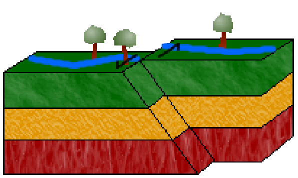
Introduction to Earthquake Engineering

Left-Lateral Strike-Slip Faults

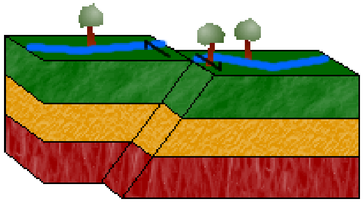


http://www.ngdc.noaa.gov/seg/image/geohazards_v1/images/647010/tif/64701011.tif

http://www.iris.washington.edu/seismic/events/faults.html

Rows in the cultivated field west of El Progresso, Guatemala, deformed by the earthquake of February 4, 1976. The thick, saturated, unconsolidated deposits have yielded by plastic deformation rather than rupture along the left-lateral strike-slip fault. This quake resulted in the deaths of 23,000 people and $1.1 billion dollars in property damage. Photo credit: U.S. Geological Survey (**http://www.ngdc.noaa.gov/seg/hazard/slideset/10/10_slides.html**)

Right-Lateral Strike-Slip Faults



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http://www.iris.washington.edu/seismic/events/faults.html

Right-Lateral Strike-Slip Faults

The fence was offset 2.6 m by the magnitude 8.2 earthquake of April 18, 1906, San Francisco, California. The section of the San Andreas fault shown here is 0.8 km north of Woodville. The photo is looking northeast. The lateral or strike-slip fault offset is large; however, the trace is nearly invisible.

(**http://www.ngdc.noaa.gov/seg/hazard/slideset/10/10_slides.html**)

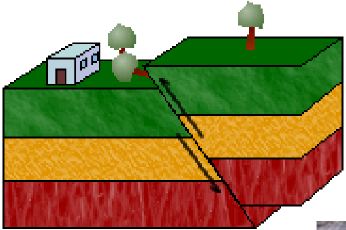
http://www.ngdc.noaa.gov/seg/image/geohazards_v1/images/647010/tif/64701002.tif

Aerial view of San Andreas fault

Aerial view of San Andreas fault

Right-Lateral Strike-Slip Fault
(http://www.ngdc.noaa.gov/seg/hazard/slideset/10/10_slides.html)

Reverse Fault



→ Shortening ←

http://www.iris.washington.edu/seismic/events/faults.html

http://www.ngdc.noaa.gov/seg/image/geohazards_v1/images/647010/tif/64701018.tif

A view of the reverse fault in a roadcut on the west side of French Gulch just south of the Sun River in Lewis and Clark County, Montana, as it appeared in 1966. This reverse fault places the lower beds of the Castle Reef Dolomite (light gray) onto the Flood Shale member of the Blackleaf Formation (dark gray). The fault dips 60 degrees W, and the overlaying strata dip about 50 degrees W. The black shales beneath the fault are badly crumbled, whereas the carbonate beds above it are undisturbed. Photo credit: M.R. Mudge, U.S. Geological Survey

(http://www.ngdc.noaa.gov/seg/hazard/slideset/10/10_slides.html)

1811-1812 New Madrid, Missouri

"The Great Earthquake at New Madrid" Henry Howe, *The Great West* (Cincinnati, 1851), p. 237, in The State Historical Society of Missouri, Columbia, Mo.

http://nisee.berkeley.edu/jpg/7275_3202_3749/IMG0014.jpg

Parolod na fece Missouri.

http://nisee.berkeley.edu/jpg/7275_3202_3749/IMG0018.jpg

New Madrid, Missouri Earthquakes

December 16, 1811 Approximate Richter Magnitude 7.5

January 23, 1812 Approximate Richter Magnitude 7.3

February 7, 1812 Approximate Richter Magnitude 7.8

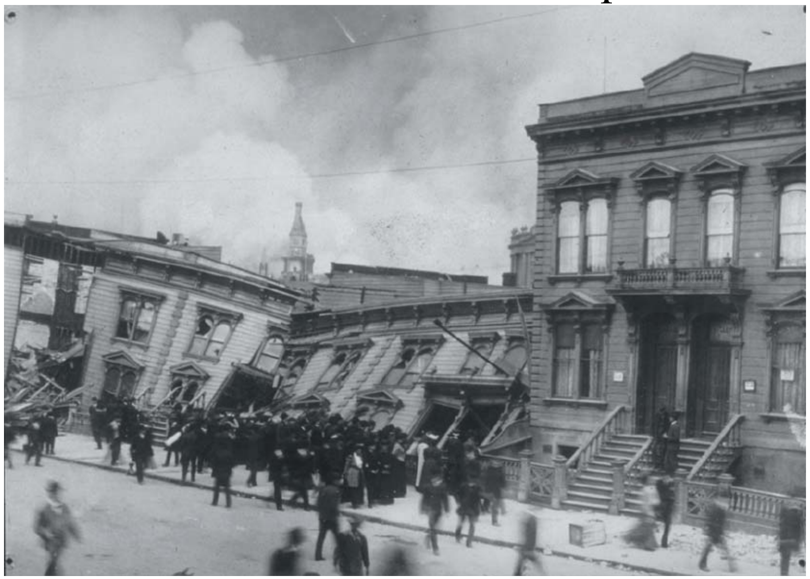
The probability for an earthquake of magnitude 6.0 or greater is significant in the near future, with a 50% chance by the year 2000 and a 90% chance by the year 2040. A quake with a magnitude equal to that of the 1811- 1812 quakes could result in great loss of life and property damage in the billions of dollars.

