THE "EJE CAFETERO" EARTHQUAKE, COLOMBIA OF JANUARY 25 1999

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SUMMARY

A moderate shallow earthquake struck the west central region of Colombia on 25 January 1999. The earthquake caused damage of approximately NZ $3.7 billion (US $1.9 billion), 1,230 deaths. About 200,000 people were made homeless.

The level of damage and losses can be attributed to the shallow focus of the earthquake and its proximity to the major towns, together with topographical effects and soft soil conditions, which amplified the ground motions in some areas. The lack of a well- co-ordinated, national emergency response strategy, and the severe impact of the event on the organisations and key individuals responsible for managing the emergency response in the affected area, impaired the emergency response in the aftermath.

This paper summarises the main findings of a reconnaissance team to the region organised by the New Zealand Society for Earthquake Engineering.

1. INTRODUCTION

The west central region of Colombia, known as the "Eje Cafetero" (coffee-growing axis) was strongly shaken by an earthquake at 1:19 pm (18:19 UTC) on 25 January 1999. The earthquake affected the regions of Quindío, Risaralda and Caldas, including the cities of Armenia (pop. 270,000) and Pereira (380,000) and fifteen other smaller towns. 1,230 people were killed and 8,000 injured. About 50,000 dwellings either collapsed or were rendered uninhabitable due to the extent of damage and 200,000 people were left homeless. The economic losses are estimated at NZ $3.7 billion (US $1.9 billion) [1].

The New Zealand Society for Earthquake Engineering (NZSEE) sent a reconnaissance team to the region four weeks after the earthquake. The goal of the mission was to document issues relevant to the occurrence of a similar event in New Zealand. One of us (JR) returned to the affected region in a follow-up visit four months later to document some aspects of the post-event recovery.

In this report we summarise our findings and draw conclusions about the potential impact of similar earthquakes on the emergency response capabilities and infrastructure of New Zealand urban centres. The information we collected consists of direct observations as well as anecdotal information compiled during interviews with individuals in the affected areas.

2. SEISMOLOGICAL ASPECTS

2.1 Tectonic Setting

Colombia is located at the northwestern corner of South America in a region of tectonic convergence between the Nazca, Caribbean and South American lithospheric plates (Figure 1). Along the Pacific margin of Colombia, the Nazca Plate is subducted eastward at a rate of approximately 70 mm/year, while along the Caribbean margin the Caribbean plate is subducted southward beneath Colombia at the slower rate of 10 mm/year. Landward of the subduction margins, several large active fault zones accommodate deformation within the crust of the South America plate. One of the largest is the Romeral Fault System [2], which represents an old suture zone between oceanic rocks on the west and continental rocks on the east. The January 25 earthquake resulted from the rupture of one element of the Romeral Fault System.

2.2 Historical Seismicity

Written records of earthquakes in Colombia extend back to the early 1500s. Since that time the Pacific margin has generated most of the damaging earthquakes, and all of the great (M>8) events. Large earthquakes of the twentieth century included the M 8.9 earthquake of 31 January 1906, and the M 7.8 Tumaco earthquake of December 23, 1979. The great earthquake of 1906 struck the border region of Colombia and Ecuador, killing about 400 people [3]. However, the region was sparsely populated and the magnitude of this earthquake was overshadowed by the M 8.2 earthquake of 18 April 1906 in San Francisco, USA, and the M 8.6 earthquake centred near Valparaiso, Chile on 17

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August of the same year. The Tumaco earthquake of 1979 was accompanied by a tsunami that killed about 500 people [3].

Despite the large size of the shallow-subduction zone earthquakes, most of the casualties and economic losses associated with earthquakes in Colombia have been caused by moderate magnitude earthquakes whose epicentres are located in the Andean region. This is explained by the distribution of greatest population along the fertile axis of the Andean volcanic chain.

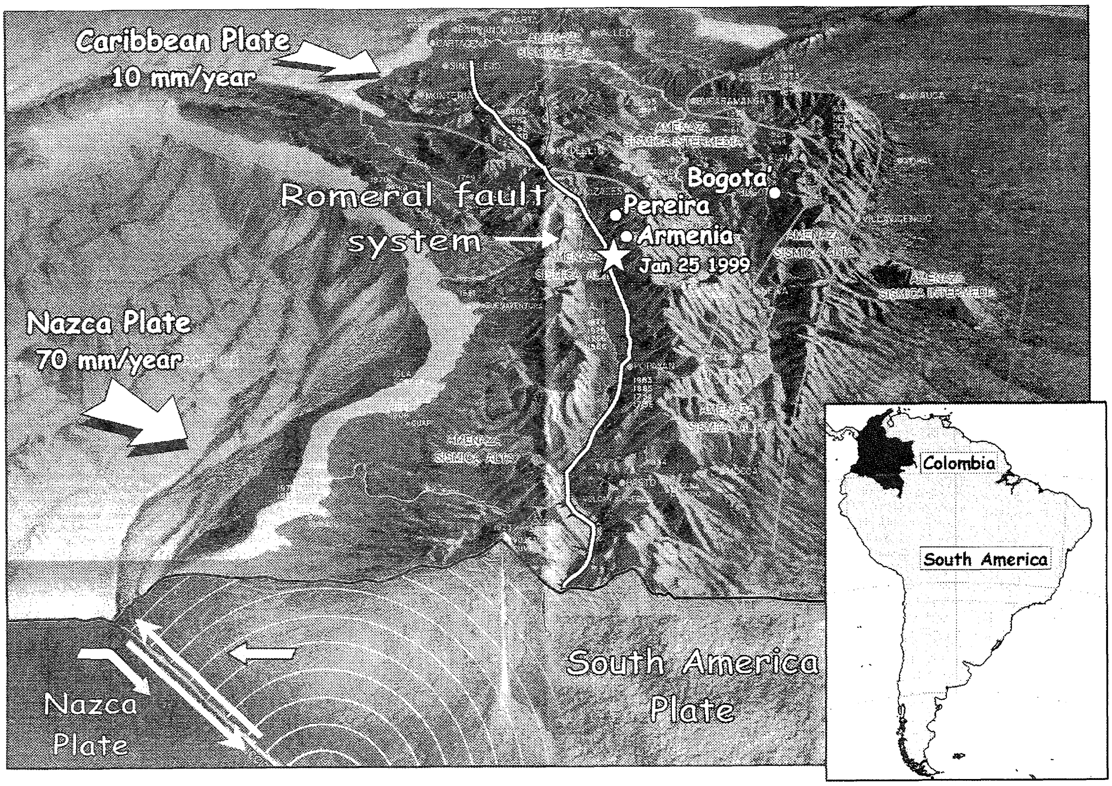


Figure 1: Topography of Colombia and main fault systems. (Adapted from [19]).

Earthquakes in the central-west Andean region of Colombia have two main sources. Intermediate depth earthquakes result from slip across a deeper portion of the subducted Nazca plate, at depths of 80-100 km beneath the Cordillera (Figure 1). Less frequently, shallow earthquakes also occur in the crust of the South American along the Romeral Fault System. Intermediate depth earthquakes have repeatedly damaged towns along the Cordillera Central, in 1961 Armenia-Calarca (M_s 6.7), 1962 Tadó (M_s 6.9), 1979 Viejo Caldas (M_s 6.7), 1992 Murindó (M_s 7.2), 1994 Paez (M_s 6.2) and 1995 Calima (M_s 6.8). By contrast, the only documented historical ruptures of the Romeral Fault System have occurred in southern Colombia. In 1983 the colonial city of Popayán was badly damaged by a shallow M_s 5.5 earthquake originated in the Romeral Fault System [3]. Although several earthquakes have been felt in Quindio (eg. in 1961 and 1995), not a single event in recent times had induced extensive damage to the city of Armenia prior to the event of 25 January.

2.3 Romeral Fault System

The Andes in Colombia comprises the Western, Central and Eastern Cordilleras, see Figure 1. The Cordilleras have resulted from collision and mountain building between the South America and Nazca plate boundaries. The Cordilleras extend predominantly in the north-south direction and are characterised by active volcanoes and bounded by intra-plate faults along their flanks. The largest intra-plate fault zone is the Romeral Fault System (RFS) which comprises a 20-40 km wide set of regional fractures that runs parallel to the western slope of the Central Range of Colombia (Cordillera Central) [2].

The RFS extends throughout Colombia, from the Guayaquil Gulf in Ecuador on the south, to the Caribbean Sea on the north (Figure 1). The number of faults varies from three to five, with additional subsidiary faults depending on the location [4]. The January 25, 1999 earthquake resulted from the rupture of a section of the RFS, where no significant historical seismicity had been documented previously. Recent geological studies however, had identified that the Romeral system in this area is active, with slip-rates on individual faults probably in the range of 0.1 to 1.0 mm/year [4, 5, 6].

2.4 The January 25 earthquake

The Colombian Geological Survey (INGEOMINAS) [7] located the epicentre of the earthquake at 4.41° N, 75.72° W, which is about 15 and 50 km south of the cities of Armenia and Pereira, respectively (Figure 2). The earthquake was only moderate in size, but shallow, with moment magnitude M_w = 6.2 [8] and estimated depth of 10 km [7]. The largest aftershock, M_w 5.8, occurred the same day at 5:40 pm local time and caused further damage.

The earthquake sequence was recorded initially by relatively distant (>100 km) stations of the INGEOMINAS and OSSO (Observatorio Sismológico del Suroccidente) seismological networks, supplemented several days later by a dense network of portable instruments deployed in the epicentral region by personnel from INGEOMINAS and Universidad de Quindío. Numerous aftershocks indicated a north-to-south alignment of epicentres, extending north from the main shock epicentre to the city of Armenia (Figure 3a). The depth distribution of earthquakes indicated a steeply-dipping rupture restricted to the upper 20 km of the crust (Figure 3b).

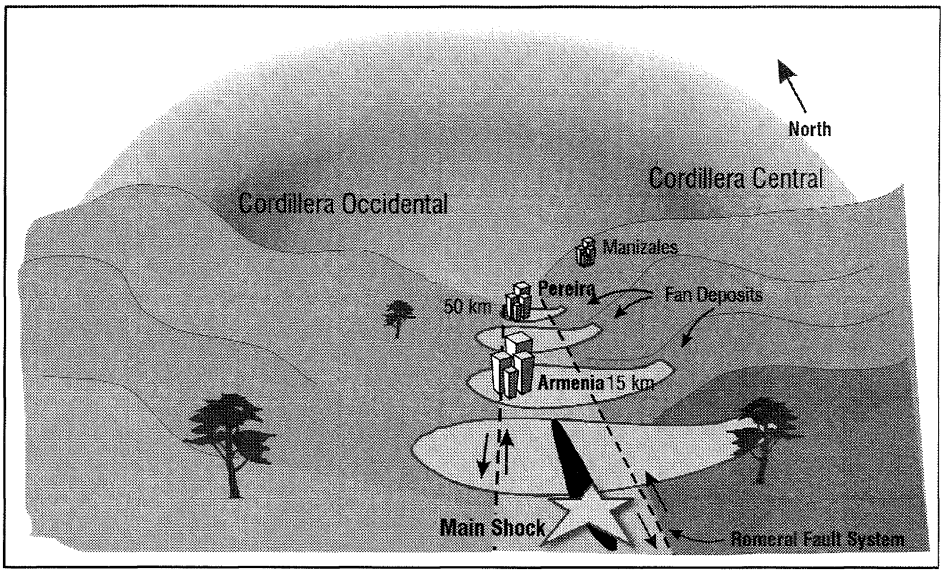
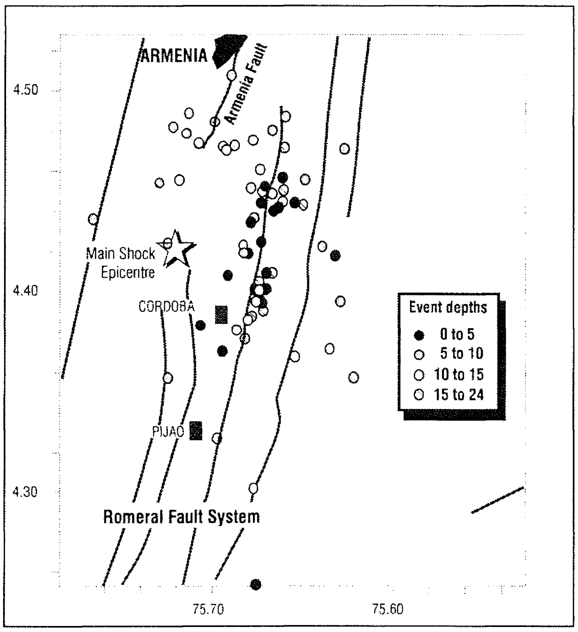
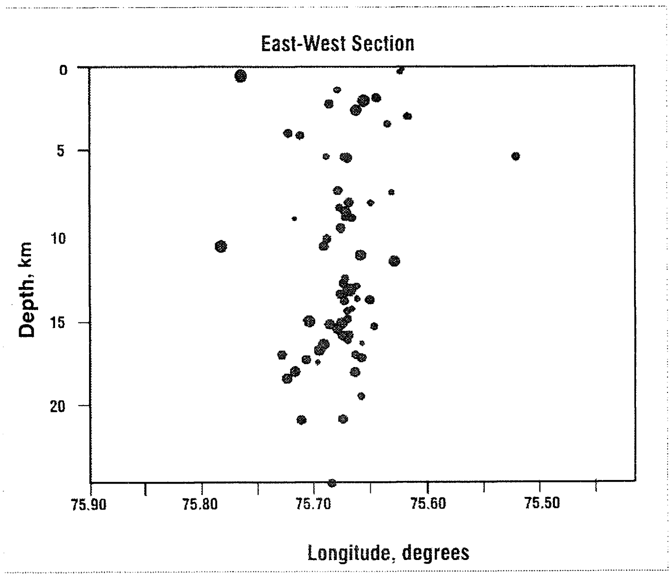


Figure 2: *Schematic view of the Romeral Fault System near Armenia.*



(a). *In Plan*



(b). *In Depth*

Figure 3: *Distribution of aftershocks [7].*

The observed damage pattern indicated MM IX intensities had occurred in specific locations within a 20 km long elliptical contour north from the epicentre. Landslides were most abundant south of Armenia in the region of the main shock epicentre, but no primary surface faulting was documented. Minor, right-lateral displacements were observed at a road margin on a narrow ridge-crest near the town of Barcelona (Figure 4), but our inspection of the surrounding area indicated that the movements were associated with lateral spreading and ridge renting, not tectonic faulting.

