



## **DAMAGES OCCURRED TO CHURCHES DUE TO THE EARTHQUAKE OF FEBRUARY 8, 1995 IN PEREIRA, COLOMBIA**

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### **ABSTRACT**

In this paper the damages produced to churches due to the earthquake of February 8th 1995 in Pereira, Colombia are studied and a description of the main structural and non-structural problems which originated these damages is done. The causes of damage are pointed out for the majority of the churches inspected. The lessons learned in this and other earthquakes allow to predict future performance of similar buildings in other latitudes for evaluation and reinforcement purposes. As a result of this study it was found that the damages were due mainly to bad structural configurations with lack of continuity and symmetry and the presence of arches without adequate bracing, that produced stress concentrations in the stiffer regions. Heavy roofs, excess heights and inadequate materials for use in seismic zones, originated severe failures in some of these buildings.

### **KEYWORDS**

Church; causes of damage; structural discontinuity; stiff beams; unbraced arches; vulnerability.

### **GENERAL CONSIDERATIONS**

This paper is an extension to a research project developed by the group of Seismic Research of the Engineering Faculty at The University of the Andes in Merida, Venezuela (Hernandez *et al.*, 1992, 1993, Montilla, *et al.*, 1993, Montilla, 1993, 1996, Uzcátegui *et al.*, 1992a, b, 1994, 1996). Under this project an evaluation was done of the damages in the churches of the State of Mérida, caused by the most destructive earthquakes that have occurred in the region. The architectural and structural configuration of many churches in South America are very similar, due to the influence of the Spanish culture on this continent; for this reason it is important to analyse and compare damages caused to churches due to strong earthquakes occurred in different parts of the continent, so that common failures may be determined, even though the earthquakes are different.

On the 8th of February, 1995 an earthquake of magnitude 6.4 on the Richter scale occurred in the Cauca region of Colombia, that was originated in the subduction zone between the Nazca and the South American plate. This earthquake affected the city of Pereira, which is located on the central branch of the Andes mountain range, and has an undulated topography constituted by small valleys and mountains. During this earthquake most of the churches in the city suffered damages, in some cases of consideration. The majority

of churches are constituted by three naves, one central and two lateral ones, with clay tile roofs resting on wooden runners on beams of wood or concrete. The columns are of concrete or masonry and the lateral walls are of brick masonry of great thickness.

## **DESCRIPTION OF CHURCHES AND OBSERVED DAMAGES**

### **La Pobreza Cathedral**

This church is constituted by a central nave and two lateral ones. It has two Towers located at the sides of the Frontispiece and in front of it. In the Presbytery zone there is a spherical cupola. The walls are of brick masonry of great thickness (Photo 1).

The minor damages observed are small cracks on the internal arches and walls and the inclination of the cross located on the top of the central cupola. All of the damages are slight and easily repairable.

### **The Balbanera Church**

It consists of a central nave and two lateral ones and a Tower located to the left of the Frontispiece. The roof is made of asbestos sheets resting on wooden runners and beams. The structure is made of reinforced concrete.

The damages occurred basically to non-structural elements. Loss of plaster was observed at the half of the Tower and an inclined crack located right at the zone of stiffness change between the Tower and the rest of the church (Photo 2). The external ornament and covering fell off the top of one of the columns of the central nave, and being very heavy they fell on to the roof of the left lateral nave close to the Presbytery, causing the failure of the roof and false roof also very heavy, which if it had been occupied could have caused injuries to people in the area (Photo 3).

### **La Trinidad Church**

It is asymmetric on the plan, constituted by four naves, one central, two to the left and one to the right. To the right of the Frontispiece and out it is plane, there is a Tower made up of five bodies or levels (Photo 4). The structure of the church is made of reinforced concrete.

The damages were concentrated in the zone of the Presbytery, in the Tower and in some non-structural elements of the Central Nave. Great cracks were observed in the walls of the Presbytery and of the Sacristy, possibly due to the stress concentration originated by sudden change in stiffness in that zone (Photo 5). In the Tower small cracks were observed in the walls; at the top of the Central Nave some plaster fell off and the ornaments of one of the columns, that fell on to the wooden benches, breaking them (Photos 6 and 7). Also small cracks were observed in the top beams of the Central Nave. Some religious images that were on high stands connected to the columns also fell off (Photo 8). The false roof, made of sheets of heavy material, nearly collapsed in the zone close to the Presbytery. The falling of non-structural elements did not cause loss of lives because the church was empty at the moment of the earthquake.

### **San Antonio Maria de Claret Church**

This church is constituted by a Central Nave, two lateral ones and a Tower located to the left of the Frontispiece (Photo 9). There is a spherical cupola in the zone previous to the Presbytery. The structural

system is of reinforced concrete. The Presbytery is conformed by a system of poorly reinforced concrete arches distributed in the longitudinal and transversal directions. The Central Nave has two longitudinal beams that finish in the arch before the Presbytery, producing a structural discontinuity in that zone (Photo 10).

