Geologic Hazards Photos Volume 1
The Behavior of Columns

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General Information About Columns

A column is a supporting pillar consisting of a base, a cylindrical shaft and a capital. These columns may be made of welded steel [photo No. 9] or reinforced concrete in which steel rods (rebar) are imbedded in the concrete. These steel rods may be tied together with metal strips at intervals (ties) [Nos. 1, 4, 11], or they may be wrapped spirally around the column with metal strips (spirally wrapped) [Nos. 2, 5, 16, 19]. All the metal reinforcing is embedded in the concrete [Nos. 2, 3, 19]. The Uniform Building Code requires that columns be confined by such spirals or ties. A spirally-confined column is basically more ductile than a tied column, but in lateral motion this ductility can only be achieved if ductility also exists at the column-to-beam connection at the top of the column.

Shear is a condition caused by forces that tend to produce an opposite but parallel sliding motion of the body's planes. A shear wall is a wall in a building designed to absorb these forces. A soft story is a story in a building (often the first story) with few partitions and/or open exterior walls (such as garage doors, large windows, etc.). This openness makes it vulnerable to earthquake damage.

The behavior of columns in earthquakes is very important since single column failures may lead to additional failures and result in total building collapses. For example, in the Mexico City earthquake, the most frequently observed cause of structural failure was linked to inadequate beam-to- column and slab-to-column connections [Nos. 9-11].

Sometimes the configuration of the building causes the columns to be over stressed, and when they fail, the building fails. This was the case with the Olive View Hospital, which was severely damaged in the 1971 San Fernando California earthquake. The first two floors were soft stories in which the principal support for the floors above were columns. When earthquake shaking caused the upper floors to move as a unit as much as two and a half feet, the first and second floor columns could not accommodate such a large displacement, and they failed [No. 1]. The result was that the entire building had to be demolished.

Another building configuration that resulted in column failure is shown in photos 7 and 8, the Imperial County Services Building. During the 1979 El Centro, California, earthquake, the building was destroyed due to column shortening by compression at the east end of the building.

Short columns are often damaged in earthquakes. A column twice as long is eight times more flexible. If the structure contains both short and long columns, the load will be concentrated in the shorter columns. The short columns are less subject to buckling and hence are capable of receiving high vertical loads. But under lateral loading (forces from the side), the short, stiff columns receive more than their share of the load, and fail. The condition may be avoided by equalizing the length and hence the stiffness of the columns. [No. 20]. Columns and piers may be more resistant to failure in earthquakes if they are designed to be more shear-resistant. Extra column ties or spiral wraps should be provided in the end sections of all columns and in the beam- to-column connections.

The Uniform Building Code (UBC), published by the International Conference of the Building Officials, gives requirements used in the design of buildings within the United States. The UBC contains design guidelines for earthquake-resistant features in buidlings. The Code is revised every three years, incorporating new information gleaned from building failures such as those shown in this slide set.

About the Earthquakes

Several earthquake events are represented by these slides of column damage. The statistics for these earthquakes follow:

San Fernando, California. At 14:00:41.8 UTC (6:01 A.M. local time) on February 9, 1971, a Ms 6.5 earthquake occurred twenty miles north of downtown Los Angeles (34 degrees 25' N, 118 degrees 24' W) at a depth of 8.4 km (5 miles). The San Fernando earthquake was felt over an area of 80,000 square miles. The statistics include 58 dead and $497.8 million in damage.

Esmeraldos, Ecuador. A Ms 6.7 earthquake occurred in Esmeraldos, Ecuador, on April 9, 1976, 2:08 A.M., causing 10 deaths and moderate damage.

El Centro, California. A Ms 6.8 earthquake occurred on October 15, 1979, 3:16 P.M., in El Centro, California. The earthquake caused $30 million in property damage and injured 91 people.

Mexico City, Mexico. On September 19, 1985, 7:17 A.M. local time, a Ms 8.1 earthquake occurred on the Pacific coast of Mexico. However, the damage was concentrated in a 25 square kilometer area of Mexico City, 350 km northeast of the epicenter. Within a population of 18 million effected, an estimated 10,000 people were killed, and 50,000 were injured. In addition, 250,000 people lost their homes, over 800 buildings crumbled, and property damage amounted to more than $5 billion.