In the absence of documented surface rupture the location uncertainties for the earthquake sequence make it difficult to assign the main shock rupture to a specific fault, because the Romeral system in this area comprises multiple closely spaced faults. The severe damage in Armenia gave rise to early speculation that the Armenia fault, a local element of the Romeral system, had ruptured through the central city area. However, the distribution of aftershocks later indicated that the rupture occurred on a fault south of Armenia (Figure 3a).

The focal mechanisms derived from P-wave first motions for the main shock and the largest aftershock are similar and consistent with a left-lateral strike slip rupture on a north-south trending fault plane (Figure 5) [7]. From the focal mechanisms and main shock epicentre we infer that the rupture propagated northward in the direction of Armenia. A significant vertical component of ground motion in Armenia (see later) suggests that the rupture probably extended to within a few kilometres of the central city. The severe local amplification of shaking in Armenia is consistent with rupture directivity effects but other geotechnical and topographic factors also contributed directly to the severe impact as described below.

3. GEOTECHNICAL CONDITIONS

The "Eje Cafetero" region of Colombia is adjacent to the volcanic Ruiz-Tolima complex on the western side of the Central cordillera of Colombia, at altitudes between 1,200 and 3,000 m. The topography of the region is dominated by past volcanic activity and the major rivers that drain the Cordillera. The principal towns and cities are constructed on enormous interfluves that comprise alternating layers of lahars and volcanic ash deposits derived from the adjacent Cordillera. The Quindío Fan (Abanico del Quindío) on which Armenia is constructed, covers approximately 400 km^2 [4] with a partially dissected morphology that reflects deep incision by streams since the end of the last glaciation about 10,000 years ago. The dissected "ridge and gully" topography is similar elsewhere along the flank of the Cordillera, including Pereira where the geology of the underlying deposits is exposed in roads and river banks (Figures 6, 7). Most of the first 10 m of soil deposits in the region are either silty clays or sandy silts classified as ML or MH because of their medium to low plasticity [9].

In the main two cities, Armenia and Pereira, the topography has been smoothed this century for urban development. This has been achieved with extensive anthropic fills [7, 9]. In some locations up to 6 m of unconsolidated fills have been documented [9]. Shear wave velocity studies have shown a large difference in velocities in the different soil layers, with very low values associated with the fills [9]. Figure 7 depicts a schematic soil profile of the region and the typical shear wave velocities for the different soil layers. It is worth noting that a characteristic of the region is the lack of soil deposits susceptible to liquefaction due to the high clay content of the weathered volcanic ash.

The response of the shallow soil deposits combined with topographical effects played an important role in the ground response in Armenia and Pereira. Clear evidence of this was the very different damage pattern observed between the northern and the southern parts of Armenia (Figure 8). The southwest part of Armenia has deep gullies with urban development on the ridges. In contrast, the topography in the northern part of the city is characterised by broad ridges and fewer stream gullies. Nueva Brasilia, a development of mainly two storey houses and four storey buildings located in the Southeast part of Armenia, suffered partial or total collapse of 90% of the dwellings (Figure 8). Figure 9 illustrates damage in dwellings in this part of the city.

Extensive structural damage and collapse of buildings occurred along a corridor near the centre of Armenia (Figure 8). Buildings in this corridor had been founded on anthropic fills adjacent to the escarpment of the Armenia fault. The presence of the fills induced ground amplification there. Substantial structural damage and collapse of some buildings also occurred in locations with anthropic fills in Pereira.

It is customary in this part of Colombia to cut steep slopes for roading when the soil is of volcanic origin. For example, the building shown in Figure 10 experienced appreciable non-structural damage to its façade despite being located in the northern part of the city, where damage was relatively light. We inferred the abrupt change in topography affected the ground response at this and other sites. Lateral spreading was also observed around the crest of some ridges in rural areas south of Armenia (Figure 11). As the rainy season was persistent in February 1999, water penetrated the ground cracks and triggered many slides in the days and weeks following the earthquake. Many small earthquake-triggered landslides were common around the epicentral region and also along the main east-west trunk road across the Central Cordillera between Armenia and Bogotá (Figure 1).

4. STRONG-MOTION RECORDINGS

Twelve three-component digital accelerographs were operational in the region. They were deployed by three organisations: INGEOMINAS, the regional environmental authority of Risaralda, CARDER; and the Roading Institute, INVIAS. INGEOMINAS had deployed accelerographs in Pereira, in Filandia, a town between Pereira and Armenia, and in Armenia. CARDER had six accelerographs deployed throughout the city of Pereira. These accelerographs were part of the new microzonation network established after the 1995 Calima earthquake. The instruments deployed by INVIAS were located at the base of a 210 m span cable stay bridge crossing the Otún River on the outskirts of Pereira. The superstructure of this bridge had also been instrumented with 29 additional accelerographs [10].

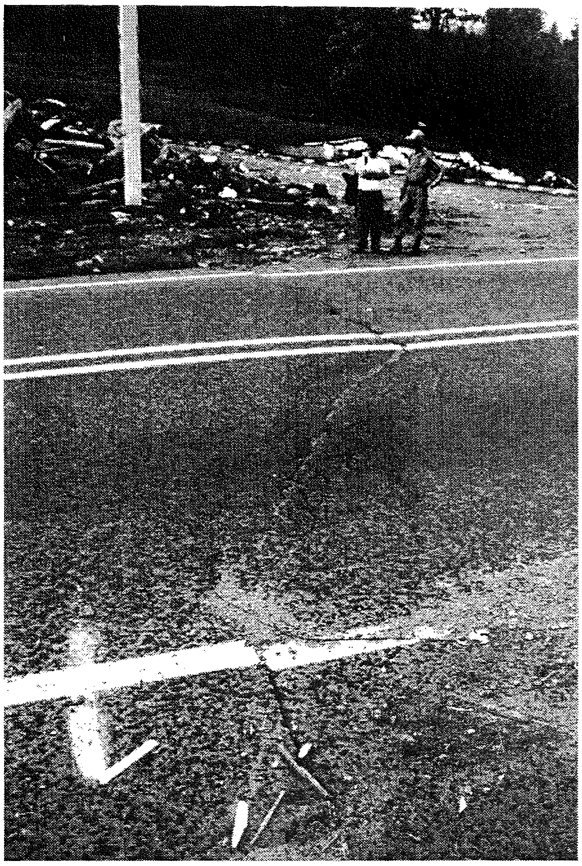


Figure 4: ***Right-lateral displacements at a road margin near the town of Barcelona.***

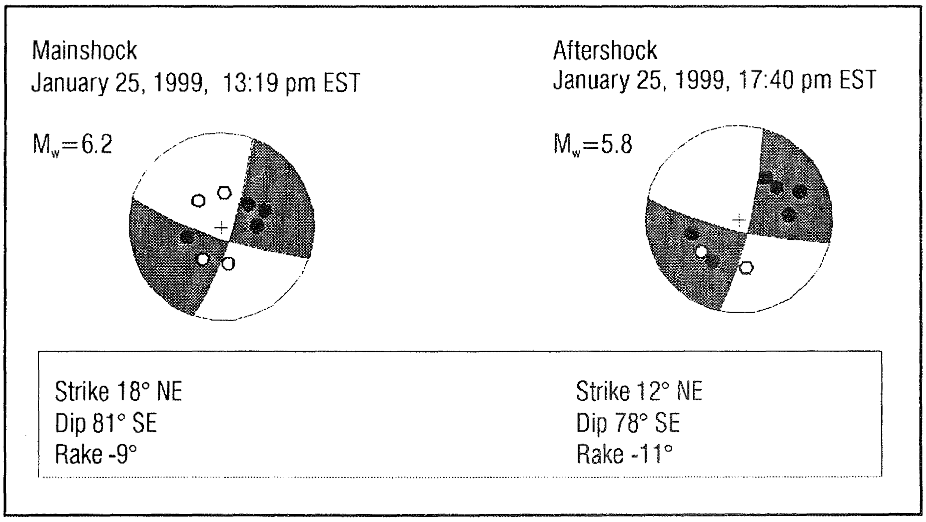


Figure 5: *Focal mechanisms [8].*

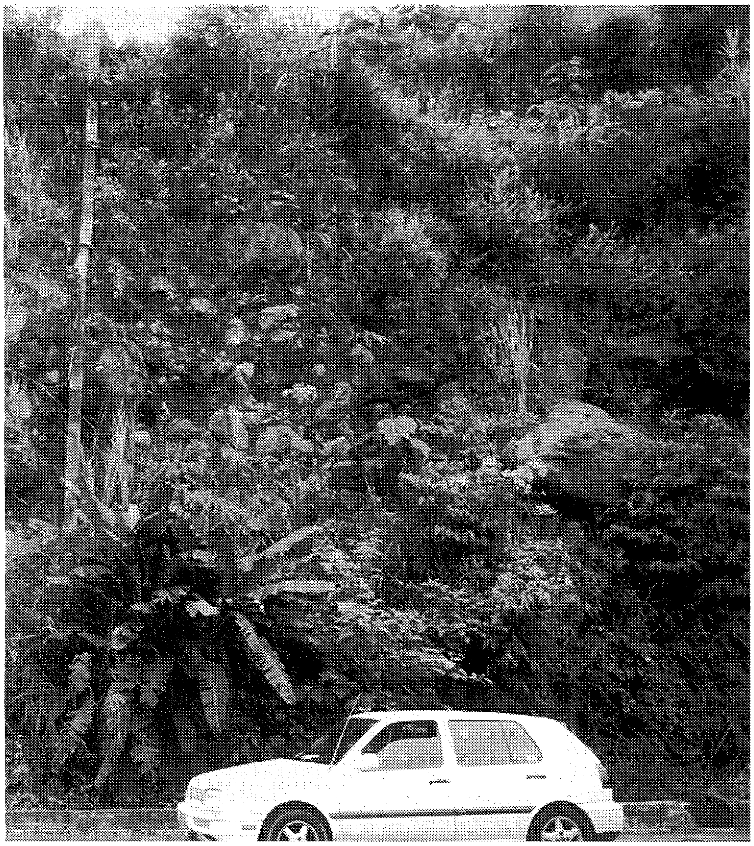


Figure 6: Lahar deposits around Pereira.

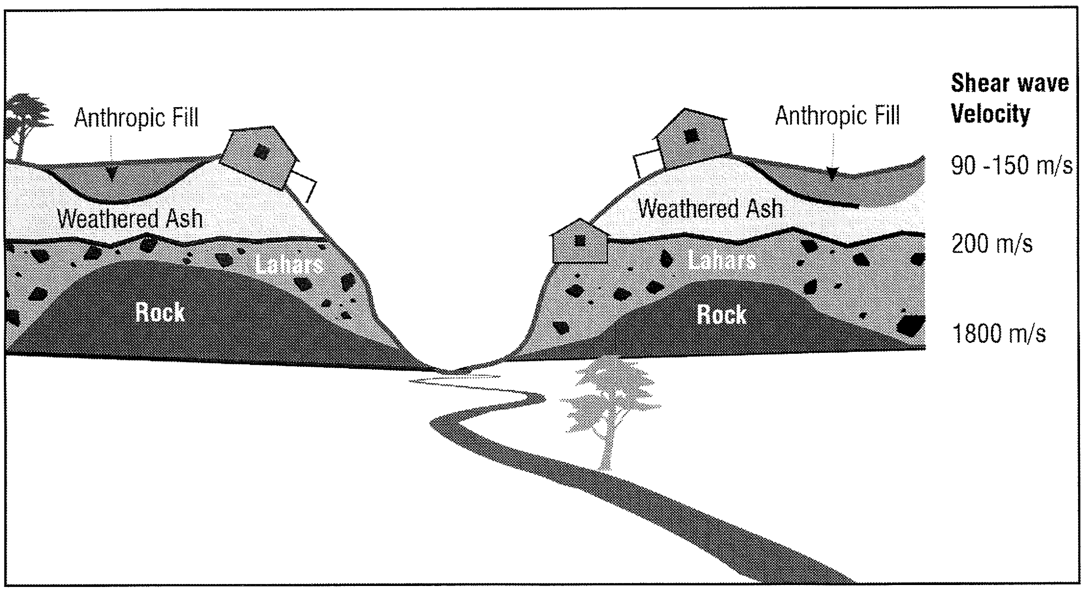


Figure 7: Typical soil profile in the region.