(http://hsv.com/genlintr/newmadrd/)

Left: Cabins shaken and damaged. People outside in panic. Near New Madrid, Missouri (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KZ600)

Right: Steamboat navigating the river full of up-rooted and broken trees. (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KZ604)

1906 San Francisco Earthquake



http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647002/tif/64700209.tif

April 18, 1906

The 1906 San Francisco earthquake was the largest event (estimated magnitude 8.3) to occur in the conterminous United States in the 20th Century. Recent estimates indicate that as many as 3,000 people lost their lives in the earthquake and ensuing fire. (http://www.ngdc.noaa.gov/seg/hazard/slideset/2/2_slides.html)

This row of 2-story buildings tilted away from the street when the ground beneath the foundations slumped. Such ground failures contributed to the shaking intensity and to the subsequent building damage. This photo was taken before fire destroyed entire block. Note billowing smoke in the sky. Photo credit: NOAA/NGDC. (http://www.ngdc.noaa.gov/seg/hazard/slideset/2/2_slides.html)

Resulting Fires from 1906 San Francisco Earthquake

http://www.sfmuseum.net/hist10/mktstfire.html

Fire engulfs the Call Building

http://www.ibiscom.com/sfeq.htm

The fires which resulted from the earthquake lasted for three days and destroyed 28,000 buildings in a 520-block area of San Francisco. In terms of 1906 dollars, the total property damage amounted to about $24 million from the earthquake and $350 million from the fire.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/2/2_slides.html)

1933 Long Beach Earthquake

http://www.ngdc.noaa.gov/seg/image/geohazards_v1/images/647005/tif/64700506.tif

Earthquake of March 10, 1933, Magnitude 6.4, Long Beach, California, USA.

Location: 5 km southwest of Newport Beach; Seriously Affected Area: 1,200 km2; 120 deaths; Damage: $40 million. Schools were among the buildings most severely damaged because they were not designed to resist shaking. Most of the damaged buildings were of unreinforced masonry. Many school buildings were destroyed. The school buildings damaged or destroyed were of an "irregular shape," built of brick and not designed to resist any lateral stress. As well, part of the failure of the brick buildings was due to shoddy workmanship and inferior mortar. Great loss of life would have occurred if the shock had taken place during school hours. Unlike the 1906 San Francisco earthquake the loss due to fire in the 1933 earthquake was almost negligible.

Photo: Collapse of John Muir School on Pacific Avenue from the 1933 Long Beach earthquake. Photo Credit: W.L. Huber

(http://www.ngdc.noaa.gov/seg/hazard/slideset/5/5_slides.html)

1940 Imperial Valley

http://nisee.berkeley.edu/jpg/2363_1013_1524/IMG0048.jpg

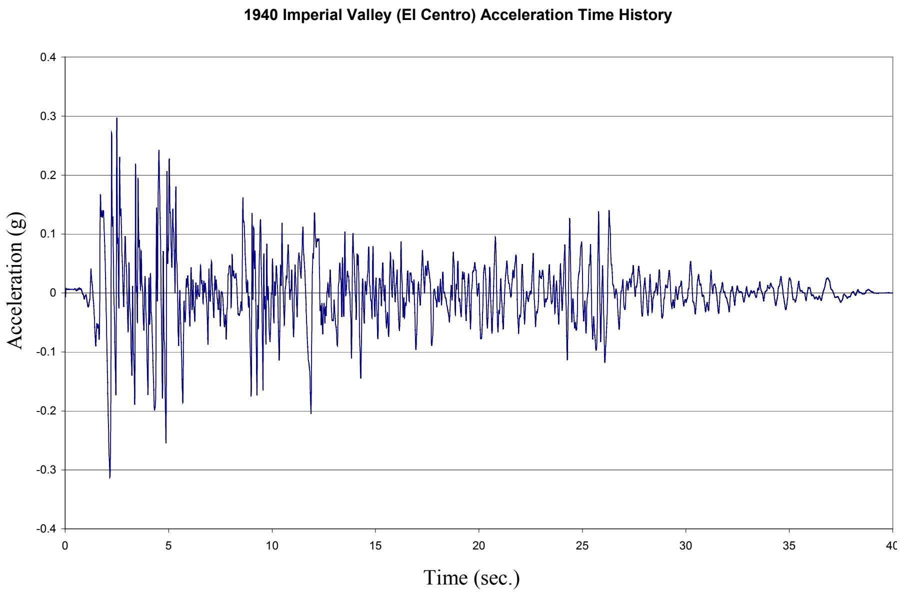
http://nisee.berkeley.edu/jpg/2363_1013_1524/IMG0049.jpg

May 18, 1940 Imperial Valley Earthquake. 6.9 Magnitude.

The strongest recorded quake to strike the Imperial Valley, the 1940 Imperial Valley earthquake caused at least $6 million in direct damage . Rails were bent out of line in three locations where they crossed the Imperial fault, and several railroad bridges were damaged, both in California and Mexico. A notable aspect of this earthquake is the recorded acceleration time history.

Left: Dunlock Hotel. Failure due to lack of ties. (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S1148)

Right: North wall of Hotel Dunlock. (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S1149)



This record is available for download at
http://webshaker.ucsd.edu/homework/ElCentro.txt

1964 Great Alaska Earthquake

March 28, 1964

The second largest earthquake of the 20th Century and the largest ever recorded in the northern hemisphere, the Prince William Sound magnitude 8.4 earthquake, occurred at 03:36 UT on March 28, 1964. The quake was felt over 500,000 square miles. The quake took 131 lives and caused $350-500 million in property damage (One hundred twenty-two of the deaths were attributed to the tsunami.) The area of the damage zone (50,000 square miles) and the duration of the quake (3 to 4 minutes) were extraordinary.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/7/7_slides.html)

Local tsunami waves triggered by this earthquake were extremely destructive in Prince William Sound and other areas of Alaska. A Pacific-wide tsunami was generated which was destructive in Western Canada, Oregon, California and the Hawaiian islands. Combined, the earthquake and tsunami took 125 lives (tsunami 110, earthquake 15), and caused about $311 million in property loss (in 1964 dollars).