San Salvador, El Salvador. A Ms 5.4 earthquake occurred in San Salvador, El Salvador, on October 10, 1986, 11:49 A.M., killing 1,000 and causing $1.5 billion in damage.

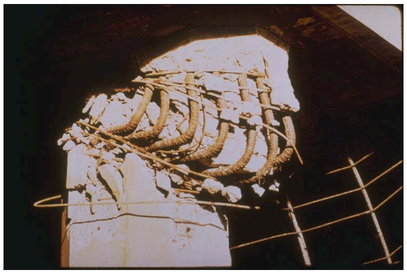
Whittier, California. A Ms 6.0 earthquake occurred on October 1, 1987 at 6:42 A.M. in Whittier, California. The earthquake caused $358 million in property damage and eight deaths.

Loma Prieta, California. On October 17, 1989, 5:04 P.M., a Ms 7.1 earthquake occurred in the Santa Cruz mountains of California. The Loma Prieta earthquake resulted in more than $7 billion in property damage ($2.5 billion in San Francisco alone). The earthquake destroyed 414 single-family homes, 104 mobile homes, 97 businesses and three public buildings. It damaged 2,575 businesses and 18,306 houses, displacing 12,000 people from their homes. It caused 67 deaths and 3,757 injuries.

Northridge, California. On Monday January 17, 1994 at 4:31 A.M., a Ms 6.8 earthquake occurred twenty miles west- northwest of downtown Los Angeles (34 degrees 13' N, 118 degrees 32'W) at a depth of 20 km (12 miles). Northridge statistics include 56 dead, 25,000 dwellings uninhabitable, $15-$20 billion in damage.

Slide Set Images

First-story column failure, San Fernando, CA Close-up of first-story column failure at Olive View Hospital, damaged in the San Fernando (California) earthquake of 1971. The column was located at the west end of Wing B on the first story of the five-story hospital. This is a typical first-story tied corner column, and the damage is characteristic of column damage found on the first floor in all wings of the hospital. These corner columns were square with a corner notch out, giving the appearance of a thick L-shaped column. Note the broken ties, the spacing of the ties, and the bent rebar. The building was laterally displaced about two feet to the north in the earthquake. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]



Spirally wrapped column failure on interstate, California Failure of a spirally wrapped column at the intersection of Interstate 5 and Interstate 210 caused by the San Fernando earthquake of 1971. The column failure possibly resulted from dropping of the overpass on top of the lower bridge. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]

Collapsed column, Interstate 5/210 interchange, California This failed column was a part of the collapsed Interstate 5/210 interchange-a 7-span, non-prestressed, reinforced concrete box girder structure, that completely collapsed in the San Fernando earthquake of 1971. The structure was carried on single column bents. The base of the column pulled out of the 6-foot diameter cast-in-place drilled shaft. At failure some hoops separated and pulled out. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]

Column failure, Holy Cross Hospital Column failure at the Holy Cross Hospital during the San Fernando earthquake of 1971. The concrete in the southeast corner fourth-story exterior column was crushed. Note the splice of the column steel and the widely spaced ties. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]

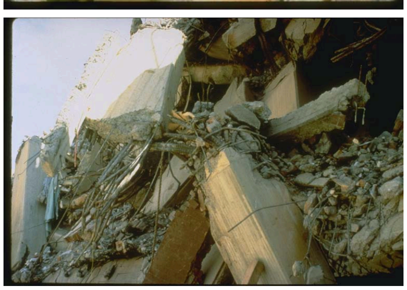
Failure of several columns, Foothills Freeway overpass Column failure at an overpass (Foothills Freeway crossing Foothills Boulevard) as a result of the San Fernando earthquake of 1971. This slide shows failures of three of the spirally-wrapped columns that provided the central support of this overpass. The third column shows relatively minor damage. Failures may have resulted from a combination of vertical and horizontal acceleration. It appears that the bridge deck may have rotated due to the ground motion. [Photo credit: E. V. Leyendecker, U.S. Geological Survey.]

