2003 Pacific Conference on Earthquake Engineering

Caracus Earthquake 1967, Revisited

R.I. Skinner

Director, Earthquake Commission Research Foundation, New Zealand

ABSTRACT: This paper examines the types of earthquake damage which occurred throughout and near the city of Caracus, Venezuela, in 1967. Attempts were made to deduce the mechanisms of damage and collapse, and their causes. The character of the earthquake motions were estimated, and included large microzone effects due to varying depths of alluvium throughout the city, and a very severe ground lurch towards the north at the Macuto Beach resort. New Zealand responses to lessons from the Caracus earthquake are discussed. A more detailed account is given in the author's original report (Skinner 1968).

1 INTRODUCTION

At 8 o'clock on Saturday evening on 29 July 1967 a moderately severe earthquake resulted in the deaths of 277 persons, injuries to 2000 more, and damage estimated at US$100 million in and near the city of Caracus, Venezuela. Estimates gave the Richter magnitude as 6.5, the epicentre as 70 km north-north-west of Caracus, and the depth as 10 km.

The writer's study of the Caracus earthquake was delayed by two months, due to a prior commitment to an earthquake engineering study throughout Papua-New Guinea. The delay resulted in little loss and substantial gains. High level contacts ensured the fullest possible support upon arrival in Venezuela. Experts in California who had already studied the earthquake damage were visited en route to Caracus. Upon arrival the writer was met by representatives of the British Embassy and of the Structures and Geology Presidential Commissions, set up to ensure a very effective study of the earthquake damage. The Commissions briefed the writer, provided him with a fully involved research engineer to act as a guide and informant, and also provided a Presidential letter asking that the writer be given any requested assistance for his studies. The Structures Commission had taken control of important seriously damaged buildings, which were provided with military guards, and the sites of collapsed buildings, for detailed engineering studies. The aim of the studies was to develop appropriate means for repair and reconstruction and for future designs.

Many factors combined to give great importance to an engineering study of the damage in and near Caracus City. The city contained over 1000 large recent buildings, nearly all being moderate variations on the same theme, a slender reinforced concrete frame with panels of non-structural high-void ceramic bricks. This large building stock promised high local returns on the development of effective means of repair and upgrading. It also promised a high international return on engineering studies because of the controlled nature of much of the building stock and the very effective engineering research procedures adopted.

The most serious obstacle to maximising lessons from engineering studies of earthquake damage was the absence of strong-motion records of ground motions.

Dramatic microzone effects were observed throughout the city. In an area of deep alluvium many tall buildings, of 10 to 22 storeys, suffered severe damage and four collapsed. In areas with a moderate depth of alluvium tall buildings suffered little damage while some buildings with a few storeys suffered more severely. On rock sites buildings suffered no damage regardless of height.

At the Macuto Beach resort the pattern of damage was completely different. The buildings, up to 14 storeys in height, and other structures, were located on deep alluvium. Regardless of height, almost all structures suffered severe damage, and some suffered partial collapse. In every case the damage arose from a severe lurch of the structure towards the south.

2 DAMAGE MECHANISMS

Accepted design practice was given a searching test by this moderate earthquake since the large recently built Caracus buildings were designed to withstand such earthquakes. The code requirements for these buildings were approximately equivalent to the intermediate level of the 1960’s Californian Uniform Building Code.

Since the slender reinforced concrete frames of the large buildings were designed for moderate earthquake and wind loads, the size and strength of the columns were dominated by gravity loads. Side, and particularly corner columns, had lesser section areas than interior columns. Also, the size of lower storey columns increased with building height which varied from 10 to 22 storeys. This resulted in most structural damage occurring in first storey columns, for damaged buildings of less than 15 storeys, while higher buildings had beam and floor damage, and damage to associated panels, extending over several lower storeys. While the beam damaged buildings may have had higher overall ductility and a higher margin against collapse, they drew attention to the extensive and expensive damage which may arise with beam yield mechanisms.