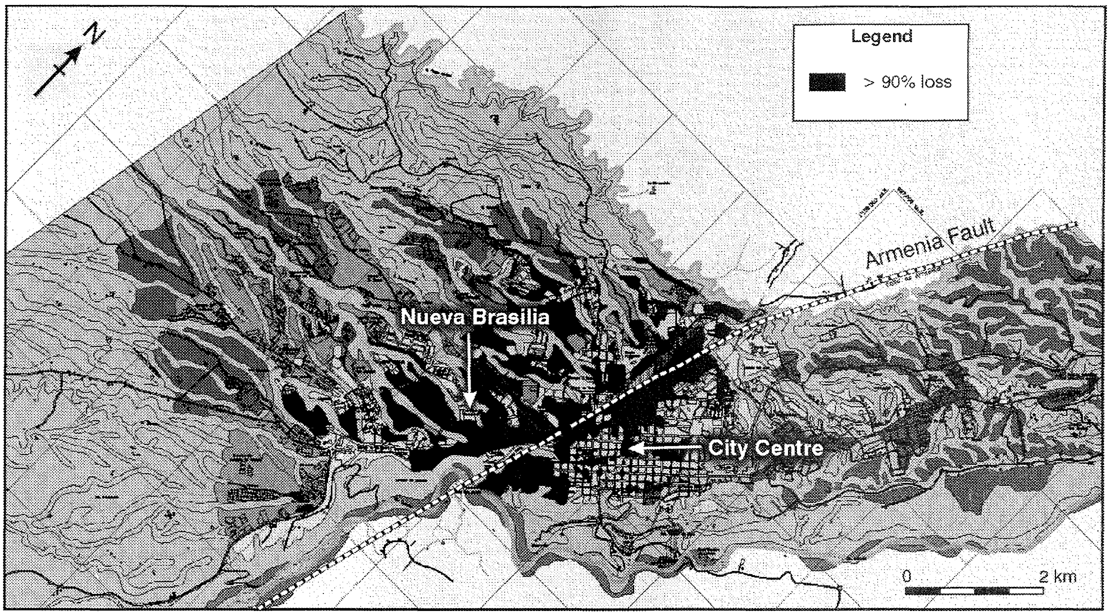


Figure 8: *Damage pattern to Armenia (Adapted from [7]).*

Figure 9: *Collapsed houses on a ridge, Nueva Brasilia, Armenia (Courtesy of El Colombiano).*

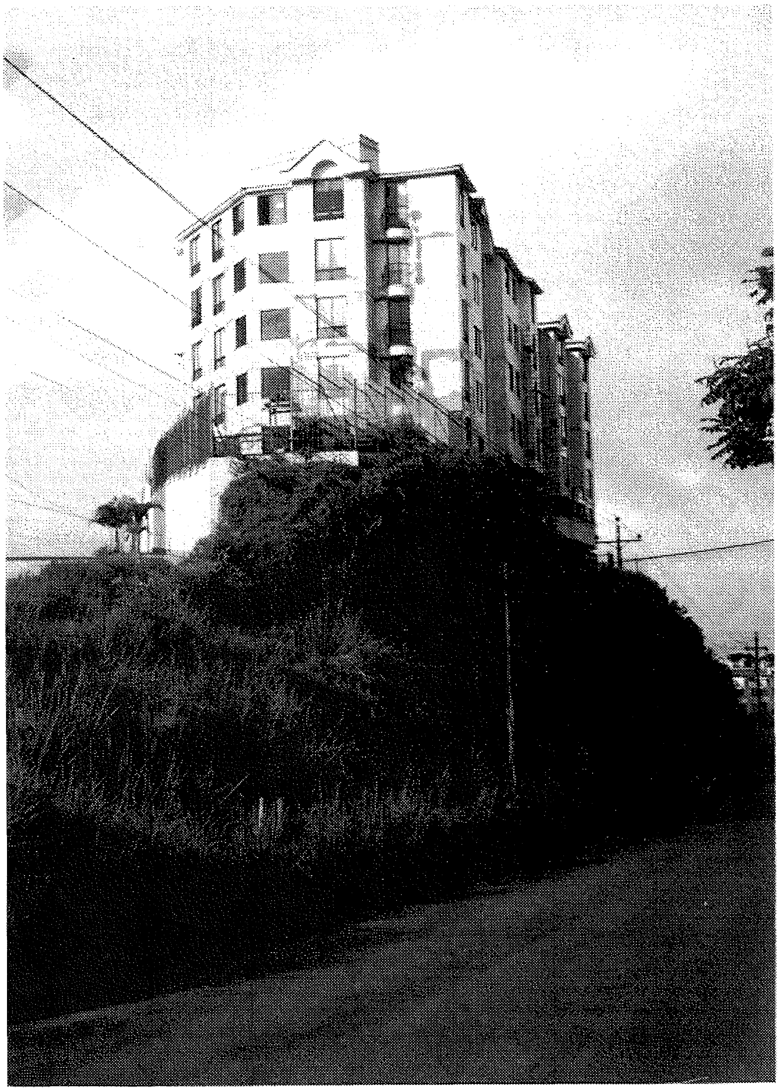


Figure 10: Steep road cuts with buildings built on the crest. Note the damage to the façade of the building.

Most stations recorded the January 25 earthquake. Records obtained from three sites only are discussed in this report. Site 1, known as the Armenia station, is located at the Universidad del Quindío in Armenia (4.33° N, 75.39° W). This station is free field and is situated on deposits of the Quindío Fan, comprising more than 30 m of weathered volcanic ash and lahar deposits. Site 2, known as the Mazpereira station, is situated on six metres of anthropic fill in central Pereira. Site 3, known as the Bocatoma station, is located on rock at the outskirts of Pereira. The coordinates for the Mazpereira and Bocatoma stations are 4.81°N, 75.69°W and 4.78° N, 75.64°W, respectively.

Figures 12 to 14 show the horizontal and vertical components of the main event recorded by the Armenia, Mazpereira and Bocatoma stations, respectively. The accelerometers recording the horizontal acceleration in these sites were oriented NS and EW. The horizontal acceleration traces shown in these figures are the vector resultant leading to maximum intensity. Intensity is defined here as the integral over time of the square of the acceleration. Table 1 provides a summary of the main characteristics of the recorded ground motion in the three sites. The Armenia record showed a relatively high peak horizontal acceleration but a moderate peak ground velocity. The peak vertical acceleration there was 3/4 of the peak ground acceleration. The Mazpereira station recorded low peak ground acceleration, but the peak ground velocity was comparable to that of the Armenia record. The Bocatoma station showed very low peak ground acceleration and velocity values. The duration of strong shaking given in Table 1 was calculated as the time interval between the first and last acceleration peak to 0.05 g. Both the Armenia and Mazpereira stations show similar duration of about 20 seconds, while the duration of shaking in Bocatoma has very short duration.

It is notable to observe the different ground response recorded by the Mazpereira and Bocatoma stations. Both stations are about 50 km away from the epicentre and are spaced 6.4 km apart. While the ground motion has substantially attenuated in Bocatoma, it is significantly amplified by the soft soil conditions at Mazpereira.

Table 1 - Characteristics of some strong motion records.

	Armenia		Bocatoma		Mazpereira	
Peak ground acceleration, g	N22°E*	0.60	N63°E*	0.095	N21°W*	0.31
Peak ground velocity, m/sec	N41°E*	0.30	N63°E*	0.044	N28°W*	0.33
Duration (0.05 g peaks)	N41°E	19.8	N63°E	1.2	N28°W	20.9

* *Component leading to maximum value*

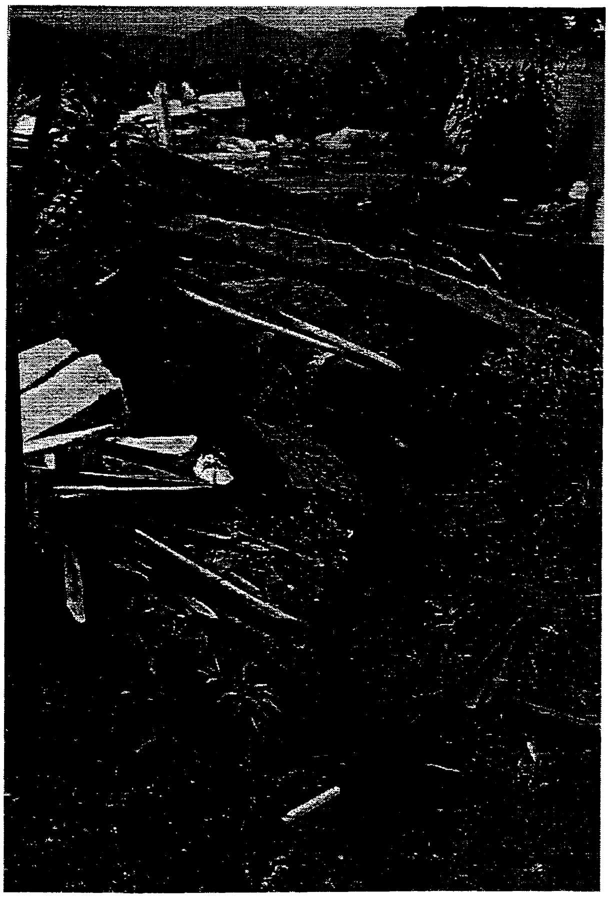
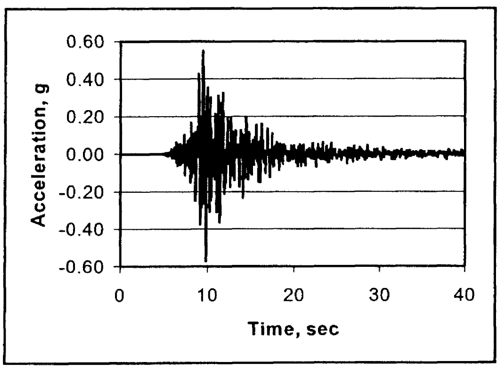
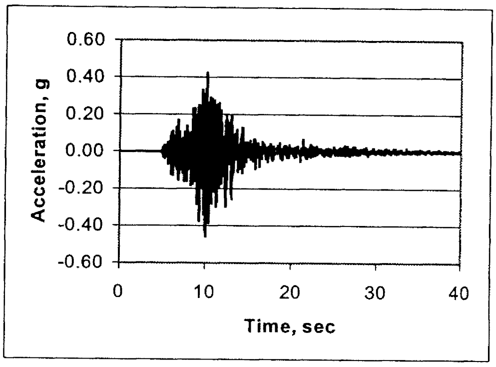


Figure 11: Lateral spreading on a ridge south of Armenia.



(a). N41°S component.



(b). Vertical component.

Figure 12: Records from the Armenia station.

Figures 15 and 16 show the horizontal and vertical acceleration and displacement response spectra derived from the Armenia station. For 5% damping ratio, horizontal accelerations exceed 1 g for nearly all the period band between 0.07 and 0.65 seconds. The period band of the maximum acceleration response coincides with the fundamental period of most structures in the region, except the higher multi-storey buildings. For older reinforced or unreinforced buildings, which are inherently rather brittle, the higher accelerations and corresponding displacement demands were barely accommodated. The design acceleration response spectra given in the New Zealand Loadings Code [11] for soft soils and the highest seismic zone and the spectra derived from the Armenia record are of similar magnitude in the period band between 0.07 and 0.65 seconds.

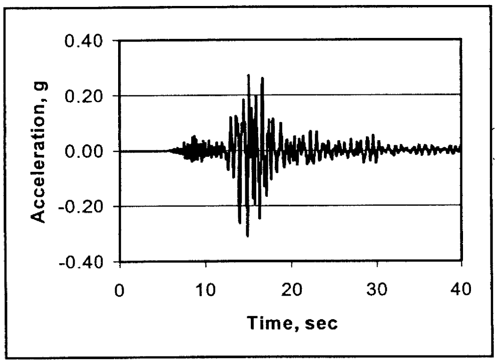


Figure 13: ***Record from the Mazpereira station (N28°W component).***

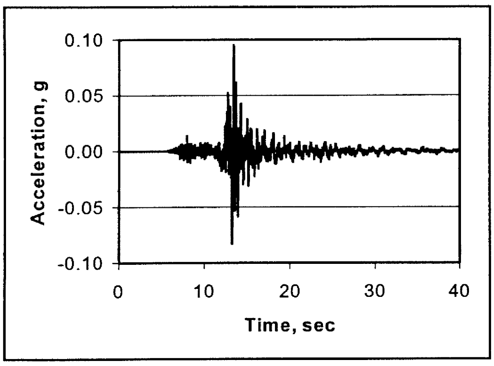


Figure 14: ***Record from the Bocatoma station (N61°E component).***

The vertical acceleration response spectra for the Armenia site, see Figure 16, show high values in the period band between 0.05 and 0.25 seconds, where the demand is of the order or exceeds 1g for 5% damping ratio. For 2% damping ratio the spectral ordinates exceed 1.5 g for most of the period band between 0.05 and 0.25 seconds. Low-rise buildings have fundamental periods in the vertical direction ranging between 0.05 and 0.15 seconds. Consequently, the behaviour of poorly detailed buildings in Armenia is likely to have been accentuated by the strong vertical response. We observed a clear example of the effects of vertical acceleration in the space timber roof of the library building at the regional environmental authority headquarters (Corporación Regional del Quindio). Nearly all the lower chords in the truss failed at a bolted joint due to increased stresses induced by flexure, shear and axial load.

It is worth noting that the largest vertical response shown in Figure 16 coincides with typical periods of precast, prestressed floor systems employed in New Zealand. These floor systems are expected to possess little damping and we believe that the effects of vertical excitation in such floors should be investigated.

Figures 17 and 18 plot the horizontal acceleration and displacement response spectra for the Mazpereira and Bocatoma sites. The ground amplification is evident when the spectra from these two stations are compared in terms of their amplitude and period band.

5. RESPONSE OF LIFELINES

5.1 Water supply

Armenia suffered considerably due to the loss of the water supply system in the first days after the earthquake. The water supply system is shown in Figure 19 [12]. The pressure in the system is obtained through gravity. The system has a single inlet, only two reservoirs and two main trunks and has little redundancy. The main trunk loop is 333 km long. 67% of the distribution network consists of asbestos-cement pipes, which are at least 15 years old. The newest section of the system uses PVC pipes. A small percentage of the system uses ductile iron, cast iron or spun concrete pipes with a steel liner [12].

The system lost pressure due to the significant number of leaks in the distribution network, but most importantly, due to damage in the domiciliary PVC pipes. The larger diameter pipes (305 to 610 mm) suffered very little damage. About 20,000 domiciliary pipes had to be plugged to restore pressure [12]. These pipes split or ruptured completely as a result of building collapse or excessive relative movement that could not be accommodated by the brittle pipes. It is uncertain whether a transient build up in pressure occurred and contributed to the damage as the system in Armenia did not have pressure relief valves. In Pereira, where the damage to the system was less severe, a pressure relief valve was activated during the earthquake [13].