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647007/tif/64700715.tif

Photo: One span of the "Million Dollar" truss bridge of the former Copper River and Northwestern Railroad was dropped into the Copper River by the earthquake, and the other truss spans were shifted on their piers. The bridge construction consisted of concrete piers on concrete caissons 35 to 50 feet (10.6-15.1 m) below the stream bed. The superstructure consisted of steel trusses. Photo Credit: U.S. Geological Survey, Menlo Park, CA (http://www.ngdc.noaa.gov/seg/hazard/slideset/7/7_slides.html)

1960 Great Chile Earthquake

http://www.ngdc.noaa.gov/seg/image/high_res/g0193506.tif

On May 22, 1960, a Mw 9.5 earthquake, the largest earthquake ever instrumentally recorded, occurred in southern Chile. The series of earthquakes that followed ravaged southern Chile and ruptured over a period of days a 1,000 km section of the fault, one of the longest ruptures ever reported. The number of fatalities associated with both the tsunami and the earthquake has been estimated to be between 490 and 5,700. Reportedly there were 3,000 injured. The Chilean government estimated 2,000,000 people were left homeless and 58,622 houses were completely destroyed. Damage (including tsunami damage) was more than $500 million U.S. dollars.

The main shock setup a series of seismic sea waves (tsunami) that not only was destructive along the coast of Chile, but which also caused numerous casualties and extensive property damage in Hawaii and Japan, and which was noticeable along shorelines throughout the Pacific Ocean area.

There were several other geologic phenomena besides tsunamis associated with this event. Subsidence caused by the earthquake produced local flooding and permanently altered the shorelines of much of the area in Chile impacted by the earthquake. Landslides were common on Chilean hillsides. The Puyehue volcano erupted forty-seven hours after the main shock. It is only a matter of time until Chile once again has a "world-class" earthquake whose impact, like the 1960 Chile event, will be felt around the world. (http://www.ngdc.noaa.gov/seg/hazard/slideset/45/45_slides.html)

Valdivia suffered catastrophic damage because of its proximity to the epicenter of the massive quake. Regional tectonic subsidence of five to seven feet occurred. There was extensive loss to agricultural lands from flooding. The horizontal ground motions, not the subsidence, caused the principal damage to structures away from shorelines and river channels. Older masonry structures were hard hit by the earthquake. However, many wood frame buildings performed well.

Damage at Corral after the tsunami. Structures were destroyed by a 10 m (33 ft) wave. Some houses and structures were swept against the hillsides. Others were swept out to sea. Photo credit: Pierre St. Amand

(http://www.ngdc.noaa.gov/seg/hazard/slideset/45/45_slides.html)

Natural Disasters Resulting from the 1964 Great Alaska Earthquake

(http://neic.usgs.gov/neis/eqlists/USA/1964_03_28_pics.html)

Photo (Left): During the earthquake, the shaking caused failure of the unstable, water-saturated material, and a slice, approximately 1,220 m long and 183 m wide, slid into the sea and carried the dock area and portions of the town with it. The slide generated a wave which slammed into the waterfront within two to three minutes of the onset of the earthquake. This wave demolished what was left of the waterfront facilities, caused the loss of the fishing fleet, and penetrated about two blocks into the town. Property damage of $15 million was incurred at Valdez and there were 30 fatalities. Photograph Credit: U.S. Department of the Interior.

Photo (Right): Tsunami damage.

(http://neic.usgs.gov/neis/eqlists/USA/1964_03_28_pics.html)

1971 San Fernando

http://nisee.berkeley.edu/jpg/6257_3021_0662/IMG0032.jpg

February 9, 1971 San Fernando Earthquake. Magnitude 6.6.

Also known as the Sylmar Earthquake, the total surface rupture on the San Fernando fault zone was roughly 19 km (12 miles) long. The maximum slip was up to 2 meters (6 feet). The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar (pictured above) suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those which occurred 23 years later in the 1994 Northridge Earthquake.

In response to this earthquake, building codes were strengthened and the Alquist Priolo Special Studies Zone Act was passed in 1972. The purpose of this act is to prohibit the location of most structures for human occupancy across the traces of active faults and to mitigate thereby the hazard of fault rupture.

Photo: The Psychiatric Unit of the Olive View Hospital. The columns of the first story of this two-story reinforced concrete building failed in shear, and the second floor dropped onto the ground translating nearly 2 meters during the 1971 San Fernando Earthquake. [Photo: Bertero, V.V.]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=GoddenJ32)

1979 Imperial Valley

http://nisee.berkeley.edu/jpg/6257_3021_0662/IMG0036.jpg

http://nisee.berkeley.edu/jpg/6257_3021_0662/IMG0037.jpg

Imperial Valley October 15, 1979. Magnitude 6.4

This major earthquake injured 91 people and caused an estimated $30 million in property damage in the Imperial Valley area.

Left: Typical modern steel elevated tank supported on four tubular legs cross-braced by horizontal beams at two intermediate levels and by very thin diagonal tie rods. Imperial Valley, California [Photo: Bertero, V.V.]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=GoddenJ36)

Right: Collapse of a steel tank during the 1979 Imperial Valley Earthquake. Imperial Valley, California [Photo: Bertero, V.V.]