High void ceramic bricks were used extensively for exterior and interior wall panels. Panel distributions were uniform over all storeys except the first where many were omitted for access and parking. These nominally non-structural panels exerted a dramatic and usually detrimental effect on the seismic performance of the buildings. Panels shattered in the most heavily loaded and deformed regions near the base of the damaged buildings The panels also inhibited the formation of beam-hinge mechanisms. Higher in the buildings the panels withstood the earthquake loads, and in many cases remaining panels greatly changed load distributions among the first storey columns. This must have increased column damage and contributed to the collapse of four 10 to 12 storey buildings in the area of deepest alluvium.

In and near the area of deepest alluvium, very similar buildings with heights ranging from 10 to 22 storeys were subject to seismic shaking with a wide range of severity.

A picture of progressive damage was formed by examining similar buildings that had suffered various degrees of damage up to total collapse. Moderate horizontal loads are taken by the panels of hollow brick. As the horizontal loads are increased, the limited number of first storey panels are destroyed and the loads are transferred to the first-storey columns, and in some cases shearing loads are also transferred to a lift and stair enclosure. As the horizontal loads are increased, panel damage extends to the second and higher storeys.

With a further load increase, buildings of less than 15 storeys suffer first storey column damage and in the worst cases column collapse, probably starting with corner and then side columns. For buildings of more than 15 storeys the heavier first storey columns survive while panel and beam damage extends upwards to about the sixth storey. A serious factor limiting the overload and plastic deformation capacity of both column and beam ends was the inadequate amount and inappropriate distribution and detailing of the transverse ties and stirrups.

The relatively distributed damage and plastic deformations at the lower storeys of the taller buildings would have resulted in significant period increases and significant overall ductility factors. However, the more restricted distribution of structural damage in the 10 to 14 storey buildings would have resulted in relatively small increases in building periods, and less significant ductility factors.

The earthquake forces at the Macuto Beach resort, 16 km north of the most severe damage in Caracus City, attacked tall buildings throughout their full height and also shorter buildings and other structures. This is in contrast with the attacks in Caracus City where severe attacks were restricted to the lower levels of tall buildings.

Of the five resort buildings, with heights of 8 to 14 storeys, only the 8 storey building escaped severe damage. A 4 storey building collapsed and a 3 storey building was so severely damaged that it was later demolished. A set of concrete canopies was supported by steel columns, which remained deformed by 15-20 cm towards the south. All significant damage was associated with very severe lurches of the structures towards the south. The dominant feature of ground motions was therefore a single very large acceleration pulse towards the north.

3 ILLUSTRATIVE CASES OF BUILDING DAMAGE

3.1 *Damaged Columns*

The 14 storey San Bosco apartment building, Figure 1(a), located on the deep alluvium in Caracus city, suffered typical column damage.

