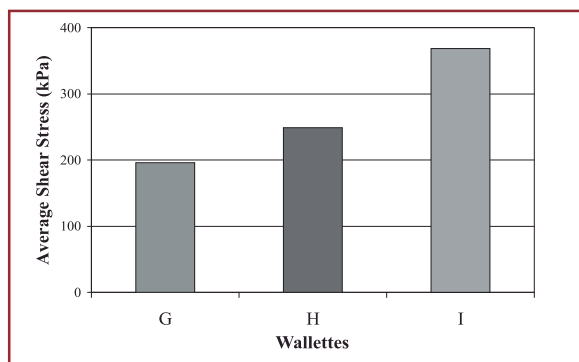


Figure 6. Typical shear stress vs. shear strain curve (wallettes of 120x120 cm.)

Figure 7 summarizes the average shear strength and the maximum average shear deformations measured in the tests.



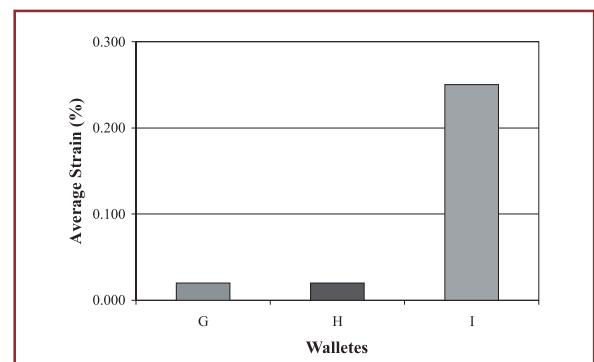
(a) Average shear strength

The wallettes Type G, used as baseline, exhibited a shear strength of approximately 196 kPa for type M mortar. The wallettes Type H, with double crossed reinforcements of 1.5 cm. wide strips, showed increases in the average shear strength of about 27%. Finally, the Type I wallettes, with a configuration similar to Type H but using 2 cm. wide strips, showed an increase of strength of approximately 88% with respect to the corresponding control specimens. In general, an increase in the shear deformation capacity of the reinforced assemblies was observed, with the exception of those that showed a local failure in the support zones. In those cases, the wallettes were not able to develop a larger deformation capacity.

Testing of Full-Scale Wall

An infill masonry wall, surrounded by an RC frame, was built, using hollow clay bricks to represent a typical construction system used in Colombia and many other parts of the world. The frame was designed and built providing enough ductility to allow for large horizontal deformations. The wall was 2.2 m. high, 3 m. long; and 9 cm. thick.

Based on the results obtained from the testing of the wallettes, it was decided to strengthen the wall with 2.5 cm wide diagonal strips, as



(b) Maximum average shear strain

Figure 7. Test results for wallettes of 120x120 cm

shown in Figure 8. The GFRP strips were applied on both sides of the wall to guarantee symmetrical behavior during the cyclic loads. The

wall was tested under in-plane cyclic lateral loads, following a displacement-controlled method. Different drifts were applied, from

0.01% to 1.5%. Figure 9 shows the displacement history at the top of the wall.

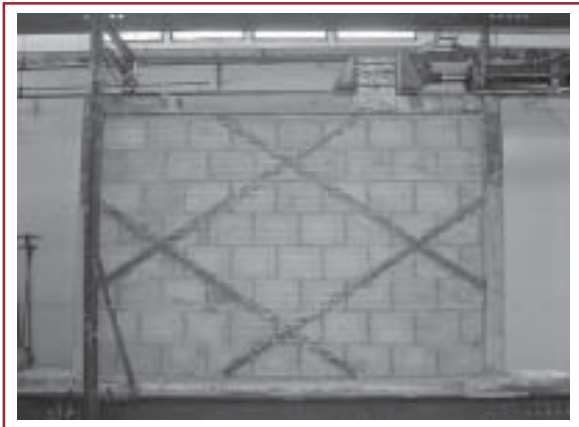


Figure 8. Full scale wall strengthened with GFRP strips

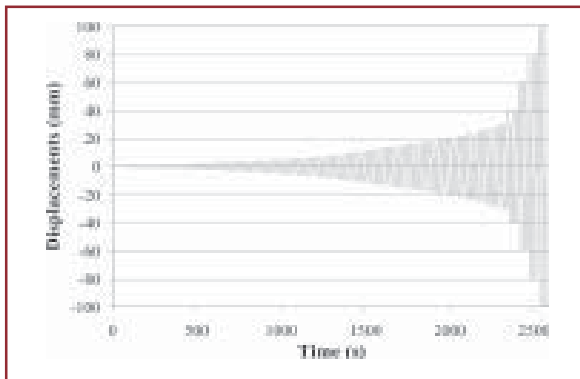


Figure 9. Displacement history

Figure 10 presents the lateral load vs. top displacement. The RC frame-wall system showed a good behavior maintaining its carrying capacity until drift values of up to 1%. The first cracks were detected approximately at 0.3% of the drift. However the masonry wall maintained its integrity and stability up to 1% drift. In addition to the separation between the wall and the frame, some cracking occurred in the masonry mainly in the top corners not covered by the reinforcement as show in Figure 11.