Spirally-wrapped column failure, Ecuador Failure of a spirally-wrapped column at the Juan Montalvo School in Esmeraldas, Ecuador, due to the 1976 earthquake. Note that the column appears to have been shortened and moved laterally. [Photo credit: J. R. Silva.]

Imperial County Services Building after 1979 earthquake View of the Imperial County Services Building after the 1979 El Centro (California) earthquake. Support framework is visible. This six-story reinforced concrete frame and shear wall structure was built in 1969 at a construction cost of $1.87 million, and was designed to be earthquake resistant. However, during the quake, the concrete at the base of the support columns was shattered, and the vertically reinforced bars were severely bent allowing the east portion of the building to sag about 30 cm. The extra load on the columns at the east end of the building came from the discontinuous shear wall at this end of the building. Rotational forces were not dissipated by the shear wall causing a compressional load on the columns. The building had to be replaced at an estimated cost of seven million dollars. [Photo credit: G. Reagor, U.S. Geological Survey.]

Damaged columns, Imperial County Services Building Close-up view of the collapsed columns of the Imperial County Services Building, El Centro. The columns failed as a result of the discontinuous shear wall on the east end of the building. The shear wall effectively stopped at the bottom of the second floor increasing the load on the columns at that end of the building. [Photo credit: C. Reed, California Geology.]

Buckled box column, Mexico City Buckled box column on the south side of center 23-story tower, one of five towers at the Pino Suarez Complex damaged in the 1985 Mexico City earthquake. The columns were hollow box sections made of four plates with exterior welds along the edges. Internal stiffener plates were spaced at regular intervals and welded to three sides along the interior length and along all four sides at the column ends. The structure was designed as a moment-resisting frame, and not much inelastic deformation developed in the beams. Local plate buckling-amplified by weld tears at the plate joints-occurred in the most highly stressed columns along the south face near the top of the common mezzanine. Buckling of columns, and deformations caused by other actions, produced tilt of the structure towards the south. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]



Close-up of failed member of Juarez Hospital Close-up joint details of the Juarez Hospital that collapsed during the 1985 Mexico City earthquake. The failure indicates lack of sufficient confining reinforcement in the vicinity of the joint. This nine-story reinforced concrete-frame structure collapsed towards the east exhibiting localized failures at the beam-to-column joints of each floor. This is an example of weak column/strong beam construction. The floors were relatively unaffected by the shaking and were damaged only when the columns totally failed. This close-up of various joints indicates that the columns were generally well-proportioned to resist gravity loads. However, there was minimal-to-nonexistent confinement through the joints. Furthermore, many joints had longitudinal bar splices at these same critical moment locations. The lack of confinement, and the presence of splices lead to a loss of vertical load-bearing capacity as soon as the bond strength was lost and directly contributed to the failure of the entire structure. The Juarez Hospital collapsed and 400 medical personnel and patients, notably infants, were trapped in the maternity wing. Rescue personnel continued to retrieve survivors as late as ten days after the earthquake by tunneling through the debris between the floor slabs. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]

Failed first-story column, Mexico City Failed first-story column in an eleven-story apartment building after the 1985 Mexico City earthquake. This column failure was induced by a variation in stiffness between the first and other floors of the building, concentrating the load in the first story columns. Note that column ties appear to be undamaged. [Photo credit: E.V. Leyendecker, U.S. Geological Survey.]

Porch column tipped when house shifted on foundation Close-up view of completely shattered and collapsed first-story columns under the Economics and Science Building at the National University in San Salvador. The damage occurred during the 1986 earthquake in El Salvador. [Photo credit: R.W. Anderson, Earthquake Spectra, Earthquake Engineering Research Institute.]

Shattered columns under Economics Building, San Salvador The 1987 Whittier (California) earthquake caused many houses to shift on their foundations. This house at 13312 Beverly Boulevard between Painter Avenue and Friends Street has shifted at least a foot on its foundation. The shifting has caused the wooden column to be tipped off its base. Further shifting would have resulted in a column and porch collapse. [Photo credit: G. Reagor, U.S. Geological Survey.]