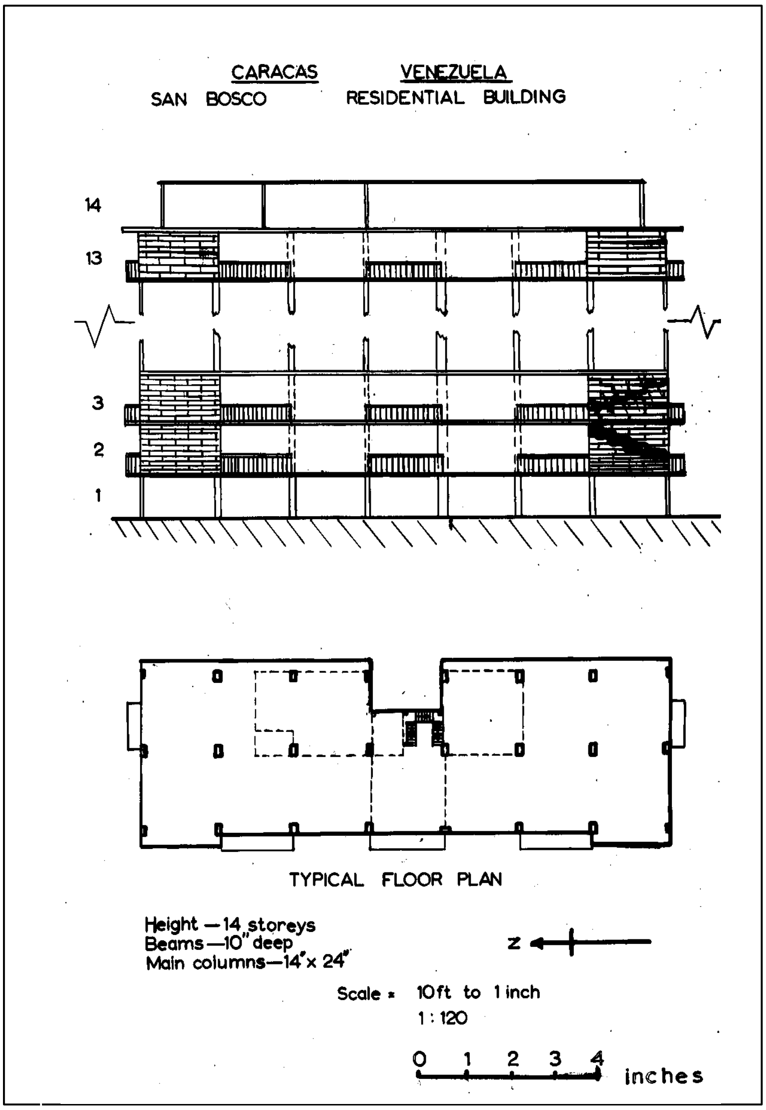

Figure 1(a): San Bosco apartments, building layout

Figure 1(b) shows damage to the corner column which would have been subject to cyclic end moments and shears, and cyclic changes in vertical loads due to overturning forces on the building. The light widely spaced ties had ends turned through only 90º at the corner bars.

Figure 1(b): San Bosco, damage at the base of a first-storey corner column.

The ties unwrapped when the surface spalled and were therefore unable to provide compression in the caged concrete. Buckling of vertical steel indicated a column height loss of 1-2 cm.

Repair and strengthening was provided by effective reinforced concrete sheaths over the first three storeys of the columns. Damaged concrete and plaster was removed from the columns. Details of the steel cage towards the upper end of an interior column are shown in Figure 1(c). Notice the use of heavier steel ties with reduced spacing towards the column ends.

Figure 1(c) : San Bosco, reinforcing steel for the upgrade of a first storey column.

Also, tie ends have been bent around corner bars through 135° so that they will not unwrap when surface concrete is shed, a procedure which has long been accepted as necessary to provide ductile reinforced concrete members. Vertical cage steel was carried through the second and third storey floors.

3.2 *Damaged Beams*

A plan view of the representative 17 storey Residencia Union Building is shown in Figure 2(a).