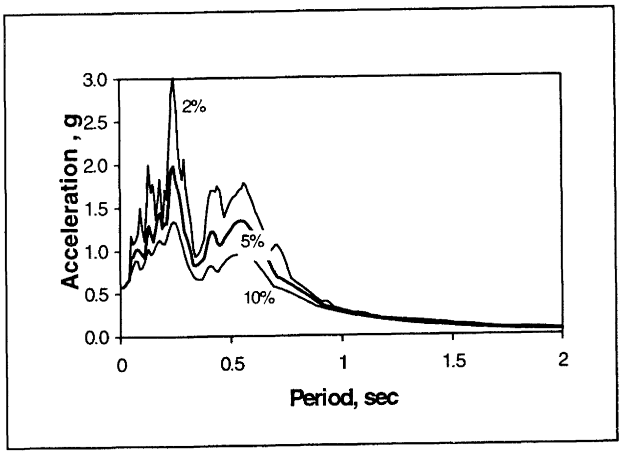
Table 2 shows the number or repairs per length of pipes reported by the water utility company in Armenia [12]. The largest number of repairs per length of pipe occurred in the asbestos-cement and PVC pipes. The asbestos-cement pipes showed longitudinal and transverse cracks and damage in the aged rubber gaskets at the junctions. In some cases it was found that the pipes themselves separated. The main types of failure in PVC pipes were longitudinal and transverse cracks. Longitudinal cracks were the main cause of failure in ductile iron pipes.

Most of the damage was concentrated in 50 to 100 mm diameter pipes. The spread of damage in the network in Armenia correlated well with the distribution of building damage shown in Figure 8 [12]. In addition to the damage in the network, the 6,600 m^3 reinforced concrete rectangular reservoir in Corbones (Figure 19), leaked due to the relative displacement between two walls at a poorly built construction joint. Four weeks after the earthquake the number of reported faults was about four times above average.

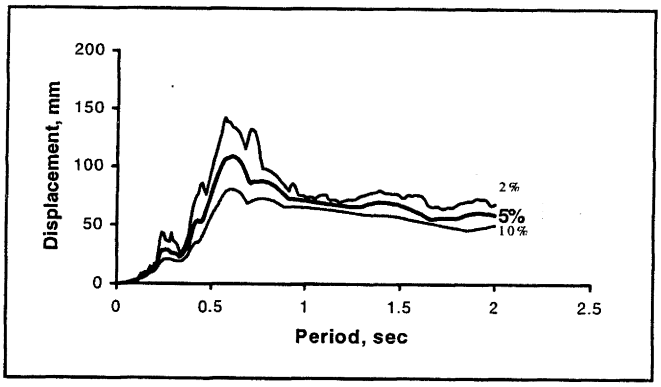
Repairs to the water supply network took a long time. Water was initially distributed using cistern trucks and bottles. One week after the earthquake there was a limited supply through the network. The main difficulties found to restore the system to normality were the number of faults and the lack of redundancy in knowledge of the system. The latter case was due to key personnel and their families being impacted directly by the earthquake or being psychologically affected, rendering them unable to return to work. As a result, there was a significant loss of time as teams sent by utility companies from other cities were unable to have direct access to plans or to establish a co-ordinated operation [12].

Table 2 - Statistics of damage in the water supply network in Armenia.

Material Type	Repairs per km length
Asbestos	1.82
PVC	1.45
Cast iron	0.97
Galvanised steel	0.52
Ductile iron	0
Spun concrete with steel liner	0

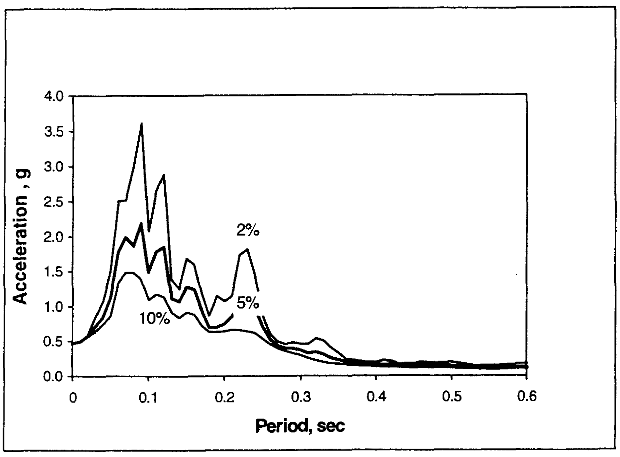


(a). Acceleration response spectra.

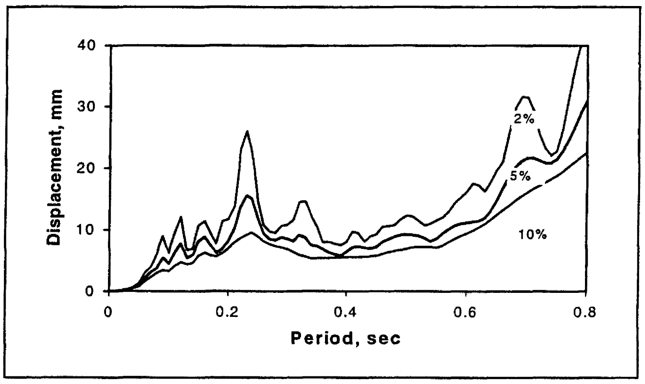


(b). Displacement response spectra.

Figure 15: Horizontal acceleration and displacement response spectra for the Armenia station (N41°E component).

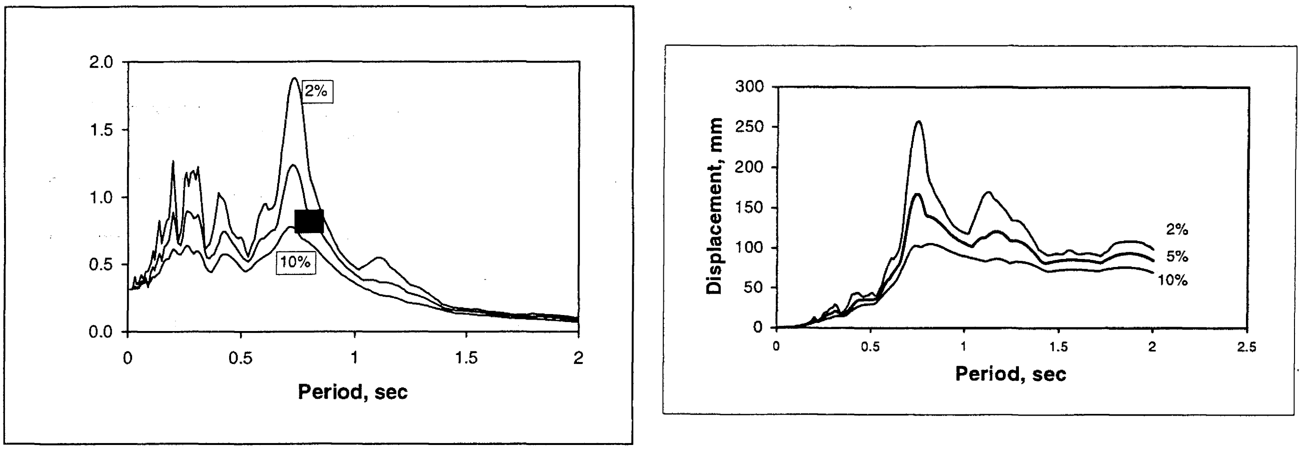


(a). Acceleration response spectra.



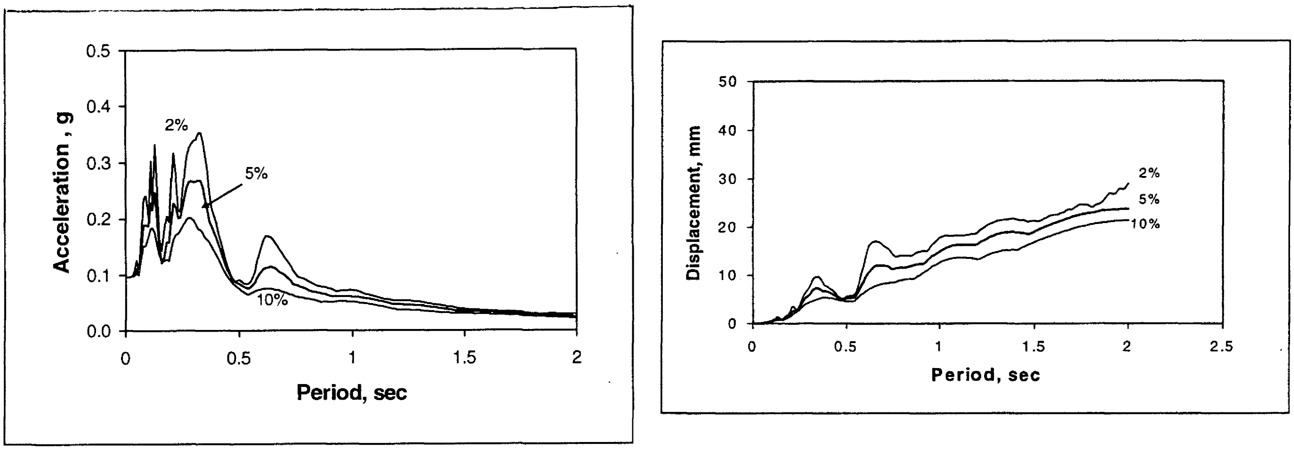
(b). Displacement response spectra.

Figure 16: Vertical acceleration and displacement response spectra for the Armenia station.



(a). Acceleration response spectra. *(b). Displacement response spectra.*

Figure 17: *Horizontal acceleration and displacement response spectra for the Mazpereira station (N28°W component).*



(a). Acceleration response spectra. *(b). Displacement response spectra.*

Figure 18: *Horizontal acceleration and displacement response spectra for the Bocatoma station (N61°E component).*

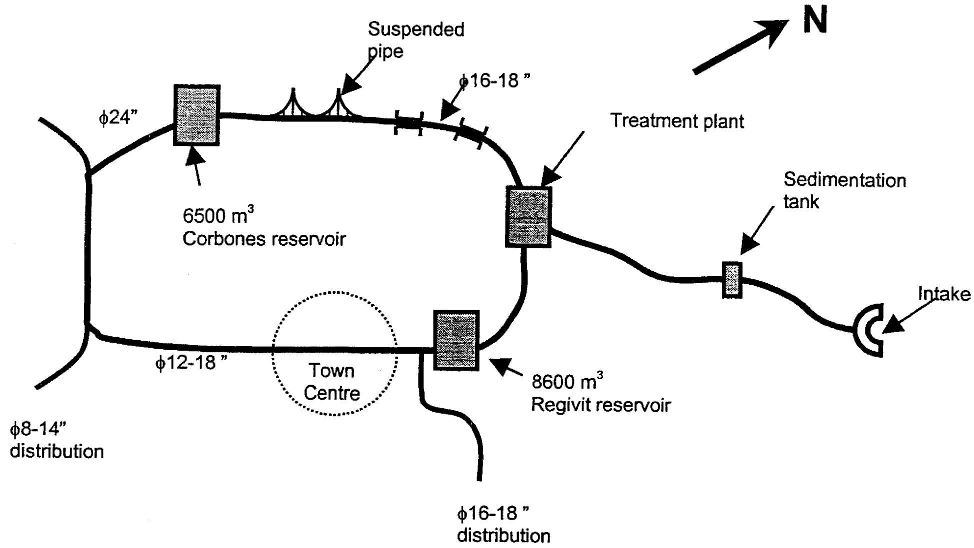


Figure 19: *Plan view of the water supply network in Armenia [12].*

In the aftermath of the earthquake, and when the potable water supply began to be restored in some areas of the city, quality measures were intensified to check for possible cross-contamination with the sewage wastewater system. Four weeks after the earthquake the system had been partially restored and was covering 80% of the city between 2 and 16 hours per day.

5.2 Power supply

The epicentral region, including Armenia, lost its power supply after the earthquake. Pereira suffered limited loss of power supply. Diesel emergency generators are commonly used for backup, due to the frequency of lightning strikes in the region, and these worked well without exception.

Power supply in Armenia was partially restored after three days. Direct material losses there were estimated at NZ \$800,000 and the loss of revenue is expected to exceed this figure by a large margin [14].

Armenia has two sub-stations with an installed capacity of 100 MVA. The only major damage in the sub-stations occurred due to derailment of a transformer. This transformer was replaced soon after the earthquake, due to the fortuitous availability of new transformer at the site which was to have been used to expand the system capacity. High voltage lines responded well with no damage reported to towers in the epicentral region. The main problem concentrated in the underground lines in the centre of the city. With the collapse of many buildings, diggers caused significant damage to these lines to the extent that it took five months to rebuild the network and restore the power supply there, at a cost of NZ \$1.25 million [14].

5.3 Telecommunications

Telephone lines were severely affected around Armenia. The Telecom building headquarters suffered partial collapse and had to be evacuated. Limited telephone lines were operational two days after the event.

This region of Colombia makes significant use of cellular telephony. It was reported that the cellular system saturated 15 minutes after the earthquake.

The control tower in the Armenia airport collapsed, thereby disabling normal air traffic control systems. Radio amateurs managed to restore emergency beacons to facilitate landings within the first 24 hours.

5.4 Hospital services

The number of hospital admissions following the earthquake was about 5,300 out of a total of approximately 8,000 people requiring treatment. The epicentral region, excluding Pereira, suffered 70% loss of capacity, mainly due to the collapse of three hospitals and five health centres. In Armenia the main regional hospital was being retrofitted and that part of the building remained partially operational. The remaining part suffered non-structural damage and was rendered out of service.

5.5 Sewerage system

The gravity sewerage system in the main town affected worked satisfactorily after the earthquake. The utility company in Armenia focussed on re-establishing the water supply to the city and little or no inspection was carried out in the sewerage system. Five months after the earthquake, ground subsidence caused by piping had been reported in some and repair work was being undertaken.

5.6 Roads

As mentioned before, the east-west trunk that forms part of the Pan-American highway and connects Bogotá with the Pacific was blocked by a number of landslides (Figure 1). Heavy rain in the highlands of the Central Cordillera led to continuous slope instability along the main trunk. Four weeks after the earthquake only temporary passage had been allowed through the main divide.

The roads in this region have many small span bridges and some bridges with larger spans. All bridges performed satisfactorily with no signs of damage being reported to the bridges and their abutments.

5.7 Other Lifelines and Services

Financial system

The financial system suffered total collapse in the city of Armenia but was not severely affected in Pereira. Banks in Armenia shifted to the northern end of the city and were operational within six days.

