Damage to Building Structures
Caused by the 1999 Quindio Earthquake in Colombia

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1. INTRODUCTION
On January 25, 1999, an earthquake of Richter Magnitude of 6.2 occurred in the Republic of Colombia. As of the 3rd of March 1999, the death toll was 1,171 and 4,795 people were injured, and more than 21,000 dwelling and non-dwelling building structures were totally collapsed [Reference 1].
The Reconnaissance Team of eight members from the Ministry of Education of Japanese Government arrived at Santa Fe de Bogota, the Capital of Colombia on March 3, 1999, and spent ten nights in Colombia. Investigation conducted by the Team covered the effects of the earthquake on the ground, lifelines and building structures.
Since most of the human damage was caused by the total or partial collapse of those low-rise building structures, field investigation results on damaged building structures, especially low-rise masonry and bamboo-plastered wall house buildings in Armenia City, are mainly introduced in the present paper.

2. BRIEF DESCRIPTION OF EARTHQUAKE
The main shock of this earthquake occurred at 1:19 p.m. on Sunday of the 25th of January 1999, and it’s Richter Magnitude was M=6.2. Location of the epicenter was about 16 km to the South of the City of Armenia, the capital of Quindio Province in Colombia (see Figure 1). The depth of the main shock of this earthquake was about 10 km. According to the Bibliography [Reference 1] which was published on March 3, 1999 from the Ministry of Interior of the Colombian Government, total number of dead people was 1,171 persons and 4,795 people were injured, while 21,178 dwelling and non-dwelling building structures were totally collapsed and more than 32,000 building structures were partially collapsed.

Figure 1 Quindio Earthquake in Colombia
(January 25th, 1999) [2]

During the main shock of this earthquake, a number of earthquake accelerograms were recorded. Among these, peak accelerations in E-W, U-D (Vertical) and N-S directions, which were recorded at the Quindio University Station located within the Armenia City, were 0.528g, 0.479g and 0.584g, respectively [Reference 2]. These values are the maximum recorded accelerations obtained during this earthquake. The acceleration response spectra for 5% of damping of this record showed that the predominant periods were 0.12, 0.20
and 0.50 (sec) in N-S component, 0.25 (sec) in E-W and 0.10 (sec) in Vertical component, respectively.

3. DAMAGE TO BUILDING STRUCTURES IN ARMENIA CITY

3.1 CITY OF ARMENIA

The City of Armenia is located approximately 180 km to the West South from Santa Fe de Bogota, and was attacked most severely by this earthquake, resulting in the worst human and building damage among all the cities affected by this earthquake.

Downtown of Armenia City is about 1,500 meters above the sea level and is located on the Western skirts of the Andes Central Mountain. The City is famous as one of the three major coffee producing cities in Colombia and is a very important city in the Colombian economy. Population of this City is about 250,000 and 80 percent of the people are living within 2,500 ha urban area.

Herein, the earthquake damage to the building structures in this City is introduced especially focusing on the medium- and low-rise masonry houses and residential buildings. According to the Seismic Risk Zoning Map in the present Colombian Standards for Earthquake Resistant Design and Construction of Building Structures (NSA-98) published in 1998, Armenia City is located in the highest seismic zone among three specified zones [Reference 3].

3.2 FIELD INVESTIGATION IN ARMENIA CITY

Field investigation in the City of Armenia was conducted during about three and a half days during from the 7th through 10th of March in 1999. On the first day of the investigation, most severely damaged areas in the South, Central and North zones in Armenia City were visited to understand the Armenia’s overall damage caused by the earthquake.

During the rest of days in Armenia, more detailed field investigation was conducted within the Central zone of Armenia City, where all the damaged buildings along through the specified roads were observed by foot. Total distance of the roads was approximately 7.5 km. In addition, some of the medium-rise residential (or apartment) buildings as well as the reinforced concrete (R/C) moment resisting frame structures in North zone were also investigated. All of the residential buildings investigated were less than five stories.

Due to the inadequate public peace within the City of Armenia, all of the field investigation was performed perfectly being guarded by the national and private policemen.

3.3 BRIEF DESCRIPTION OF EARTHQUAKE DAMAGE IN ARMENIA

During this earthquake, the worst earthquake damage both in human and building structures was concentrated in Armenia City [Reference 1]. There were 800 people being killed among the death toll of 1,171 by this earthquake, 2,300 persons were injured among the total of 4,795, and the total number of completely collapsed houses and residential buildings was more than 10,000, which was more than 55 percent of the total number of the totally collapsed dwelling damage caused by this earthquake (Photos 1 and 2).

It is reported that the estimated maximum ground acceleration within the City of Armenia was 0.89g in the horizontal direction, which was calculated based on the recorded ground acceleration obtained at the Quindio University Station.