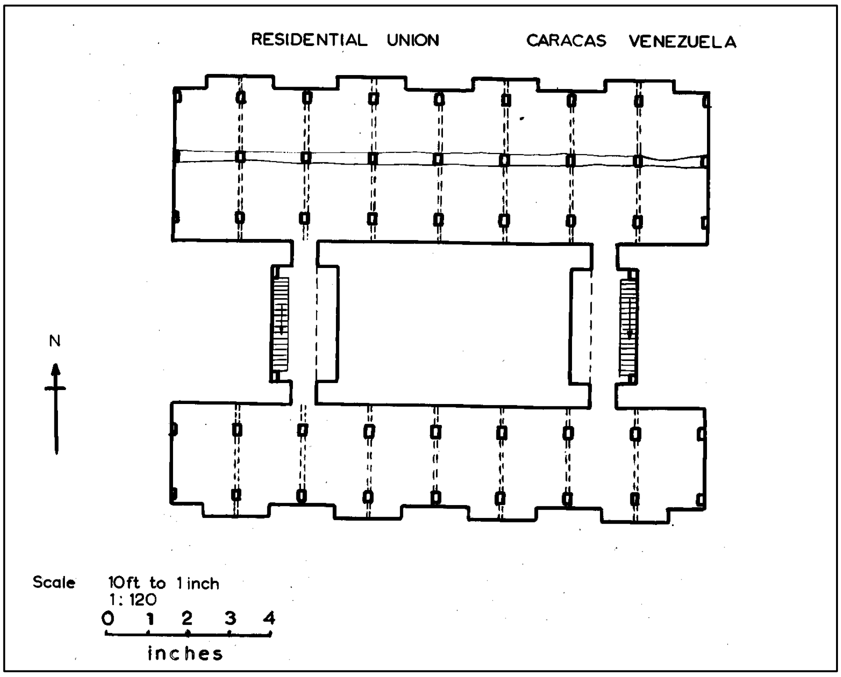

Figure 2(a): Residencia Union

The 8-bay by 2-bay and the 8-bay by 1-bay residential blocks are connected by two link blocks which contain the stairways and lifts. Shallow longitudinal beams are contained within the thickness of the waffle floors. Transverse beams are deeper and suffered damage next to the interior columns up to the sixth floor level. There was also associated floor damage and severe panel damage up to the sixth floor.

Figure 2(b) shows typical damage to the protruding lower third of a first storey beam which has shattered with little ductility, and with little development of compression concrete by the excessively spaced stirrups. The waffle floors appeared to suppress damage at the upper surfaces of the beams. Also shown is a sample of the extensive props provided throughout the seriously damaged areas of many buildings.

Figure 2(b): Residencia Union, damaged end of a first storey beam.

3.3 *Impulsive Damage at Macuto Beach*

While not a typical building, the Macuto Sheraton Hotel is chosen because it illustrates most clearly the impulsive unidirectional damage which occurred in all buildings and some other structures at Macuto beach. Figure 3(a) shows a simplified cross-section of the 10-storey 11-bay hotel which ran east-west close to the east-west sandy beach. The damage to the tops of the northern pair of cylindrical columns is illustrated in the Figure 3(a) inset.

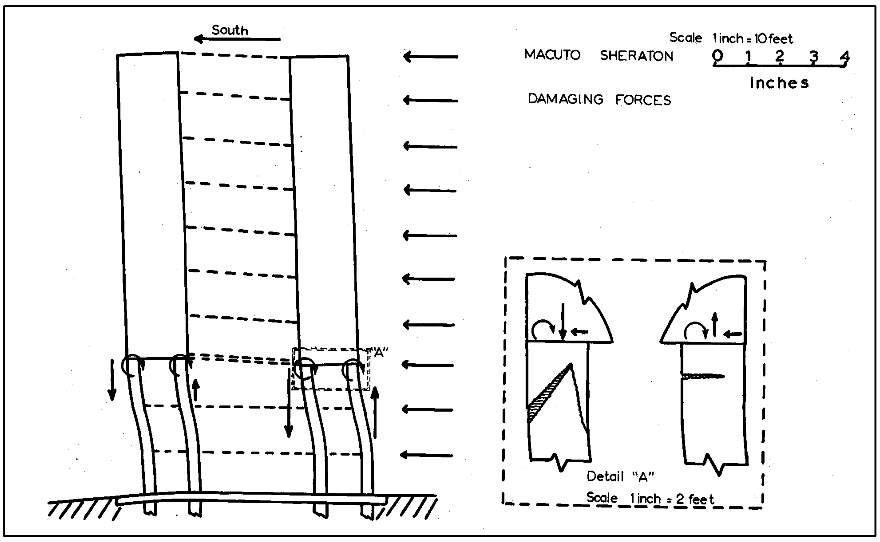

Figure 3(a): Macuto Sheraton Hotel, forces and damage at the top of the cylindrical columns

This damage is fully explained by a single loading pulse towards the south on all the building masses. This would result in the illustrated beam-end forces and in the illustrated pattern of column-top damage. Figure 3(b) shows the top of the compressed cylindrical column. The spiral transverse reinforcing was substantial and did not unwrap, but suffered some tension failures. However, these ties were completely inadequate for the very large diameter columns, and had a capacity to generate a compressive stress of only about 1.5 MPa.