Refuse collection and waste fills

A major concern in the early stages of the emergency was the possibility of development of epidemic diseases with the loss of operation of the refuse collection system. It also became apparent that the refuse stations were unable to cope with the volume of construction debris once demolition and cleaning of the city got underway. Landfills were full of debris during the first weeks after the earthquake.

Food supply

Food shortage was one of the main causes for distress in Armenia, where the large majority of homeless people concentrated. Controlled, local distribution of food from warehouses reportedly posed the greatest difficulties. Anxiety and desperation led to looting, although it has been reported that widespread looting occurred as a result of gangs arriving from other towns.

6. EMERGENCY PREPAREDNESS AND RESPONSE

6.1 Emergency Management in Colombia

Emergency management for natural disasters in Colombia is organised around local and regional emergency management committees, linked through a national policy and co-ordinating institution – the National Directorate for Risk Mitigation and Disaster Preparedness (Figure 20) [15]. The intention is to provide an "all-hazards" approach to risk mitigation and disaster preparedness, largely devolved among a broad range of community organisations and expertise. Membership of a Regional or Local Committee (in New Zealand this would be an Emergency Management Group) is very broad. The national Civil Defence, a popular and largely volunteer organisation, is merely one of many institutions represented under the committee structure (Figure 20).

Regional and local emergency management committees in Colombia (EMC's) perform diverse professional functions, broadly organised under Technical, Operational and Educational functions, respectively. Technical functions include not only assessment of natural hazards and risk, but also mitigation and response issues related to urban planning, economic development planning, housing, public infrastructure, and resettlement. Educational functions are focussed toward public education and awareness. The Operational function is primarily the co-ordination of emergency response and recovery.

This holistic approach to emergency management has generally been regarded as progressive, and has served as an example throughout Latin America during the 90's and the IDNDR (International Decade for Natural Disaster Reduction). *"The system has also enjoyed considerable prestige because it departed from the traditional models for Civil Defence, directed towards emergencies with a military response orientation."*[1]

Doubts had been expressed about the national-tier system capabilities prior to the January 25 earthquake, but were directed more to the difficulties of mustering and co-ordinating local and regional resources, and for maintaining technical competency, rather than the underlying philosophy of the system design. In practice, the January 25 earthquake provided the first real test of the national level of co-ordination, because there had never been an event that exceeded the local or regional capacity. *"In the moment that the nation had to respond, the response did not proceed within the possibilities of the system. The individual member organisations of the system responded well, as best they could, but without overall direction from the national level."*

In the aftermath of the January 25 earthquake, severe shortcomings in the EMC response capabilities were identified, as the required response to the earthquake quickly scaled to a national level, then an international level. Linkages to the National Directorate were apparently weak and inadequately resourced. At the national level, the authority and jurisdiction for managing the response were unclear. International aid flowed through parallel diplomatic channels, allegedly without effective local co-ordination among the EMC's of the affected region.

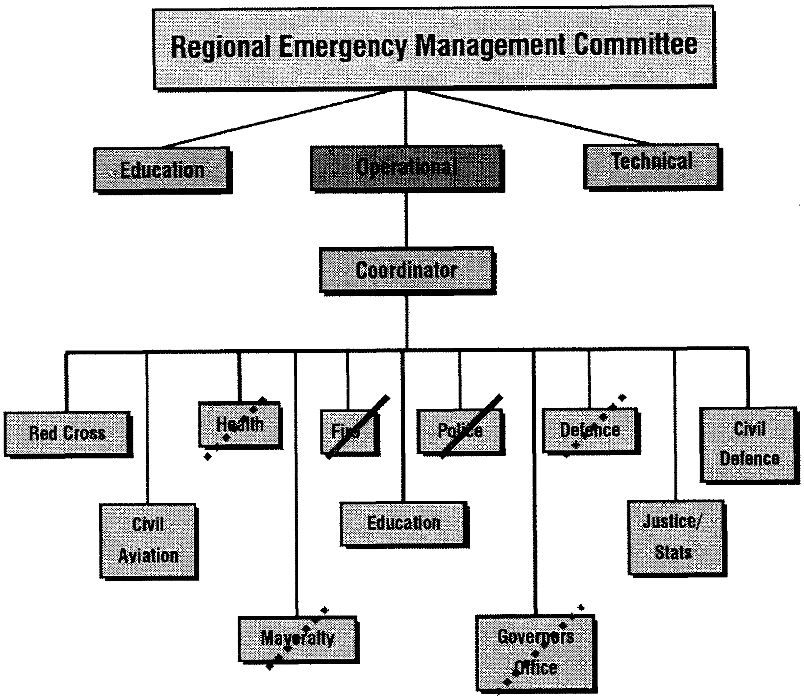


Figure 20: *Emergency management in Colombia comprises a national policy and strategic planning office of risk mitigation and disaster preparedness (DNPAD). Operational responsibilities are largely devolved to multi-institutional, regional and local emergency management committees at provincial, district and city level. The regional emergency management committee for Quindio Department was severely impaired by the total or partial loss of critical elements (diagonal solid and dashed lines, respectively) during the January 25 earthquake."*

In the aftermath there was extensive reporting and analysis of the emergency response and the performance of key institutions [16]. During our visit, a broad consensus was emerging, that the national emergency management system in practice was ill-prepared to cope with a disaster on this scale (Figure 21). The following summary of events is compiled

[1] O.D. Cardona, President, Colombian Association for Earthquake Engineering. Written communication.

from the testimonies and written communications of people in key organisational roles, in regional and national Civil Defence, the Ministry of Defence, Ministry of Health, regional councils, water utilities, engineering consultants, and the Colombian Red Cross.

6.2 Emergency Response in Risaralda

The city of Pereira had in some ways been "prepared" for this event through the occurrence of the Calima earthquake in 1995, which caused US$50 million in damage. The 1995 earthquake prompted revision of the national building code and a comprehensive microzonation and seismic vulnerability study for Risaralda Department [17]. As a result of this work, regional seismic hazard was better understood. The vulnerability of lifelines was being studied in projects co-ordinated by the regional environmental authority (CARDER). However, as described below in Section 7, the 1995 earthquake evidently caused considerable non-structural damage to many buildings that were subsequently given a cosmetic make-over following that event, only to be further weakened or destroyed by the January 25 earthquake.

In Pereira, the physical impact of the January earthquake was less severe than Armenia, in terms of fatalities and total building collapses, but the damage was extensive all the same. More than 10,000 buildings were identified as damaged or collapsed [18]. The heavy rescue phase of the earthquake was handled well by the emergency services, but the response demand was described as exhausting and close to their effective limit. The area of building collapses was confined largely to a couple of central city blocks and was not associated with post-earthquake fire, except for one outbreak that was brought under control at a local chemical plant.

The major difficulty in Pereira was the task of organising effective reconnaissance teams to evaluate the extensive building damage. Following the 1995 earthquake considerable effort went into devising damage evaluation criteria, reporting forms for tagging buildings and a response-zoning plan for effective co-ordination of the post-earthquake response. These plans were activated within 1-2 hours of the January 25 earthquake, but nobody had been tasked with overall responsibility for co-ordination. The scale of the impact quickly revealed a critical local shortage of suitably qualified engineers to evaluate building damage in multi-floor structures, while the few knowledgeable (and therefore known) people were overwhelmed trying to handle offers of help from cities elsewhere. The problem of finding qualified forensic engineers had a large impact in the decision making process. Structural engineers in general had never been introduced to post-earthquake building assessment procedures.

A major logistical problem was the lack of an integrated computer system suitable for constructing and managing the database of building inspections, which grew within 30 days to over 10,000 inspections. Donated computers were found to have incompatible operating systems or different versions of common software. These problems compounded difficulties for the authorities confronted with immediate safety issues for the displaced population, and within days also faced with insurance issues and disputes regarding the "tagging" of buildings by engineers and architects of differing competence or opinion [18].

Figure 21: "Earthquake!...earthquake!", warns the National Office of Risk Mitigation and Disaster Preparedness. The caption above "(caught) with their trousers down" epitomises a nation's view in hindsight, that its emergency management system failed to effectively manage the response as intended [16].

Not withstanding these difficulties, and those in Quindío (see below) where the impact was even more severe, the availability in abundance of giant bamboo cane (100-150 mm diameter *Bambusa Guadua*) allowed many buildings to be propped. The quick harvesting and application of bamboo mitigated the collapse of many buildings in aftershocks and thereby averted greater loss of life in the aftermath.

Staff from the Pereira water utility described how their response was aided by the fact that no staff were lost or directly affected by the earthquake, and a program had begun during the previous year to broaden institutional knowledge of the utility network. Restructuring and partial privatisation of water and waste utilities in Pereira during the previous year had resulted in a partial loss (fragmentation) of network knowledge, but a common radio frequency still operated and aided the co-ordination of the response despite heavy traffic in the first few hours.

6.3 Emergency Response in Quindío

The emergency response was severely impaired in Quindío, especially in the city of Armenia. Major contributing factors included the physical collapse of the central fire station, regional council chambers, blood bank, and partial collapse of the central police station in Armenia, associated with loss of life (Figure 22). The collapse of the fire station resulted in the death of 18 trained officers and the loss of Armenia's heavy rescue equipment, which had been regarded as the best in the region. In the surrounding municipalities, the collapse of three community hospitals and five health centres resulted in a 70% reduction in hospital health care.

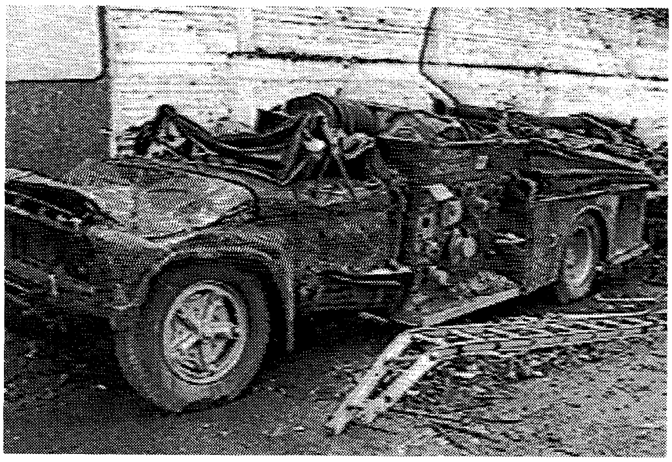
The physical impact demonstrated the risk posed by several highly vulnerable critical buildings and the vulnerability of construction in areas of anthropic fill. These had been identified previously in seismic vulnerability studies conducted by the University of Quindío on behalf of the regional EMC. A seismic retrofit program had commenced in the previous year, with the central hospital among the first. The work had not been completed at the time of the earthquake, but this portion of the hospital survived with only minor damage.

From a New Zealand perspective the impact of the January 25 earthquake in Armenia was exaggerated by the physical collapse of key facilities. However, many aspects of the organisational response provide insight into potential difficulties that New Zealand communities are likely to experience responding to similar earthquakes in older parts of their urban centres.

Armenia had an active, multi-organisational EMC. The EMC met on a monthly basis, maintained contingency response plans and operated dedicated communications. Its Operations Committee consisted of senior representatives of the constituent member organisations (Figure 20). The regional (Quindío) civil defence had a written earthquake contingency plan [19], but Armenia had not experienced any earthquake on the scale of the January 25 event since its foundation 110 years ago.

The earthquake struck during the lunch hour, a time when most people including key EMC members were in their homes or away from their place of work. Three members of the EMC operations committee arrived at the pre-designated co-ordination centre (Red Cross HQ) approximately one hour after the earthquake. At 5.00 pm, other members of the EMC arrived and a meeting was held, at which time it was realised that key EMC representatives were required to provide leadership "on the streets". Co-ordination passed by default to the national level and the regional committee did not meet again for 15 days. Several members of the Operations Committee, including its Co-ordinator, described how the impact of the event on themselves and their respective families, severely reduced their effectiveness to perform previously designated command roles for several hours after the initial shock.

(a). Police Headquarters



(b). Fire brigade truck in the collapsed headquarters

Figure 22: Impaired critical elements in the emergency response in Armenia. (Courtesy of the Colombian Civil Defense).

The health authorities unilaterally activated their own contingency plans on the afternoon of the first day, and with assistance from the Colombian airforce an evacuation of seriously injured commenced the following day. Only six orthopaedic surgeons were available in a regional population of approximately 400,000. Most fatalities resulted from crushing or asphyxiation, with 80% of deaths described as immediate. Perhaps 20% of fatalities resulted from delayed treatment. Despite the scale of the challenge, however, the response of the community was described by many as remarkable, despite the breakdown of formal institutions. Civic centres for treatment of the injured were organised spontaneously at three sites in Armenia.

By contrast, opportune looting of property and some violent attacks on the displaced population did occur in following days, allegedly by criminal gangs from other towns. This led to criticism of the authorities for a failure to ensure public order in the aftermath of the earthquake. Our inquiries suggest that a series of unfortunate coincidences and circumstances contributed to the slow response.

Public order is officially a police responsibility, under the jurisdiction of the Governor of the Department (province). The collapse of the police infrastructure and civic chambers with associated loss of life resulted in a temporary breakdown of the normal command structure. However, the army brigade commander in the area had been newly appointed from another region of Colombia only days before the earthquake, had few local contacts and few troops at his disposal. Similarly, the regional civil defence commander had taken up his post in Armenia only one week earlier and was visiting Bogotá at the time of the earthquake.

Within 48 hours, international aid and offers of help from many Colombian nationals were arriving without effective local co-ordination. Only the health authority and Colombian Red Cross evacuation and its refugee tracking system were described consistently as being well co-ordinated and effective. The international and national media arrived in large numbers within the first few days and allegedly posed an additional burden, requiring food, lodging and the attention of exhausted local officials.

In summary, the impact of the earthquake on key individuals and their families, and the lack of effective national co-ordination once the local system broke down, were recurring themes among all those we interviewed.

7. PERFORMANCE OF STRUCTURES

7.1 Construction systems

This region had a wide range of construction systems for buildings and bridges. They range from primitive "bahareque" dwellings to reinforced concrete multi-storey buildings and a structural steel cable stayed bridge designed in accordance to modern seismic codes.