Severe damage was caused to the arches located to the right of Presbytery, at the top and at the column-arch joint; in both places loss of concrete cover and buckling of longitudinal bars were observed (Photo 11). The two central columns that support the arch before the Presbytery showed a considerable lack of verticality, opening the arch, and significant cracking at the base (Photos 12 and 13). The last span of the longitudinal beam that finishes at these columns resulted seriously affected (Photo 10). The border wall of the left lateral nave, made of brick masonry and of great thickness, suffered excessive lack of verticality outwardly, in the zone of the Presbytery, resulting seriously cracked. The top part of this wall, which was laterally unsupported, fell off into the neighbouring building, originating damage to it. Later it was completely demolished (Photo 12). Some religious images that were resting simply on wooden pedestals fell over breaking themselves, without causing injuries to people because the church was closed at that moment. This church was close to collapsing in the Presbytery zone.

### **San José Church**

This church has a Central Nave, two lateral ones and two small Towers located at each side of the Frontispiece (Photo 14). The plan is rectangular and asymmetric. It is very high in the Central Nave and its height is reduced considerably in the lateral naves. The roof is made of reinforced concrete slabs, supporting false domes internally. The structural system is of reinforced concrete frames infilled with brick masonry, which form a series of arches in the longitudinal and transverse directions inside the church. The Chorus has a very stiff transverse beam and its structure has a construction joint that separates it from the rest of the church; however, during the construction a connection was made crossing the joint with the reinforcing bars of the longitudinal beam. In the longitudinal direction, between the Chorus and the Presbytery, there is a stiff beam that is interrupted before this last one (Photo 15).

This church had generalised damages, in both structural and non-structural elements. The most severe were concentrated in the zone of the Presbytery and the Chorus, that were close to collapsing. In the zone of the Presbytery, at the top of the columns the concrete suffered fracture and the reinforcing bars buckled due to stress concentration because of a short column effect and due to sudden stiffness change as a result of the discontinuity in the longitudinal beam in the Presbytery (Photo 16). In the zone of the Chorus, at the construction joint, separation occurred between this body and the Central Nave; but, due to the connection through the joint of the reinforcing bars, serious damage was caused in this zone (Photos 17 and 18). In the lateral walls great cracks were produced, specially close to the great opening of windows, that produced zones of weakness fracturing the wall. There was also considerable damages at the zone of union between the church and the Pastoral House, due to uncoupled movement of both buildings. Some heavy parapets that were located above the access doors, presented severe cracks in the union with the church and were near to overturn (Photo 14). Some religious images fell down breaking themselves.

### **CAUSES OF DAMAGE IN THE CHURCHES OF PEREIRA**

The observed damages were due fundamentally to the following causes:

The poor structural configuration of most of the studied churches, that have a Central Nave with very stiff longitudinal beams that are not continuous in the Presbytery, and create zones of high stress concentration, that in most of cases, are the main cause of damage.

The great height of the Central Nave, which makes the building very flexible in that zone, with taller and more separated columns than in the Presbytery. It makes the Presbytery zone stiffer and as a consequence, it

supports greater seismic forces and not having sufficient strength, concentrates the damages in this area.

An irregular plan form creates considerable torsional effects, that contribute to stress concentration in certain parts of the church.

The existence of unbraced arches contributes to create weakness zones in the structure.

The great stiffness and low strength of the massive construction with brick masonry, attracts a great part of the seismic forces. The walls of this type of construction are fragile and of low seismic capacity.

The non-existence of seismic-resistant design provisions.

The deterioration of the quality of the material with time and the lack of maintenance of the building, with the consequential loss of strength.

Very heavy non-structural elements, unbraced or badly supported.

Great openings in lateral infill walls that weaken them, originating bad seismic behavior in the building.

## CONCLUSIONS

This paper describes the main damages caused in the churches of Pereira during the earthquake of February 8th 1995. In view of the similarities between the religious buildings in all Latin America, the lessons learned in this earthquake and others occurred before allow to predict their performance and to know the vulnerable zones, in order to correct and improve them in the existing buildings and to avoid them in future projects. Hereafter, the construction of frames with beams without continuity along the structure of the church and of arches without adequate bracing must be avoided, since they have shown to be vulnerable to seismic actions and also avoid the construction of parapets and false ceilings made of heavy materials that are not properly anchored.

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Photo 1. Facade of La Pobreza Cathedral.



Photo 2. Facade of Balbanera Church.



Photo 3. Ornaments fell off the Balbanera Church.



Photo 4. Facade of La Trinidad Church.



Photo 5. Great cracks in the Presbytery of Balbanera Church.



Photo 6. Plaster fell off from the top of column in Balbanera Church.





Photo 7. Broken wooden bench in Balbanera Church.



Photo 8. Religious images fell off in the Balbanera Church.



Photo 9. Facade of San Antonio Church.



Photo 10. San Antonio Church. Discontinuity in the zone of the Presbytery



Photo 11. San Antonio Church. Severe damage at the column-arch joint.



Photo 12. San Antonio Church. Lack of verticality of central column.



Photo 13. San Antonio Church. Cracking at the base of the central column.



Photo 14. Facade of the San Jose Church.



Photo 15. San Jose Church. Beam without continuity to the Presbytery



Photo 16. San Jose Church. Fracture of short columns at the Presbytery



Photo 17. San Jose Church. Separation of the structures of Chorus and Central Nave.



Photo 18. San Jose Church. Severe damage in the section between the Chorus and the Central Nave.