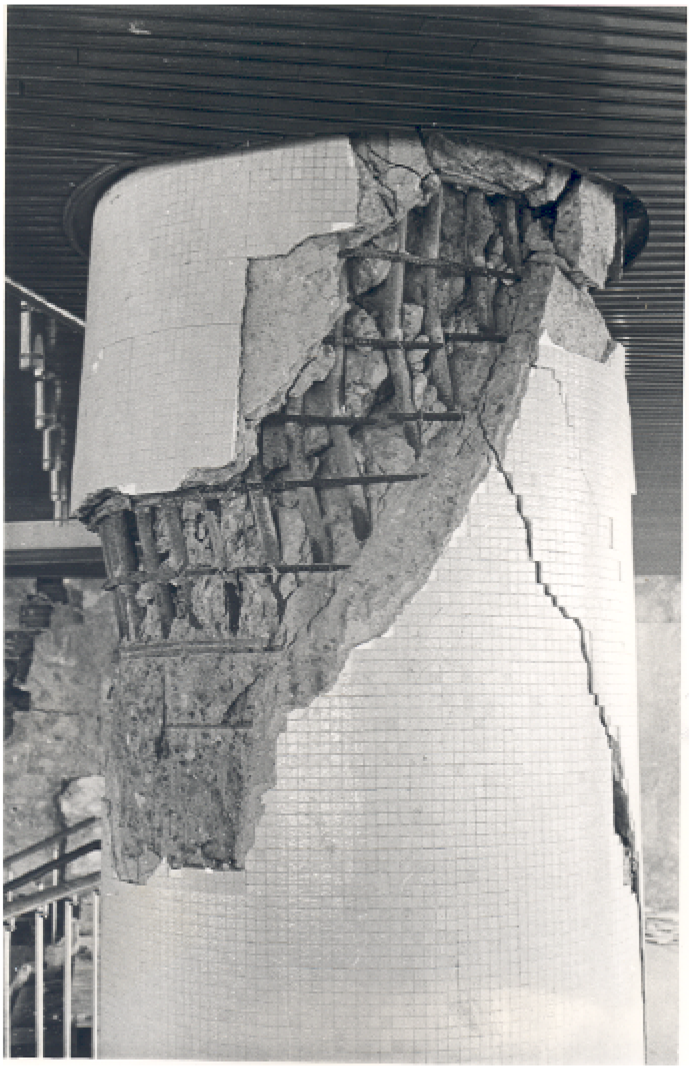

Figure 3(b): Macuto Sheraton, detail of a compressed and damaged column

4 SOME NEW ZEALAND RESPONSES

As a result of the engineering studies of the Caracus earthquake, New Zealand introduced or strengthened a number of measures to reduce the impacts of our earthquakes.

The New Zealand Structural Loadings Code was modified to include the effects of flexible ground on seismic design loads. Provisions for such effects are still undergoing development in New Zealand and elsewhere. Impulsive damage to buildings closer to the causative fault highlights ongoing problems arising from the Wellington fault.

Structural designs and codes were modified to provide a capacity to survive increased cyclic and transient seismic overloads. Beam and column yield strengths were selected to ensure beam-hinge mechanisms during large lateral deformations, the common form of capacity design. The reinforcing steel in the hinging regions of the beams was detailed to provide for several cycles of large plastic deformation without failure or serious loss of strength.

The New Zealand strong-motion accelerograph network was greatly expanded and further selected buildings and other structures were provided with sets of accelerographs. Such recording is now an important component of the major New Zealand GeoNet recording programme, which is being set up by the Earthquake Commission and the Institute of Geological and Nuclear Sciences.

There was increased recognition among New Zealand structural designers and researchers of the value of overseas and New Zealand earthquake damage studies, and the value of related research in structural laboratories.

Another consequence of the study of building deformation mechanisms and their limitations was the development of special devices to provide buildings with increased flexibility and energy absorbing capacity. The most common applications of these devices are known as seismic isolation (Skinner et al 1993).

The very effective post-earthquake structural engineering research at Caracus was probably dependent on extensive presidential powers. New Zealand should use the experience from the Caracus and other earthquake study missions to plan and authorise procedures aimed at maximising the earthquake engineering advances from studies of future New Zealand earthquakes.

REFERENCES:

Skinner, R.I. 1968. Engineering Study of Caracus Earthquake, Venezuela, 29 July 1967, *Bulletin 191, DSIR, New Zealand:* 59 pages.

Skinner, R.I., Robinson, W.H. and McVerry, G.H. 1993. *An Introduction to Seismic Isolation*, John Wiley and Sons: 354 pages