"Bahareque" was the traditional construction system in the main cities until the 1940s and was the preferred system in smaller towns until much later. In this system, bamboo canes (*Bambusa guadua*) are employed as the main structural material.

A significant economic growth occurred in the region in the late 1970s and early 1980s as a result of a boom in the coffee market. Unfortunately, all housing development carried out during that period were designed using unreinforced clay brick masonry construction. Buildings were designed for gravity loads only and employed either one-way reinforced concrete frames or beamless waffle slabs combined with clay brick masonry infills. Reinforcing details to ensure ductile behaviour in the critical region in these buildings were nearly non-existent.

Deformed bars, used as longitudinal reinforcement in reinforced concrete beams and columns, appeared in the market in the mid-1970s. The use of cold worked reinforcement in the way of twisted square and round reinforcing bars seemed to be widespread in the buildings built before the 1970s. In general, poor quality concrete and compaction was common to many old reinforced concrete buildings there.

Colombia introduced its first seismic design code in 1984 [20] following the 1983 earthquake in Popayán. The code was largely based on the ATC-3-06 document [21] with reinforced concrete seismic design provisions adapted from the ACI 318-83 building code [22]. The code divided the country into three seismic hazard regions and showed the coffee-growing axis as being in a high seismic hazard area.

The seismic design coefficient given in the code for elastic response of buildings with fundamental periods less than 0.6 seconds was 0.63 g for soft soil conditions in this region. Reduction of the design lateral forces, to account for inelastic behaviour, was 1.5 for confined masonry and 6 for reinforced concrete frames, regardless of the fundamental period of the structure. Inter-storey drift for reinforced concrete structures was limited to less than 1.5% if the analysis was carried out using moment of inertia of the gross cross sections or to less than 2.1% if the effects of cracking were accounted for in the analysis.

The code prohibited the use of unreinforced masonry construction in regions of high and intermediate seismic hazard. Instead, the use of nominally reinforced masonry construction, termed confined masonry, was encouraged for the construction of one and two storey dwellings.

The preferred structural systems chosen since the introduction of the seismic design code were confined masonry for 1 or 2 storey dwellings and space reinforced concrete frames founded on shallow footings for multi-storey buildings up to 12 floors. Partitions in multi-storey buildings are commonly built using hollow-core clay brick walls infilling the frames.

The amount of non-structural damage in Medellín caused by the 1992 Murindó earthquake and in Pereira due to the 1995 Calima earthquake prompted the review of the seismic design code. The recently released Seismic Design Standard [23] incorporates the results of a new seismic hazard study [24] and imposes tougher restrictions on inter-storey drifts. This standard allows only 1% inter-storey drift when an analysis is carried out using the gross cross section properties. Additionally, it requires that architects be responsible for the seismic design of partitions. A consequence of the tighter inter-storey drift limits has been the shift in design to use structural walls to provide the lateral load resistance. Some buildings in the area had been built according to the new standard.

The following sections discuss the performance of the several structural systems found in the region.

7.2 "Bahareque" Construction

Many dwellings built using "bahareque" performed poorly during the earthquake. The main causes for the poor structural performance were the presence of a heavy clay tile roof and the lack of positive connections and a proper diaphragm at roof level. In addition, we observed that clay brick walls, which were not connected to the return walls, had replaced the original "bahareque" façade of a large number of these houses when streets were widened to give way to the new urban development. A number of "bahareque" dwellings that survived the earthquake lost the newer facades.

7.3 Unreinforced Masonry Construction

This construction system caused the largest number of deaths in this earthquake. A large number of one and two storey dwellings, buildings up to three storeys high and churches collapsed. Nearly entire developments, such as Nueva Brasilia (Figure 9) had been built using unreinforced masonry with heavy clay tile roofs.

7.4 Old multi-storey buildings

Many old multi-storey buildings had at least one of the following structural deficiencies that affected their seismic performance,

- Lack of seismic gaps
- Frames in only one direction
- Beamless waffle-slabs
- Presence of partial or totally unreinforced masonry infills
- Stiff staircases forming a vertical truss in the building
- Deficient reinforcement detailing

Similarly to old pre-1970 construction in New Zealand, the practice of constructing buildings without leaving any separation between them was common in the region. The lack of gaps resulted in excessive pounding between buildings. Their interaction created a "building block" effect that altered the dynamic response of the individual buildings. Corner buildings were ratcheted out diagonally towards the streets as a result of pounding against only one adjacent building in each direction. Figure 23 shows an aerial view of the main plaza in Armenia, where the corner multi-storey building and the Bolivar theatre, also located in the corner of another block, collapsed. Figure 24 illustrates a corner building in Pereira. The building was displaced out in both directions and debris filled the gap that opened against the adjacent building.

The lack of a two-way lateral load resisting system was possibly one of the most important structural causes for the poor performance and even collapse of many multi-storey buildings. In many cases stiffness and strength, in the direction orthogonal to the one-way frame, was provided by the one-way slab. Yielding lines running in the slab and torsional cracks in the beams were visible in some buildings that remained. In some cases, like the Armenia Mayoralty House, the building employed beamless waffle slabs. This building was extremely flexible and suffered extensive non-structural damage.

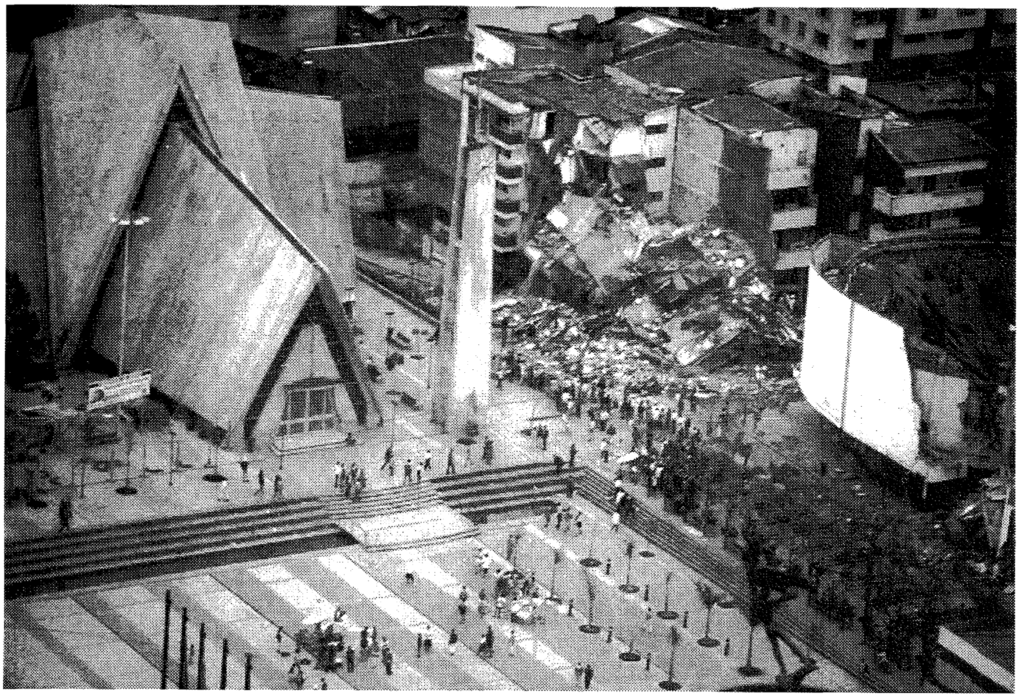


Figure 23: ***View of Plaza de Bolivar in Armenia showing collapsed corner buildings. Theatre Bolivar is at the right hand side. (Courtesy of El Colombiano).***

The use of masonry walls to infill frames was common in New Zealand buildings built in the 1950s and 1960s. The presence of infilled masonry walls in frame buildings provides them with stiffness and strength to a threshold level. Beyond this level old buildings incorporating such walls perform very poorly. Figure 25(a) shows a soft storey failure caused by the collapse of the infill walls in a building in Armenia. Figure 25(b) illustrates the extent of cracking across the mortar joint in the infilled walls in a building in Pereira. Partial height infilled walls induced short column effects in many buildings.

7.5 Precast concrete construction

There were two types of buildings incorporating precast concrete elements. Torres del Norte, a residential complex of 4-storey buildings, was built using precast concrete walls and solid slabs in northern Armenia. These buildings survived essentially unscathed. Only a few blocks suffered some sort of visible damage.

In contrast, frame buildings incorporating precast concrete ribs with a cast-in-place topping suffered extensive damage. It was found that the concrete topping was unreinforced and not connected to the ribs. The ribs themselves were not connected to any structural element. Figure 26 shows the separation between the rib and concrete topping in the typical flooring system employed in the region. We believe the lack of structural integrity accounted for the poor performance observed in these type of buildings.

7.6 Industrial facilities

Several industrial facilities were heavily damaged in the earthquake. However, access to them was restricted and we could only inspect a few facilities. Among the damaged industrial facilities is the building of the Nicol textile factory (Figure 27). The structure of this factory has a saw-teeth roof. Long asbestos-cement roof tiles are seated on slender steel trusses. The trusses are seated on columns that cantilever about four meters from the base. Some trusses buckled laterally as a result of poor bracing and one truss lost the seating and fell onto the working area. Fortunately there was no loss of life there because workers were out in their lunch break.

7.7 Modern structures

In general modern structures showed better performance than older ones. In particular one and two storey confined masonry dwellings showed excellent performance. Some multi-storey frame buildings showed clear formation of beam plastic hinges (Figure 28). Those multi-storey buildings that showed extensive damage had at least one of the following deficiencies:

- Deformation incompatibility
- Lack of well defined load paths in diaphragms
- Pounding against adjacent structures

The damage observed during the 1992 and 1995 earthquakes in Colombia highlighted the problems of deformation compatibility between flexible frame buildings and stiff and brittle hollow-core clay brick partitions and between frames and cast-in-place staircases (Figure 29). The presence of the

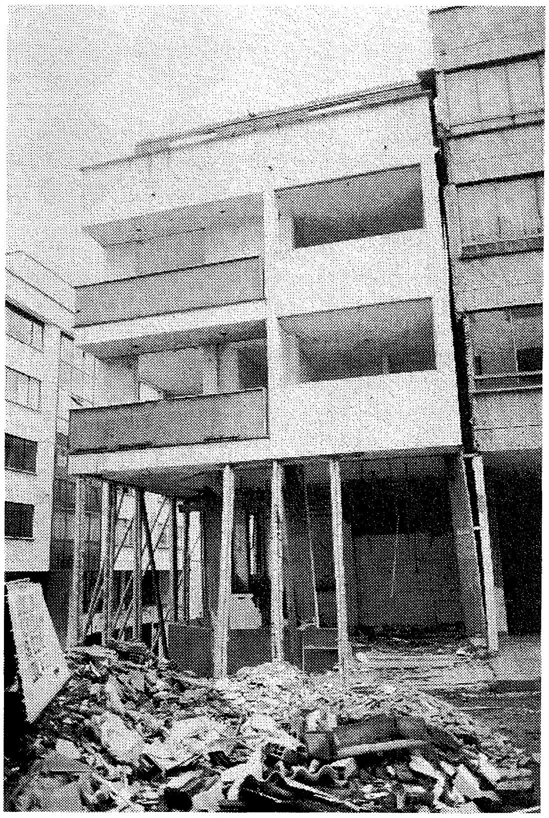


Figure 24: ***Excessively displaced corner building in Pereira.***

clay brick infilled walls changed the dynamic performance of buildings and induced partial soft storey mechanisms in some frame buildings or local column shear failures. In Pereira many buildings that had had cosmetic repairs to the infilled walls after the 1995 earthquake were damaged again during this earthquake.

Buildings with structural concrete walls we inspected showed generally good performance, except for "El Jardín" Courts in Pereira (Figure 30). This 10 storey building has perimeter structural walls and internal columns. The floor system is a cast-in-place concrete one-way 450 mm thick joisted slab with 50 mm thick concrete topping. The partitions in this building suffered heavy non-structural damage. Some floor tiles near the perimeter walls were slightly dislodged indicating warping of the diaphragm or sliding shear. We believe the main reason for the damage is the lack of positive connection between the channel wall and the diaphragm (Figure 30 (b)). This is because the link beams and the corridors are located between two floors and are unable to provide a load path. As a result, the building was subjected to a large torsional response. The perimeter rectangular concrete walls showed incipient signs of hinges above the first floor whereas the channel wall remained uncracked. This building was designed in 1995 using commonly accepted structural analysis packages that assume the diaphragm as infinitely rigid. Results of the analysis are unable to show a load path for the diaphragm forces nor do they indicate the magnitude of such forces.

The interior fittings and office furniture and the façade in the lower five storeys of the 20-storey Quindío Regional Government Building in Armenia (Figure 31) were extensively damaged during the earthquake. Interior glass partitions were shattered, file cabinets and office equipment overturned. In the lift machine room, located in the uppermost floor of the building, some of the electric motors were displaced. At first glance it seems difficult to explain why a building with a reasonably long fundamental period suffered such damage.

The tower incorporated a four-storey annex, the Regional Council Chambers, which collapsed totally during the 5.40 pm aftershock (Figure 32). The annex when constructed was locked to the central tower between two columns protruding from the Regional Government Building (Figure 33). The annex had large vertical irregularities as the main columns around the façade were recessed for architectural purposes. The lack of a proper seismic gap between this building and the tower increased the likelihood for poor performance. A common problem with past designs, and even newer ones, is the failure to ensure sufficiently large seismic gaps between buildings. The size of these gaps can be underestimated by carrying out analyses based on gross section properties.

In Armenia, the combined response of the four-storey Council Chambers and 20-storey regional government tower induced a large torsional response, particularly in the shorter building. Pounding between the buildings during the response is evident in two specific points where the concrete cover spalled off the columns in the tower. Pounding evidently exerted very high accelerations, rich in high frequencies that inflicted damage to office furniture and non-structural partitions on the taller building.