3.4 STRUCTURAL SYSTEMS ADOPTED IN DAMAGED BUILDINGS IN ARMENIA

Although a considerable amount of damaged building structures were observed within the City of Armenia, representa-
tive or typical structural systems adopted in the severely damaged building structures can be classified into following categories:

(a). Bamboo-plastered (or Timber) Wall Structures:
One of the traditional wall structures in some Latin American countries, where structural (and/or partition) walls are composed of bamboo (or “quincha” in Spanish) or timber frames, mud or clay fillers and chopped straws as wall surfaces in some cases, and plastered finish as being observed in Photos 3 and 4 (hereafter “Bamboo Wall” for short).

(b). Unreinforced Clay Brick Masonry Wall Structures:
In most of this kind of walls, there are no wall girders such as a collar beam in case of the R/C masonry wall structures provided along the top of each wall. Most of the structural members or frames in roofs and ceilings adopted in this type of wall structural system are composed of bamboo and/or timbers as shown in Photo 5.

(c). Confined Masonry Wall Structures:
One of the typical masonry wall structural systems widely accepted and constructed in Latin American and South-East Asian countries for low- and medium-rise houses or residential buildings. In this type of structural wall system, there are cast-in-place R/C slender columns provided at most of the extreme edges and intersections of masonry walls. In addition, cast-in-place R/C collar beams, wall girders or floor slabs are usually provided along the top of each masonry wall (see Photo 7). In most of the cases, longitudinal Re-bars and hoops in R/C columns are installed before masonry wall units are placed within the wall plane. Therefore, after brick or block masonry units are placed with mortar in one or half story height, then concrete in columns is cast, and R/C col-
lar beams, wall girders or floor slabs are finally constructed by cast-in-place concrete after all the masonry walls and R/C cast-in-place columns are completed. A total of four longitudinal Re-bars are usually provided in each of the R/C column sections. This type of masonry walls are called as “Confined Masonry Walls” in Latin American countries.

(e). Other Structural Systems:
In addition to the above structural systems adopted widely to the severely damaged building structures in Armenia City, considerable structural damage was observed in some of the ordinary R/C moment-resisting frames in which unreinforced masonry brick or block walls are also provided within the plane enclosed by the R/C column and beam or slab members (Photo 9). In most of those cases having extensive earthquake damage to the structural or non-structural members, inadequate structural designs or structural systems such as the extremely irregular structures or framing systems were adopted, for example, buildings with irregular configuration, buildings with abrupt changes in lateral resistance and/or lateral stiffness, buildings with unusual size and shape, buildings on steep hillsides or on soft soils, and so on.

(d). Masonry Filled Slender R/C Frame Structures:
Relatively smaller size and shape of moment-resisting frames which are composed of R/C slender columns and beams (or cast-in-place flat slabs or waffle slabs in some cases). After moment-resisting frames with slender structural members are completed, then all the exterior and partition walls are filled with unreinforced masonry brick or block units and mortar (Photo 8). Most of the perimeters in each masonry wall panel are usually not connected firmly to the attached R/C column and beam (or floor slab) members by using the connecting pieces such as small size of steel Re-bars as being observed in Chinese Construction methods [Reference 4]. This type of structural systems seem to be widely adopted in Colombia especially in medium-rise residential buildings less than five stories.

3.5 DAMAGE TO BUILDING STRUCTURES AND DISCUSSIONS
During this earthquake, some of the medium-rise or relatively taller building structures located in the City of Armenia were structurally damaged. Among these, it can be noted that some of the important buildings such as the police station (5-story R/C), fire station, telecommunication office (6-story R/C), city office, hospitals, schools, banks, churches, hotels and other commercial facilities were included, and some of those were severely damaged or completely collapsed [Reference 2].

Although a considerable amount of building structures were damaged during this earthquake in Armenia City, most
of the human damage was caused by the total or partial collapse of the relatively low-rise buildings, especially one- and two-story bamboo-plastered wall or unreinforced masonry wall house buildings, therefore most of the description of this paper is mainly focused on those low-rise building structures.

(a). Bamboo-wall Structures:
In most of the severely damaged bamboo-plastered (or timber) wall structures, all the vertical wall-edges at the L-, T- and + - shaped intersections in plan were not connected each other or inadequately connected. As a result, each of the walls behaved independently during the earthquake, some walls separated from adjacent walls at their vertical connections and finally overturned in out-of-plane directions which resulted in the severe structural damage (Photos 10, 11 and 12).

This fact means that, if such types of wall structures cannot keep their original boxed-wall shapes during the strong-motion earthquakes, then considerable amount of severe structural and human damage will be expected to occur during a future earthquake.

In case of this type of boxed-wall structures, it is necessary to connect the vertical connections between adjacent walls, and to connect the horizontal connections between walls and adjacent strong collar beams firmly. Once this type of building structure is designed and constructed so as to keep its original box-shaped building configuration, then each of the walls can develop its excellent anti-seismic capacity such as higher in-plane lateral stiffness and strength during earthquakes, that results in the much more safer building structures against earthquakes.