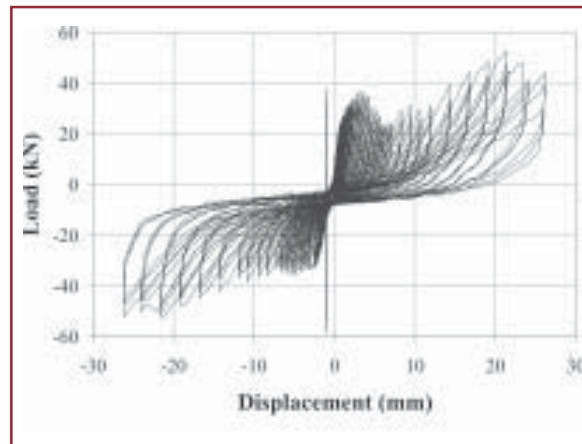


Figure 10. Lateral load vs. top displacement



(a) Initial tracking in the corners

(b) Fracture of corner unit

Figure 11. Frame-wall system cracking for a drift of 1%

A significant global reduction of damage levels were observed for the masonry wall with respect to results reported on similar URM walls (Yamin, 1994). Global stability and overall seismic behavior were greatly improved with the GFRP reinforcement for in-plane loading.

CONCLUSIONS

The following conclusions can be drawn from this investigation:

- Strengthening of non-structural masonry walls using GFRP laminates represents an interesting and promising alternative for the reduction of damage, generally sustained by this type of elements for medium and high-intensity earthquakes.
- A large percentage of the damages caused by earthquakes are associated with failure of URM elements. Speed and ease of installation of FRP laminates make them a very attractive alternative for rehabilitation and strengthening of these elements.
- The tests have shown the efficiency of the GFRP laminates for increasing the shear strength as well as the ductility of the system. The level of global damage was reduced and an increase in the stability and global integrity of this kind of walls were also observed.
- It is recommended to use strips applied in a cross-pattern on both sides of the wall to avoid asymmetries and out-of-plane bending. Areas of high load concentration such as corners should be filled with grout to avoid the fracture of the units.

- Construction practices vary from region to region. Furthermore, masonry typologies vary by years. As a consequence, different kinds of masonry typologies can be observed. The masonry typology of a particular wall should be studied to fully-realize the benefits of the FRP reinforcement and not overestimate the wall response. Different loads configurations, out-of-plane stability, durability, environmental effects, temperature changes and other factors that can affect the use and benefits of the system should be also studied.

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“SISTEMA PROBABILÍSTICO DE INFORMACIÓN GEOGRÁFICA DE AMENAZA SÍSMICA DE COLOMBIA”

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ABSTRACT

Computation of seismic hazard at rock or firm sites has been a well established technique for many years. Hazard is generally expressed in terms of exceedance rates (ER), defined as the mean annual number of times in which a given value of intensity is exceeded. The inverse of the ER of some intensity is called its mean return period. Usually, the practice was to compute seismic hazard in terms of ER of peak motion values, such as peak ground acceleration, velocity and displacement,. More recently, uniform-hazard response spectra (UHS) have been constructed in a more direct and precise way, by means of attenuation equations that relate, typically, magnitude and distance with response spectral values for a range of periods. By performing a conventional hazard analysis on a period by period basis, it is possible to construct response spectra whose ordinates are, all, associated to the same return period, thus constituting a UHS. In order to compute approximate uniform-hazard response spectra at places affected by local soil amplifications, several approaches have been adopted in the past to overcome analytical difficulties. We present a coherent approach to construct UHS of different intensities at soft soil sites by means of interactive Internet-software named Zp, which will be illustrated with deterministic validations on Armenia city during the 25 January Armenia Earthquake and probabilistic examples for Bogotá city.

PALABRAS CLAVES:

- Espectros de Respuesta, • Diseño Sísmico, • Peligro Sísmico • Dinámica de Suelos.

INTRODUCCIÓN

Desde la década de los 80 se iniciaron estudios por parte de la Universidad de los Andes (*Uniandes*) e Ingeominas para la zonificación geotécnica de la ciudad de Bogotá. Dicha labor se efectuó mediante diversas técnicas hasta llegar a una distribución de zonas que para hoy se tienen bien definidas y delimitadas. Fue así como en 1992 se acordó realizar el proyecto

de forma conjunta entre *Uniandes* y el *Ingeominas*, trabajo que fue terminado en 1997. En 1999, *Uniandes* y la firma PSI Ltda realizaron el estudio de amenaza sísmica sobre puntos ubicados sobre la línea proyecto de metro de la ciudad de Bogotá, para lo cual se hicieron perforaciones hasta la roca y se midió la velocidad de onda en el sitio mediante técni-

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