Collapsed Cypress section of Interstate 880 Side view of the Cypress section of Interstate 880 which collapsed as a result of the 1989 Loma Prieta (California) earthquake. Note the failed column support (buttress) in the center of the photo. The upper deck of the double deck structure dropped almost vertically onto the lower deck along a one-mile section of the freeway. Columns supporting the upper deck were thrown transverse to the longitudinal axis of the roadway. Some columns sheared off at the hinge at the bottom of the upper column; some remained attached to the upper deck. Other columns were found completely intact on the ground. Fifty-one spans of this structure were involved in the collapse which killed forty-one motorists. [Photo credit: Wilshire, U.S. Geological Survey.]

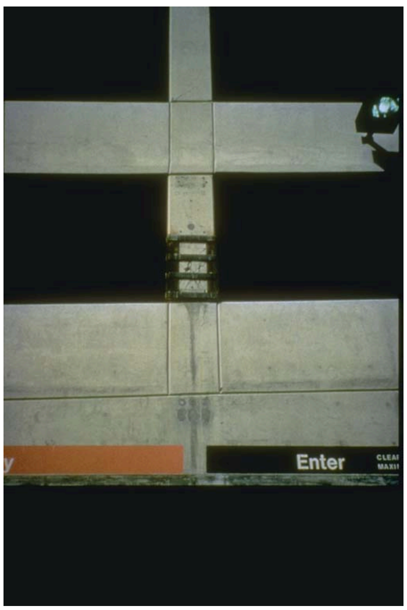
Bases chipped when columns tipped during Loma Prieta earthquake Cosmetic damage to columns caused by the 1989 Loma Prieta earthquake. Pedestals were chipped when the columns tipped on the Old Bank of America Building at North First and Santa Clara Street in San Jose. A greater distance between floors at the ground story than in upper stories results in greater vulnerability to earthquake damage in that story. There is a significant discontinuity of strength and stiffness between the vertical structure of the first floor and the remainder of the structure. [Photo credit: C. Stover, U.S. Geological Survey.]

Overpass columns damaged in Northridge earthquake Columns supporting the Highway 10 overpass at Venice Boulevard were damaged in the Northridge (California) earthquake of 1994. There was insufficient shear reinforcement, leading to lack of the necessary column confinement. The columns were spirally wrapped. [Photo credit: M. Celebi, U.S. Geological Survey.]

Parking garage columns damaged in Northridge earthquake Parking garage at California State University in Northridge damaged in the 1994 earthquake. The garage was of precast, post-tensioned construction and was built in 1991. The center columns were crushed, resulting in caving-in of the floors and extreme bending of the external columns. No cars were in the structure at the time of the earthquake. A nearby shear wall was essentially undamaged. [Photo credit: M. Celebi, U.S. Geological Survey.]

Splayed column bases, Northridge earthquake A splaying of support columns near their bases due to earthquake-induced motions of the upper stories in an apartment building in Northridge. The apartment was located on Meridy Street near Zelzah Street. The first story of the building was relatively open with few partitions; the second floor was supported by columns. This common configuration is known as a "soft story." This condition creates a discontinuous load path resulting in an abrupt change of strength and stiffness at the point of change. [Photo credit: J. Dewey, U.S. Geological Survey.]

Failed bridge support, Northridge earthquake Bridge column supporting Interstate 10 (Santa Monica Freeway) at the La Cienega-Venice overcrossing failed in the 1994 Northridge earthquake. [Photo credit: M. Celebi, U.S. Geological Survey.]



"Short column" effect, Northridge earthquake Reinforced concrete garage building off Ventura Boulevard at the intersection of Highway 405. Damage was caused by the 1994 Northridge earthquake. Although the building appears to have shear walls, several columns were damaged. The columns were made more vulnerable to damage when their spans were shortened by the balcony parapets. This is knows as the "short column" effect. When columns are shortened, the effect is to make them less ductile. An attempt has been made to repair the column by putting a partial jacket around it. [Photo credit: M. Celebi, U.S. Geological Survey].

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