(http://nisee.berkeley.edu/jpg/6257_3021_0662/IMG0037.jpg)

1987 Whittier Earthquake

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647008/tif/64700817.tif

Earthquake of October 1, 1987, Whittier Narrows, California. Magnitude 5.9

The most severe damage occurred in the "Uptown" district of Whittier, the old downtown section of Alhambra, and in the "Old Town" section of Pasadena. These areas had high concentrations of unreinforced masonry buildings. Residences that sustained damage usually were constructed of masonry, were not fully anchored to foundations, or were houses built over garages with large door openings. Many chimneys collapsed and in some cases, fell through roofs. Wood frame residences sustained relatively little damage. Estimated $358 million in property damage.

Photo: Partial collapse of the May Company's three-level parking garage at Quad Shopping Mall in Whittier. The structure, built in 1965, is located at the corner of Whittier Blvd. and Painter Ave. Photo Credit: G. Reagor, U.S. Geological Survey (http://www.ngdc.noaa.gov/seg/hazard/slideset/8/8_slides.html)

1985 Michoacan Earthquake

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647003/tif/64700308.tif

On September 19, 1985, a magnitude 8.1 earthquake occurred off the Pacific coast of Mexico. The damage was concentrated in a 25 km2 area of Mexico City, 350 km from the epicenter. The underlying geology and geologic history of Mexico City contributed to this unusual concentration of damage at a distance from the epicenter. It is largely built upon soft, poorly consolidated lake sediments from the former Lake Texcoco, which was drained by the Spanish following their occupation of the region. Thick sequences of soft sediments like these tend to amplify seismic waves and cause the ground to shake much more vigorously than the surrounding bedrock..

In the area of greatest damage in downtown Mexico City, some types of structures failed more frequently than others. In the highest damage category were buildings with six or more floors. Resonance frequencies of these buildings were similar to the resonance frequencies of the subsoil. Because of the "inverted pendulum effect" and unusual flexibility of Mexico City structures, upper floors swayed as much as one meter and frequently collapsed. Differential movements of adjacent buildings also resulted in damage. A flexible building often failed if it was held by adjacent, more rigid lower buildings. Damage or failure often occurred where two swaying buildings came in contact. Corner buildings were also vulnerable to damage. Of a population of 18 million, an estimated 10,000 people were killed, and 50,000 were injured. In addition, 250,000 people lost their homes and property damage amounted to $5 billion.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/3/3_slides.html)

(http://www.johnmartin.com/earthquakes/eqshow/647003_00.htm)

Photo:Mid-floor failure of Hotel de Carlo caused by pounding(repeated striking) from building at left. Note deflection of building at right. Construction is concrete frame. Here two buildings of similar height were built too closely together. The natural period of the buildings was close to the period of the earthquake causing lateral displacements large enough to allow them to `hammer' each other. Photo credit: C. Arnold, Building Systems Development, Inc.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/3/3_slides.html)

1989 Loma Prieta

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647013/tif/64701319.tif

On October 17, 1989, a 7.1 magnitude earthquake occurred near Loma Prieta in the Santa Cruz mountains. Movement occurred along a 40-km segment of the San Andreas fault from southwest of Los Gatos to north of San Juan Bautista.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/12/12_slides.html)

The significance of this earthquake is the warning it delivered of the dangers faced by people, governments, and businesses in seismically active areas. The message was delivered live, to the millions in the nation and the world tuned to the World Series. The subsequent dramatic coverage provided by the news media on hand for the event was unprecedented for any previous earthquake. With such attention, it is hoped that preparedness efforts will be similarly stimulated and will continue at a high level. (http://www.eqe.com/publications/lomaprie/conclusi.htm)

Photo: The collapsed area of the Bay Bridge looking from east to west. The top of this slide shows four beams, running in transverse direction. These four beams are supported on right and left trusses as seen in the slide. The lower deck plate girder is in a green- gray color; the upper deck floor beam is in a clear gray color. The upper deck had four stringers supported on four seat supports. The lower deck had 11 stringers supported on 11 seat supports. Originally the lower deck was designed for trucks and trains and the upper deck for cars. San Francisco Oakland Bay Bridge [Photo: Astaneh-Asl, Abolhassan]

(http://www.ngdc.noaa.gov/seg/hazard/slideset/13/13_slides.html)

1992 Landers

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647017/tif/64701720.tif

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647017/tif/64701701.tif

Sunday morning June 28, 1992. Magnitude 7.6 (Ms) followed by a smaller 6.7 (s) magnitude earthquake about three hours later.

The largest shock occurred approximately six miles southwest of Landers, California and 110 miles east of Los Angeles. The second earthquake was entered approximately eight miles southeast of Big Bear City in the San Bernardino Mountains near Barton Flats. A distance of seventeen miles and 7,000 feet in elevation separate the two earthquake locations. In addition to depicting the differences in terrain of the two locations, examples of structural damage, liquefaction, surface faulting, and earthquake-generated landslides are associated with this earthquake.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/17/17_slides.html)

Left: This figure shows the four to six foot fault scarp of the Landers earthquake. Measurements indicate a movement along the fault line a maximum of 18 feet horizontally and six feet vertically. The width of the rupture zone appeared to range from eleven feet at the narrowest point to 140 feet across at the widest point. Photo Credit: Lindie Brewer, U.S. Geological Survey

(http://www.ngdc.noaa.gov/seg/hazard/slideset/17/17_slides.html)