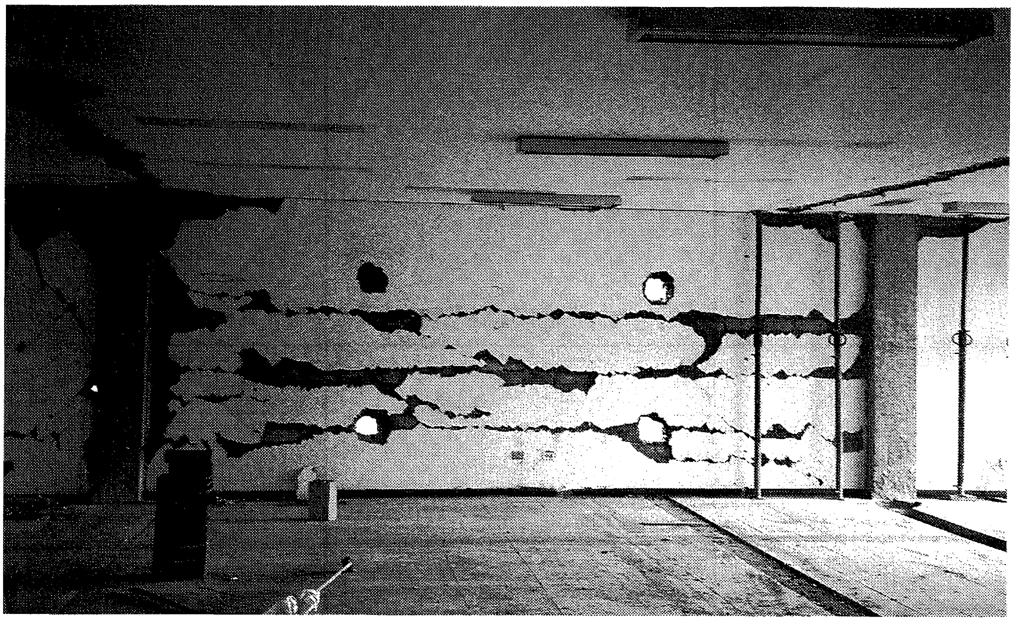
7.8 Special structures

There were some special structures in the area. One of them is the folded plate cathedral in Armenia (Figure 23). This structure suffered no damage. Another structure with folded plates was Pereira's sports stadium. The roof of the stadium has a 20 m long folded plate cantilever. The cantilever suffered partial collapse due to the fracture of the longitudinal reinforcement at the face of knee joint due to low frequency vertical excitation. This structure had been retrofitted using external post-tensioning cables following the 1979 Viejo Caldas earthquake. It is believed that no work was carried out to seal the cracks that opened during that event. Twenty years after the earthquake the bars and cables were severely corroded.

Another special structure was the 210 m long span cable stayed bridge located at the outskirts of Pereira (Figure 34) connecting this city with the towns of Dosquebradas and Manizales. This bridge has a reinforced concrete deck supported on steel girders. It sustained no damage and remained functional after the earthquake. The bridge was built with a comprehensive network of static and dynamic instrumentation. Analysis of the data collected during the 25 January event shows 0.175 g acceleration at the base of one pier, a fundamental period of 2.05 seconds and a damping ratio of 1.5% [10].

(a). Intermediate soft storey mechanism in Artalva Courts, Armenia, caused by the collapse of the infill walls. (Courtesy of E Castrillon).

Figure 25: Poor behaviour of buildings with unreinforced masonry infilled frames.



(b). Extensive damage to an infill masonry wall in Pereira.

Figure 25: Poor behaviour of buildings with unreinforced masonry infilled frames.

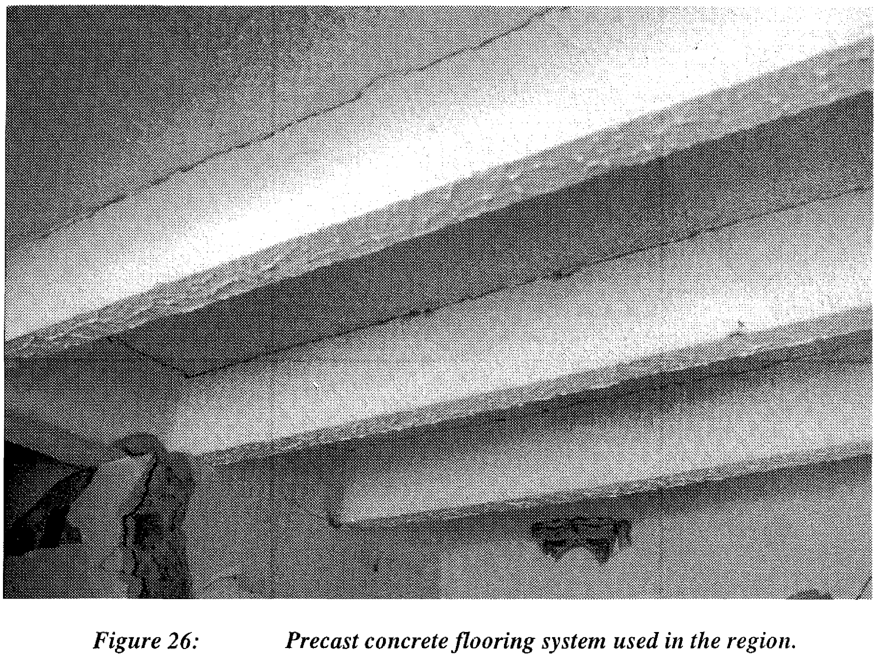


Figure 26: Precast concrete flooring system used in the region.

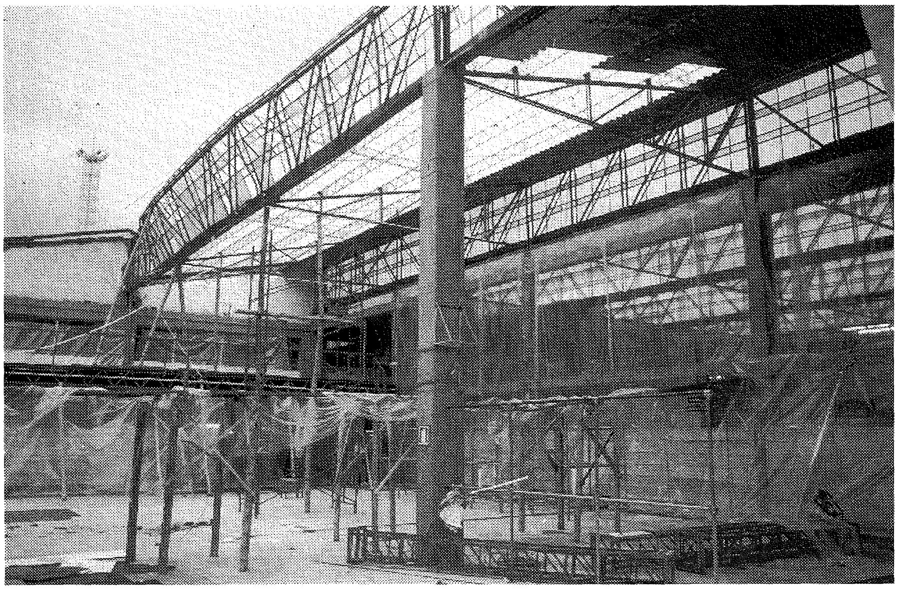


Figure 27: *Lateral buckling of a structural steel roof truss in Nicol Industries.*

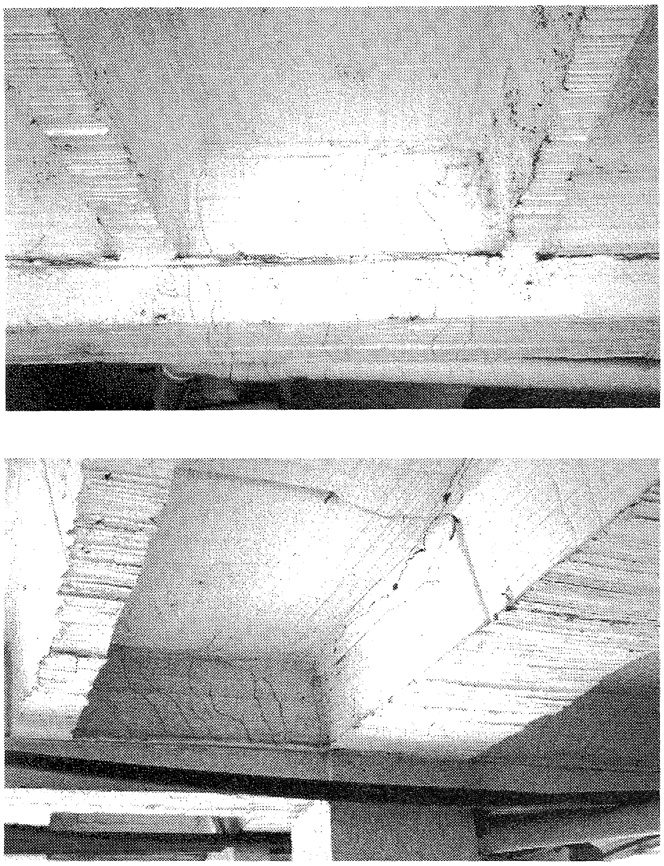
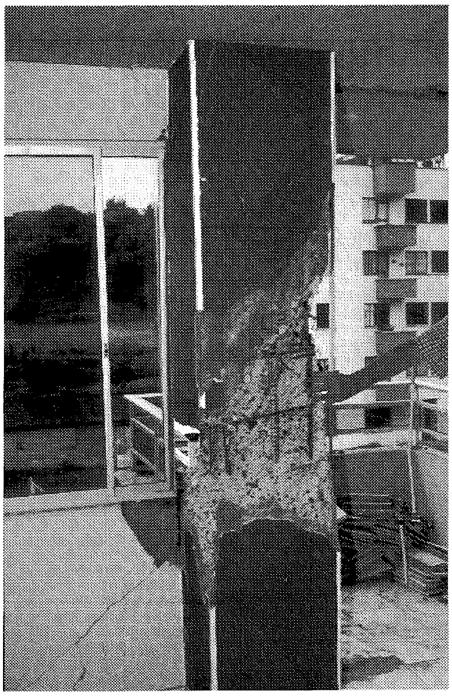
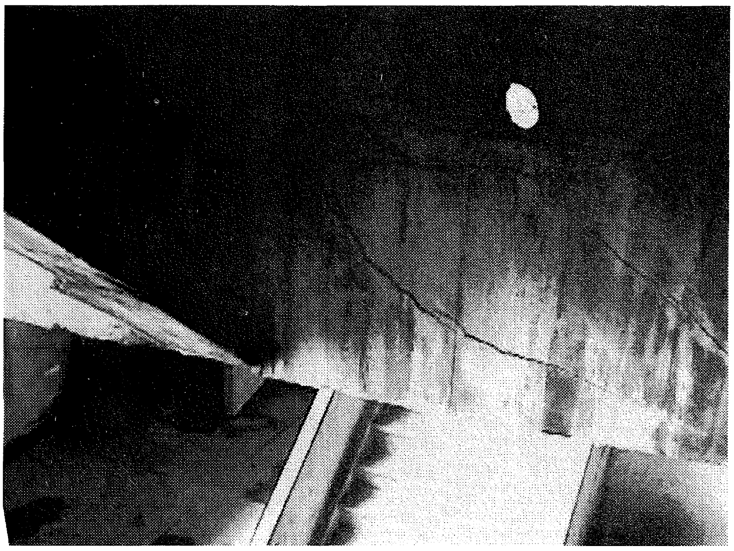


Figure 28: Positive and negative plastic hinges in a gravity dominated beam of a reinforced concrete frame (Veraneros Courts).



(a). ***Short column induced by the presence of an infill wall.***

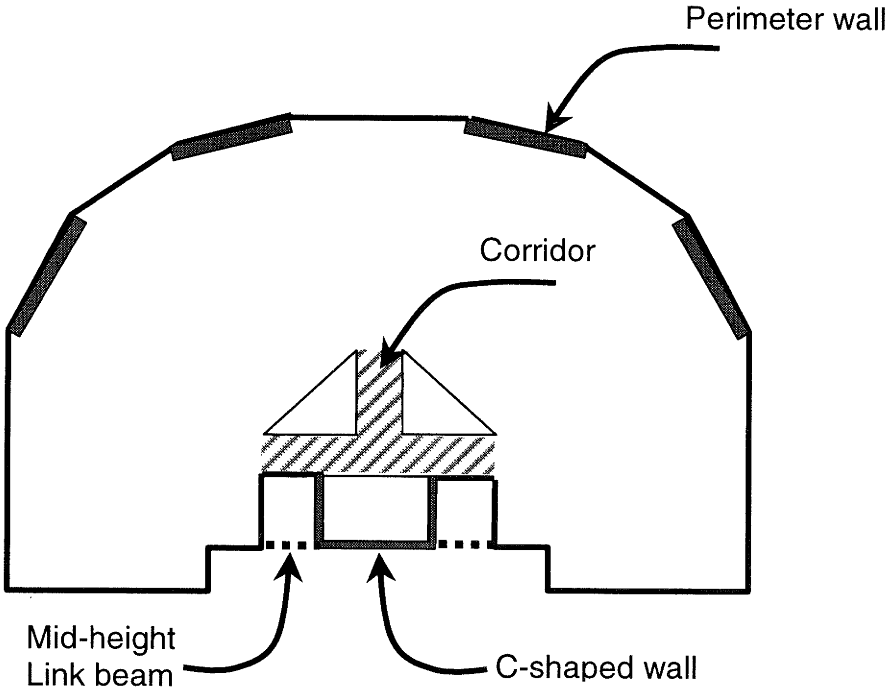


(b). *Large torsional cracks due to the interstorey restraint caused by a staircase. Hernan Ramirez Villegas Sports Stadium, Pereira.*

(c). ***Non-structural damage to a clay brick façade.***

Figure 29: ***Damage due to lack of deformation compatibility.***

(a). Elevation



(b). View of typical floor.

Figure 30: "El Jardin" Courts, Pereira.