(b). Unreinforced Masonry Wall Structures:
In most of the severely damaged unreinforced clay brick masonry wall structures, each of the masonry units as well as the vertical wall-edges were not connected each other especially at the wall intersections in plan. In addition, there were no collar beams or no horizontal floor diaphragms provided and/or connected along the top of the masonry walls. As the results, each of the walls behaved independently during the earthquake, some of the masonry units were cracked, crushed or broken, or separated from each other, or some of the masonry wall panels separated from other wall(s) at their vertical connections and finally overturned in out-of-plane directions which caused the severe structural damage such as total collapse or partial collapse especially in the low-rise unreinforced masonry buildings (Photos 13 and 14).

This fact means that, if such types of unreinforced masonry wall structures are not strengthened by the appropriate rehabilitation methods, then considerable amount of severe structural and human damage will be expected to occur again and again during coming next big earthquakes in many earthquake countries.

(c). Confined Masonry Wall or Masonry Filled Slender R/C Frame Structures:
In severely damaged building structures where this type of structural system was adopted, some or most of the
unreinforced clay brick or block masonry units were separated each other and/or removed from the attached R/C column- and beam- or slab-members, and some of the masonry parts were dropped down from their original position into out-of plane directions. This is because each of the masonry units was not connected each other as well as not being connected to the attached or surrounding R/C frame members so firmly. As the results, remainder R/C columns become the slender independent columns, some of which were buckled, broken or crushed, and finally the columns lost their gravity load-carrying capacity that resulted in the total or partial collapse of the whole buildings (Photo 15).

In other cases of structural damage observed in these types of structures, shear cracks or partial damage occurred within the unreinforced masonry wall panels propagated into the adjacent confining R/C column-members, which resulted in the local collapse of the R/C columns such as in-plane or out-of-plane buckling or crushing, and finally the columns lost their vertical and lateral load-carrying capacity (Photo 16). This seems to be mainly caused by the relatively small size and shape of the R/C columns and inadequate reinforcing methods provided into the slender column sections.

Other cases of the structural damage observed in R/C columns and beam-to-column connections of these types of structures was coming from the lack of concrete sections and discontinuity of concrete sections at around the beam-to-column connections, which are mainly caused by the leakage of water and cement-mortar from the concrete forms in Colombia during concrete casting, because of frequent usage of crashed or chopped bamboo materials as the concrete forms (see Photos 17 and 18).

Furthermore, poor reinforcement details were also observed especially in R/C beam-to-column connections in severely damaged confined masonry wall structures and masonry filled slender R/C frame structures (Photos 19 and 20).

In addition, it is worthy of note that the extensive earth-
quake damage to the structural or non-structural elements were observed in the building structures having an inadequate structural design or structural systems such as the extremely irregular structures or framing systems, for example, buildings with irregular configuration, buildings with abrupt changes in lateral resistance and/or lateral stiffness, buildings with unusual size and shape, buildings on steep hillsides or on soft soils, and so on (see Photos 21 through 24).

4. RAPID DAMAGE EVALUATION IN PEREIRA CITY

The City of Pereira is the Capital of Risaralda Province and is located approximately 35 km to the North of the City of Armenia. Population of Pereira is about 410,000 and this City is also one of the three major cities being surrounded by the coffee growing regions in Colombia. Human damage of this City was that about 50 people were dead and 650 persons were injured.

After this earthquake, the Local Committee of Emergency of the City Office of Pereira conducted the post-earthquake rapid damage evaluation for about 7,000 building structures within the City by using the investigation forms. Results of this rapid damage evaluation are: total number of the buildings in Severe Structural Damage was 925, Architecturally Important Damage was 1,260, Moderate Damage was 167 and Little Damage was 995.

According to the classification by the City Office of Pereira, all the building structures in this City are classified four different structural systems and the percentage of each type of building to the total number of the buildings in Pereira City is in the followings: that is; Unreinforced Masonry Building is 56.7%, Confined Masonry Building is 20%, Reinforced Concrete Building is 13%, Bamboo Wall Dwelling Houses is 7.6% and the rest is other buildings. Among these, more than 80 percent of the buildings are one- and two-story buildings. These facts are very important and worthy of note to work out the anti-seismic strategy for safer building structures against next big earthquakes in Colombia.

All of the results of this rapid damage evaluation and information presented herein are based on the hearing performed at the Pereira City Office in the afternoon of the 10th of March 1999 by the authors.

5. CONCLUDING REMARKS

Although a considerable amount of building structures were damaged during the earthquake, most of the human damage was caused by the total or partial collapse of the relatively low-rise buildings, especially one- and two-story dwelling buildings which were constructed by unreinforced masonry or bamboo (or timber) wall structural systems. In addition, since most of the existing building structures are one- and two-story residential buildings which are constructed by unreinforced masonry buildings and bamboo wall houses in Colombia, most of the damage description was mainly focused on those most popular low-rise buildings in the present paper.
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7. REFERENCES