Right: Part of Divinos' Steak House in Big Bear City located at the intersection of Knight and Big Bear Road collapsed. It was a unreinforced masonry structure. Such structures performed very poorly during this earthquake and several that partially collapsed have been demolished. Photo Credit: Lindie Brewer, U.S. Geological Survey (http://www.ngdc.noaa.gov/seg/hazard/slideset/17/17_slides.html)

1994 Northridge

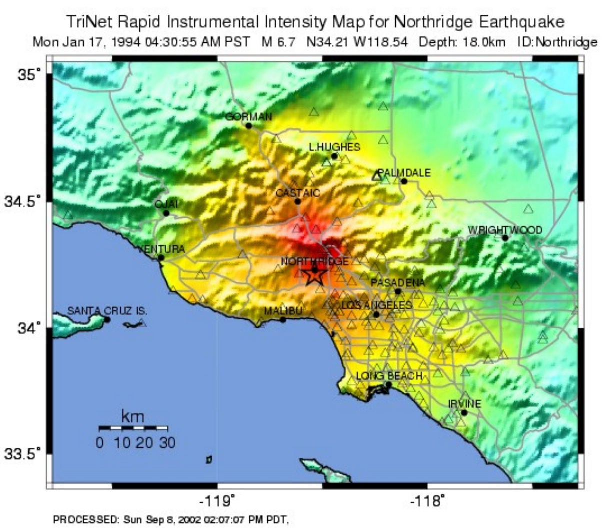
http://nisee.berkeley.edu/jpg/5074_1631_0643/IMG0068.jpg

4:31 A.M. (Local time) on Monday, January 17, 1994. Magnitude 6.8 earthquake twenty miles west northwest of downtown Los Angeles.

Damage was most extensive in the San Fernando Valley, the Simi Valley, and in the northern part of the Los Angeles Basin. Soft (very flexible) stories, which current building codes attempt to discourage, collapsed and caused loss of life. Concrete-frame buildings and concrete parking structures were seriously damaged, and many collapsed. Steel high rises and other steel buildings generally performed well, although there was significant and widespread damage to a number of steel buildings throughout the area. Concrete tilt-ups, including many office buildings, failed in great numbers.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/18/18_slides.html)

Photo: Over all view of Kaiser Permanente office building looking toward the northeast. The brick facades at either end of the structure have separated from the concrete frame, and the second floor of the structure has completely collapsed. The bays at the north and south ends of the building are also partially collapsed from the second to the fifth floor. Granada Hills, California [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR160)



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Shake Maps

http://www.trinet.org/shake/Northridge/intensity.html

Great Hanshin-Awaji (Kobe) January 17, 1995

http://nisee.berkeley.edu/jpg/6317_3071_0971/IMG0086.jpg

http://nisee.berkeley.edu/jpg/6317_3071_0971/IMG0045.jpg

Great Hanshin-Awaji (Kobe) Earthquake, January 17, 1995

On the first anniversary of the moment magnitude (MW) 6.7 1994 Northridge Earthquake, Kobe, Japan was struck by an MW 6.9 earthquake. Both earthquakes struck in the pre-dawn hours, both ruptured beneath densely populated areas, and both caused horrible damage. Yet in Kobe there were many more deaths, financial losses dwarfed those in Northridge, and the amount of destroyed building stock and infrastructure was far worse in Kobe than in Northridge. The greatest intensity of shaking for the 6.9 magnitude earthquake was in a narrow corridor of two to four kilometers stretching 40 km along the coast of Osaka Bay. The worst destruction ran along the previously undetected fault on the coast, east of Kobe. (http://www.ngdc.noaa.gov/seg/hazard/slideset/21/21_slides.html)

Despite differences in design and construction practices, the same general principles frequently came into play: highway collapses were often primarily due to insufficient lateral ties in the concrete columns, nonductile concrete frame buildings did much worse than ductile design, shear walls typically helped to lessen catastrophic damage, and soft soils resulted in greater damage to the structures constructed on them.

The most important lesson in both earthquakes is that the knowledge to significantly improve structures to resist earthquake damage and thereby avoid most of the deaths and financial losses exists; what is lacking is a consistent willingness to marshal the resources necessary to put that knowledge to work on the scale necessary to prevent disasters.

(http://www.eqe.com/publications/kobe/execsumm.htm)

Top: Collapse of a span of the Nishihomiya Bridge on the new Harbor Expressway. Kobe, Japan [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KG86)

Bottom: Air view of damaged quay walls and port facilities on Rokko Island. Quay walls have been pushed outward by 2m to 3m with depressed areas called graben 3m to 4m deep forming behind the walls. Kobe, Japan [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KG45)

1999 Chi-Chi, Taiwan Earthquake

http://www.ngdc.noaa.gov/seg/image/high_res/g0211516.tif

September 21, 1999, 1:47 AM local time. Magnitude MW 7.6.

This earthquake was felt throughout the island of Taiwan. A five county area, including the city of Taichung, experienced the greatest number of casualties and most severe damage. 2,405 deaths and 10,718 injuries were reported. As many as 82,000 housing units were damaged or destroyed, resulting in nearly 600,000 people being temporarily or permanently displaced from their homes.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/47/47_slides.html)

Many low-rise buildings in downtown Puli also collapsed. About one out of every five-corner buildings was severely damaged by the earthquake. This could be attributed to a combination of "soft story" and "torsional" effects. It is common that buildings along major streets have stores set up on the first floor. There are only slender columns at the front of the building at the ground floor. Local engineers refer to this type of building as "soft leg shrimp." The corner buildings have columns on two adjacent sides and walls on the other two sides. Thus, torsional effects would put significant additional shear on these columns.