Figure 31: ***View of the Quindío regional government building.***

8. SOCIAL ISSUES

The first impact on the population after the earthquake was grieving for family members, friends and for material losses. Children and elderly were most affected. An increase in domestic violence was reported and attributed to the sense of frustration caused by the loss of jobs, the habitat and the daily routine in areas where people were left homeless.

Population living in temporary accommodation, particularly in tents, found problems of adaptation as the privacy and intimacy of the family structure were suddenly changed to a community based structure. Crime, alcoholism, violence and pregnancy were observed to develop in these areas amongst the youth.

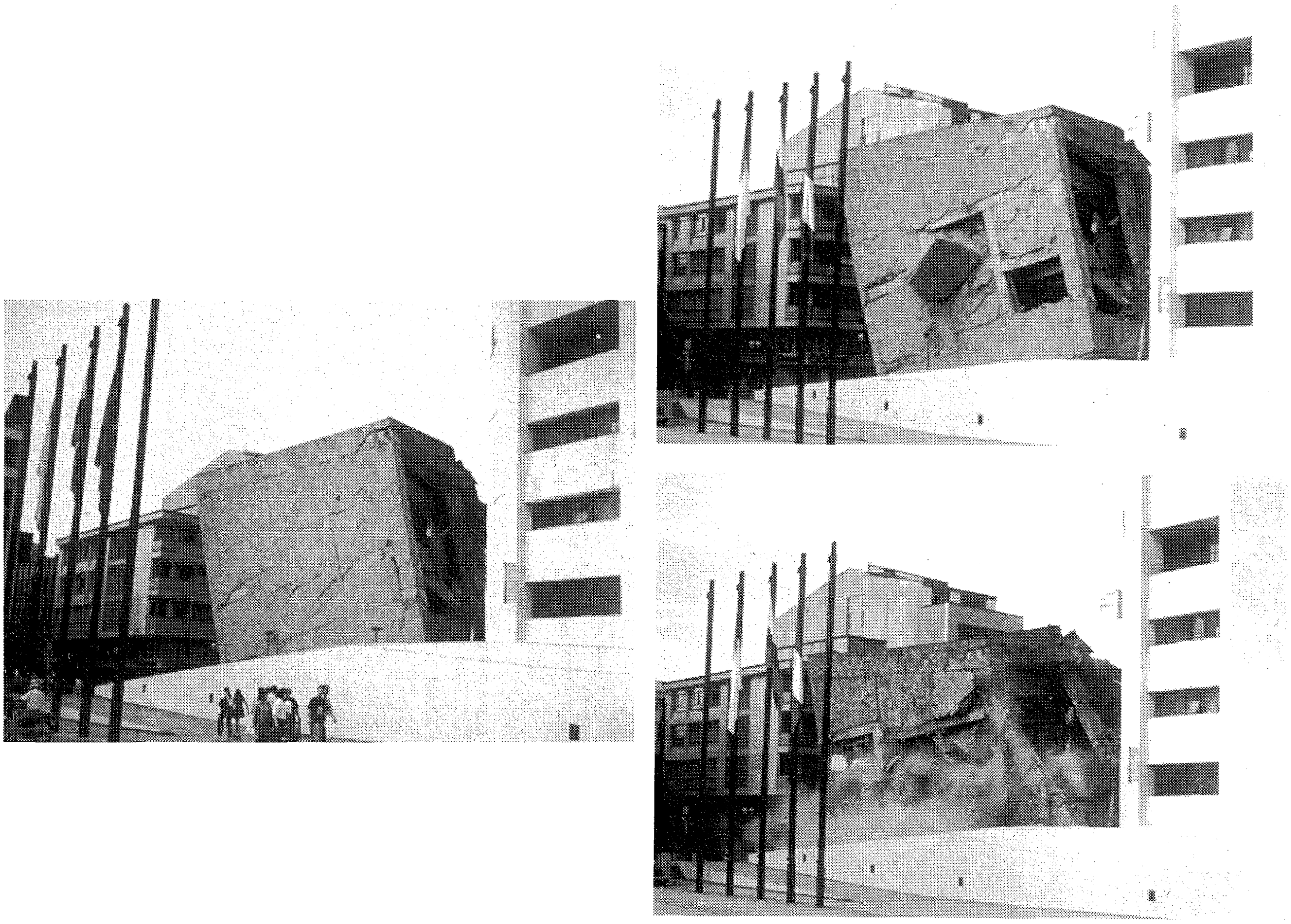
As many schools collapsed or were rendered uninhabitable, classes were mainly held in tents. The loss of the habitat combined with high temperatures caused learning difficulties and loss of concentration among the children.

The Red Cross of Colombia established a series of seminars for the most affected part of the community to teach them how to handle grief and recover their self-esteem. Group therapy was also part of the Red Cross Strategy.

9. HEALTH ISSUES

During the first weeks of the recovery phase a large number of the affected population developed gastroenterological diseases as a result of the change in diet. Food supplies flown from abroad had large quantities of canned sea-food, which is not part of the staple diet in the Andean population of Colombia.

An abnormal number of respiratory diseases had been reported in Armenia five months after the earthquake. Many people had to breathe in a very dusty environment during the first weeks when demolition work and removal of debris was intense. There was concern as to the long-term health effects caused by high concentrations of suspended asbestos-cement particles from crushed roof tiles. It will be some years before any health effect due to asbestos-cement dust inhalation is known.



(a). Immediately after the main event.

(b). Building collapse during the 5:40 pm aftershock.

Figure 32: Quindío council chambers. (Courtesy of Quiceno Bro.).

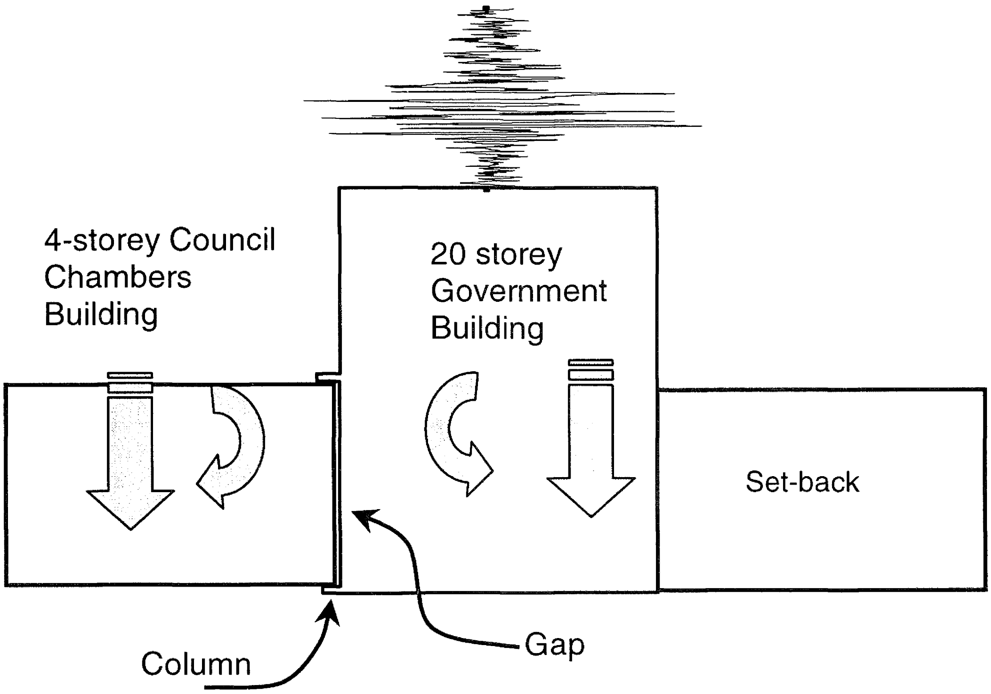


Figure 33: Plan view of the Quindío Government building and the Regional Council Chambers building.

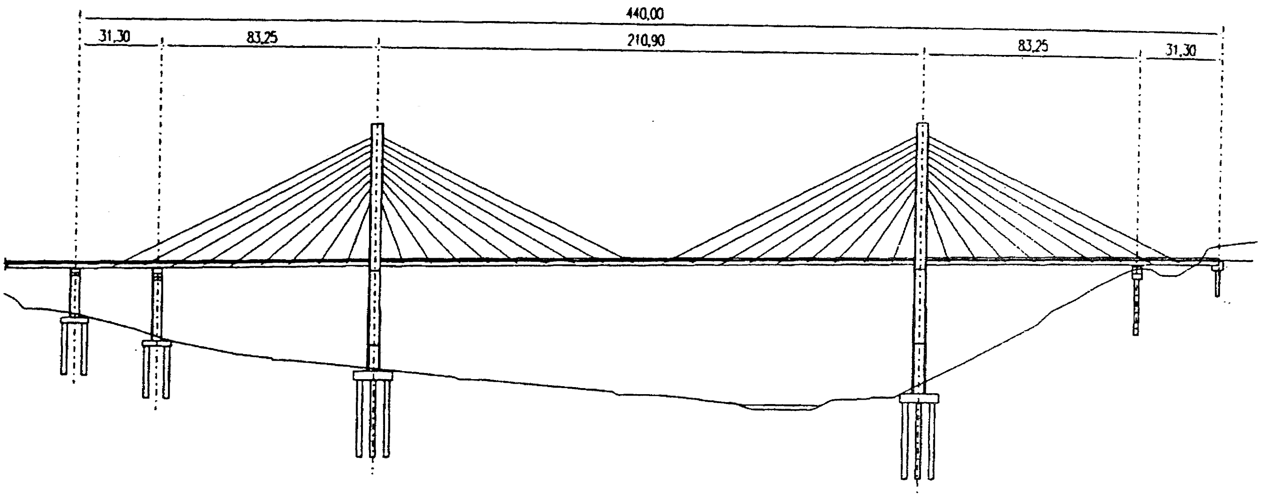


Figure 34: *Elevation of the Pereira-Dosquebradas cable stayed bridge [25].*

10. INSURANCE ISSUES

At the time of our reconnaissance the community focus was shifting from response to recovery and the newspapers were full of discussion about the economic catastrophe associated with business interruption, unemployment and related economic losses. Issues related to insurance were beginning to emerge on a scale unprecedented in the short (< 20 years) history of earthquake insurance in Colombia [26].

A meeting in Pereira with representatives of the Association of Insurers revealed the following concerns:

- Mortgagees are required to carry earthquake and fire insurance, but only one company provides full replacement cover. The industry "norm" is 75% of the capital value, with an excess of 5% of the capital value.

- Major uncertainties about liability for communal areas exist in the case of multi-storey condominiums (i.e. stairs, lifts, patios, and major structural elements). One insurer claimed that this merely requires occupants to present their claims simultaneously, but in many cases several insurers were involved, or some occupants of freehold property were uninsured.

- Thousands were uninsured or under-insured, and for mortgagees with little equity in their homes, many faced potential ruin. At the time of our visit this situation was exacerbating an already difficult task for engineers evaluating the safety and potential demolition or repair of damaged buildings.

11. CONCLUSIONS

11.1 Earthquake Characteristics

The experience gathered from this mission, highlights the hazard posed by a relatively small, shallow earthquake located close to population centres. Some of the physical effects of the Colombia earthquake can be attributed to local risk factors not typical of the New Zealand environment. However, the recorded ground motions associated with soft soils and narrow ridge-and-gully topography, possibly also reflecting rupture directivity effects, highlight a potential vulnerability for New Zealand urban centres centred close to active fault zones.

- The Colombian experience confirms the importance of research into "microzone" effects and its applications to seismic risk assessment. Microzone and wave propagation studies have been conducted at a few centres in New Zealand, but coverage is sparse and these topics remain priorities for investigation.

11.2 Engineered Structures

- Structures designed and built prior to the introduction of modern seismic design standards were most seriously affected, but some modern buildings also sustained significant damage for a variety of reasons.

- Vertical ground response close to the epicentre was also large in the short period band. Investigations should be conducted as to the effects of such response on different structural systems employed in New Zealand, particularly pre-stressed concrete systems.

- The loss of operation of key institutions in the epicentral area was caused by partial or total collapse of buildings. Police, Fire Brigade, Blood Bank and airport buildings collapsed. Three hospitals and five health centres collapsed and the main telecommunications building suffered extensive structural damage. In contrast, a partially seismically retrofitted hospital building in the epicentral area was damaged only where the retrofit work had not been completed.

- The lack of sufficiently large seismic gaps accounted for significant damage in this earthquake, mainly when floors in adjacent buildings where non-coincident. This highlights the importance of selecting an appropriate seismic gap in the design process, and the potential dangers of underestimating the size of the gap as a result of the assumptions made during the structural analysis process.

11.3 Lifelines

- The loss of the water supply system in Armenia was principally attributed to the extensive damage suffered by PVC pipes in the domestic reticulation network. These pipes split or ruptured completely as a result of building collapse or excessive relative movement that could not be accommodated due to their inherent brittleness.
- Diesel emergency generators worked well without exception. These generators are well maintained and often used due to frequent loss of power supply as a result of lightning.
- Digging during the rescue phase and principally during post-response demolition work caused severe damage to the underground power supply in central Armenia.
- The cellular telephony network is extensively used in the area affected by the earthquake. The network became saturated during the first 15 minutes after the main event. This led to isolation of the epicentral area in the immediate aftermath.

11.4 Emergency Response and Recovery

Among the widespread social impacts of this earthquake, a number of key factors are potentially relevant in the New Zealand context.

- The lack of clear, national leadership for the emergency response, combined with the severe impact of the earthquake on the regional organisations and key individuals responsible for managing the emergency response in the affected areas, contributed to an impaired response in the aftermath. The experience of the emergency management committees in Colombia clearly indicated that for an event of this nature, prompt and unambiguous national co-ordination and resourcing are critical.
- Confusion during the tagging and post-earthquake assessment of buildings led to litigious situations. Structural engineers and insurers need to be introduced to basic concepts of forensic engineering.

11.5 Insurance

Beyond the immediate concerns of life-safety there were also major uncertainties about insurers liabilities for communal areas in the case of multi-storey condominiums (i.e. stairs, lifts, patios, and major structural elements). The uncertainties arose wherever several insurers were involved, or when some occupants of freehold property in a multi-unit complex were uninsured.

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