(http://www.eqe.com/revamp/taipei13.htm)

The Taiwan Building Code requires that urban buildings provide public walkways within the property lines adjacent to streets. This resulted in commercial buildings with arcades at ground floor, with less stiffness than upper stories, forming a soft-story at ground level.

The most vulnerable buildings were multistory commercial and residential structures three to eight stories in height built of reinforced concrete with unreinforced masonry infill walls. Most of these buildings had a “soft” story—a story with most of its space unenclosed—and a shallow foundation and offered little or no lateral resistance to ground shaking.

Tilted building. Structural support on one side of the building failed. Other structures in the photo are also tilted in various directions.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/47/47_slides.html)

1999 Duzce, Turkey Earthquake

http://www.ngdc.noaa.gov/seg/image/high_res/g0193405.tif

Duzce, Turkey Earthquake, November 12, 1999

The magnitude 7.2 quake occurred at 6.57 pm local time (1657 GMT). Duzce lies on the eastern fringe of the region hit by the August 17 quake. Some areas experienced a one-two punch from the 1999 earthquakes. 260 people were reportedly killed, more than 1282 were injured, and at least 102 buildings were destroyed. (http://www.ngdc.noaa.gov/seg/hazard/slideset/44/44_slides.html)

Commentators for the BBC blamed unscrupulous land and building contractors and poor quality illegal housing for the high death toll. "Murderers" declared the headline of the Turkish newspaper Hurriyet. It published photographs of illicitly built apartment buildings that had collapsed while surrounding legal buildings remained intact. (http://www.wsws.org/articles/1999/aug1999/turk-a19.shtml)

Collapsed building in Duzce. Note the failed beam/column connections in the foreground, the unbroken pane of glass in the window frame on the ground, and the building that still stands in the background. The street has been cleared of rubble. Photo credit: Roger Bilham, Dept. of Geological Sciences, University of Colorado (http://www.ngdc.noaa.gov/seg/hazard/slideset/44/44_slides.html)

Masonry Structures

http://nisee.berkeley.edu/jpg/2350_1031_1035/IMG0040.jpg

Unreinforced masonry is very susceptible to damage during earthquake ground shaking. Solid brick masonry is very heavy and its tensile strength, and therefore its flexural strength per unit weight for in-plane and out-of-place seismic forces, is very small. (http://nisee.berkeley.edu/ebooks/)

Photo: Unknown location. City Hall in the distance. 1906 San Francisco, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S3045)

Masonry Structures

http://nisee.berkeley.edu/jpg/5074_1631_2462/IMG0002.jpg

Two-story commercial unreinforced masonry building on Venice Blvd. in Santa Monica strengthened with diaphragm ties. Bearing walls constructed of three withes of bricks. Damage patterns observed on the front face include corner damage and in-plane diagonal cracking of the piers. Santa Monica, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR392)

Cut Stone Backed with Brick

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647002/tif/64700212.tif

Stanford University Library Building. An extreme case of destruction of walls made of veneer of cut stone backed with brick. Interior walls of brick. The central dome was supported upon a steel frame. Palo Alto, California [Photo: Huber, Walter] 1906 San Francisco

(http://www.ngdc.noaa.gov/seg/hazard/slideset/2/2_slides.html)

Concrete Structures

http://nisee.berkeley.edu/jpg/5074_1631_0642/IMG0025.jpg

http://nisee.berkeley.edu/jpg/5074_1631_0642/IMG0026.jpg

Concrete is a relatively heavy material which, like masonry, has a very small (practically negligible) tensile, and thus flexural, strength. Therefore, it is usually reinforced with steel when used in structures. When the concrete is properly reinforced with steel it can be used effectively in seismic-resistant construction, but it still has relatively low strength per unit weight when normal weight aggregates are used. The use of lightweight aggregate concrete offers a significant advantage in seismic regions. (http://nisee.berkeley.edu/ebooks/)

For regions of moderate to high seismic risk it is necessary to reinforce the concrete structural members carefully: the proper amount and correct detailing of the reinforcing steel plays an important role in the seismic response of a reinforced concrete structure

Left: Van Nuys Holiday Inn on Orion Blvd. at Roscoe. Seven-story reinforced concrete structure, moment resisting frame system in longitudinal direction. This building suffered nonstructural damage during the 1971 San Fernando earthquake, and was subsequently repaired. It is the closest instrumented building to the epicenters of both the 1971 and 1994 earthquakes. Van Nuys, California [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR212)

Right: Van Nuys Holiday Inn. Close up of columns shear-bond failure in fourth-story column. Similar damage was observed in most columns of the fourth story. Van Nuys, California [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR213)

Concrete Structures

http://nisee.berkeley.edu/jpg/5074_1631_0642/IMG0019.jpg

http://nisee.berkeley.edu/jpg/5074_1631_0642/IMG0021.jpg

Left: Overall view of the building, south and east sides. 15-story reinforced concrete building. The building was occupied when photographed. Corner of Ocean Ave. and California Ave.,Santa Monica, California [Photo: Stojadinovic, Bozidar]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR206)

Right: Close-up view of the horizontal cracks. The cracks are along the floor-plate/outside wall joint. Cracks at window corners.

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR208)

Rebar Splices

http://nisee.berkeley.edu/jpg/5074_1631_0642/IMG0086.jpg

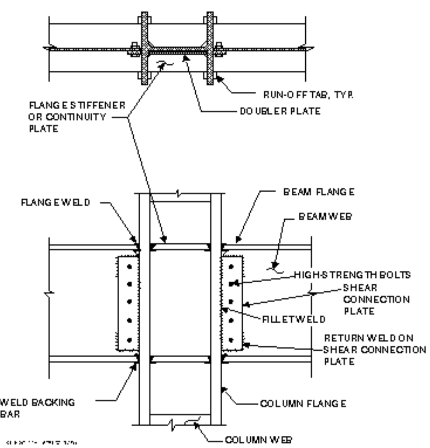
http://nisee.berkeley.edu/jpg/5074_1631_0642/IMG0088.jpg

St. John's Hospital Admin. Bldg (1994 Northridge)

Southwest corner of the building is shown with crack in the shear-wall, severe damage at the location of the splice, buckled rebar.

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR273)

Steel Structures



http://www.eqe.com/publications/revf94/steel-side.html

http://www.eqe.com/publications/revf94/steel.html

Steel is a manufactured material, with usually excellent quality control, that is fabricated in structural shapes. While its stiffness per unit weight is practically the same as any other traditional constructional material, its strength and particularly its ductility and toughness per unit weight are significantly higher than concrete and masonry materials. (http://nisee.berkeley.edu/ebooks/)

A problem in attaining efficient seismic-resistant construction of steel structures is in the field-connection of the structural members.

Right: Fracture of a column flange and web at a moment connection (http://www.eqe.com/publications/revf94/steel.html)

Buckling

http://nisee.berkeley.edu/jpg/5074_1631_0641/IMG0027.jpg

Because of its high strength per unit weight, the slenderness of steel structural members usually exceeds significantly the slenderness of similar structural members made of other traditional materials. Thus buckling becomes a serious problem, and the higher the yielding strength of the steel the greater the danger of buckling. Most structural shapes are formed by plate elements which can undergo local buckling, particularly when strained in the inelastic range. Therefore, in earthquake-resistant design, the compactness requirements for the cross section of the critical regions of structural members are more stringent than for design against normal (standard) loading condition.

Photo: Fracture of tube as a result of local buckling of the member. Los Angeles, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR315)

Failure of Welds

http://nisee.berkeley.edu/jpg/5074_1631_0641/IMG0031.jpg

Architectural elements were removed to reveal the failure of the weld between the tube and the connecting plate, as well as a fracture of the tube. Los Angeles, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR319)

Wood-Frame Houses

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647012/tif/64701212.tif

Damaged roof and porch of Skyland Community Church, Skyland and Miller Road in the Santa Cruz Mountains. The wooden structure sustained severe damage. Photo Credit: C. Stover, U.S. Geological Survey

(http://www.ngdc.noaa.gov/seg/hazard/slideset/12/12_slides.html)

Chimney Damage

http://nisee.berkeley.edu/jpg/5074_1631_2462/IMG0037.jpg

Damage to chimneys is a common feature during earthquakes and is an example of unreinforced masonry failure. If it is not properly reinforced, the chimney can break off at roof level and endanger those below.

Example of chimney damage. Tarzana, California [Photo: Reitherman, Robert] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR427)

Soft Story Collapse

http://nisee.berkeley.edu/jpg/5074_1631_0641/IMG0050.jpg

A soft story is defined as a story of a building with a smaller yield strength and stiffness than other stories. "Soft-story" buildings are buildings with unusually weak stories, which can easily collapse in an earthquake. The ground floor is the most common location for a soft-story, which is usually due to tuck-under parking or large commercial spaces.

(http://www.quake06.org/quake06/best_practices/IMSSB.html)

Photo: Leaning soft-story apartment building. Near intersection of Reseda Blvd. and Plummer St., Reseda, California [Photo: Reitherman, Robert]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR338)

Soft Story Collapse

http://nisee.berkeley.edu/jpg/5074_1631_0641/IMG0037.jpg

http://nisee.berkeley.edu/jpg/5074_1631_0641/IMG0041.jpg

Left: Soft story collapse of a three-story wood-frame with stucco exterior apartment building. The first story of the building consisted of an open parking area and apartment units. Los Angeles, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR325)

Right: Soft-story collapse of apartment building. Corner of structure in NR328. Sherman Oaks, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR329)

Bridges

http://nisee.berkeley.edu/jpg/2362_1012_2044/IMG0069.jpg

http://nisee.berkeley.edu/jpg/5074_1631_0651/IMG0037.jpg

Left: 1971 San Fernando - Collapsed freeway structures at interchange of Interstate-5 and Interstate-210. Los Angeles County, California [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S4358)

Right: 1994 Northridge - Interstate 5/Hwy 14 North Connector. Collapsed span between bent 2 (crushed) and bent 3 (standing). Simple supported span to the left has collapsed. Los Angeles County, California [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR728)

Column Failure

http://www.ngdc.noaa.gov/seg/image/geohazards_v1/images/647022/tif/64702205.tif

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 (http://www.ngdc.noaa.gov/seg/hazard/slideset/22/22_slides.html)

Column Failure

http://www.ngdc.noaa.gov/seg/image/geohazards_v1/images/647022/tif/64702216.tif

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

(http://www.ngdc.noaa.gov/seg/hazard/slideset/22/22_slides.html)

Splice Failure

http://nisee.berkeley.edu/jpg/6317_3071_0981/IMG0031.jpg

Failed column showing splice failures - 1995 Kobe

Pier #142, the last of the failed section, showing splice failures and a change of superstructure to steel box girders at pier #143 (from Kawashima). Hanshin Expressway [Photo: Thewalt, Christopher R.]

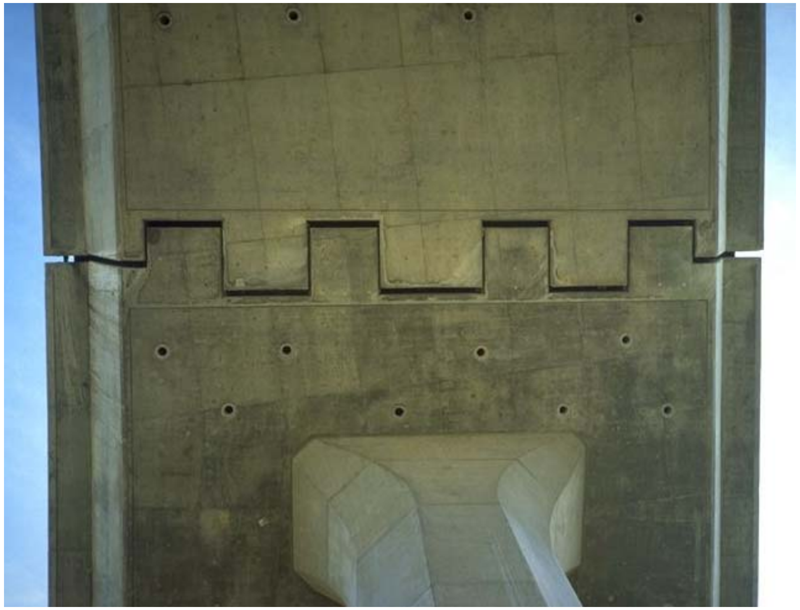
(http://nisee.berkeley.edu/jpg/6317_3071_0981/IMG0031.jpg)

Yielding of Steel Pier

http://nisee.berkeley.edu/jpg/6324_3122_2969/IMG0004.jpg

Yielding of steel pier #353. Hanshin Expressway [Photo: Thewalt, Christopher R.] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KB244)

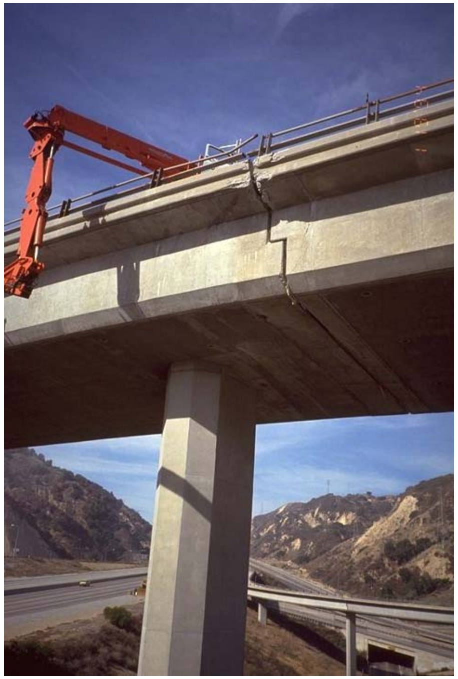
Expansion Joints



http://nisee.berkeley.edu/jpg/5074_1631_0652/IMG0076.jpg

View up at flyover from Hwy 118 westbound to Interstate-5 southbound. Expansion joint appears to be open. Pacoima, California [Photo: Aschheim, Mark] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR661)

Pounding of Superstructure



http://nisee.berkeley.edu/jpg/5074_1631_0651/IMG0016.jpg

Southbound I-5 to northbound Hwy 14. Joint showing evidence of pounding. The seat-width appear to be undisturbed, yet the flange reflects disruption. Possible relative rotational movement along a vertical axis. Also diagonal cracks may be seen on the right hand side section. Los Angeles County [Photo: Santana, Guillermo]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR707)

Abutment Settlement

http://nisee.berkeley.edu/jpg/5074_1631_0652/IMG0051.jpg

Abutment settlement, at Nordhoff Way bridge over Southern Pacific Railroad. Northridge, California [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR636)

Railroads

http://www.ngdc.noaa.gov/seg/hazard/slideset/1/1_slides.html

http://www.ngdc.noaa.gov/seg/hazard/slideset/1/1_slides.html

Left: Ground Deformation-Landslide

Damage to the Union Pacific Railway occurred when hillside fill slid away from beneath a 121 m section of the branch line just outside Olympia, more than 60 km from the epicenter. Photo Credit: University of California, Berkeley. (http://www.ngdc.noaa.gov/seg/hazard/slideset/1/1_slides.html)

Right: Earthquake of April 29, 1965, Seattle, Washington.

The magnitude 6.5 earthquake killed 7 and caused 12.5 million in property damage.

Dams

http://nisee.berkeley.edu/jpg/2362_1012_2044/IMG0049.jpg

http://nisee.berkeley.edu/jpg/2362_1012_2044/IMG0048.jpg

Damage to Lower San Fernando Dam and Lower Van Norman Reservoir. San Fernando Valley, California [Photo: Steinbrugge, Karl V.]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S4337)

Water Tanks

http://nisee.berkeley.edu/jpg/2362_1012_0138/IMG0096.jpg

http://nisee.berkeley.edu/jpg/6317_3071_0971/IMG0095.jpg

Left: Elephant foot deformation of water tank on the hill behind Olive View Hospital. Sylmar, California [Photo: Steinbrugge, Karl V.] 1971 San Fernando (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S4183)

Right: Tilted tank at the Karumojima tank farm. Note the ground cracking due to lateral spreading in the foreground. Kobe, Japan [Photo: unknown] (http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KG95)

Water Pipes

http://nisee.berkeley.edu/jpg/2362_1012_0138/IMG0098.jpg

http://nisee.berkeley.edu/jpg/5074_1631_0631/IMG0089.jpg

Left: Damage to water pipes at tank above Olive View Hospital. Sylmar, California [Photo: Steinbrugge, Karl V.] San Fernando 1971

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S4185)

Right: Geyser from broken water pipe, Northridge. Northridge, California [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=NR89)

Differential Settlement

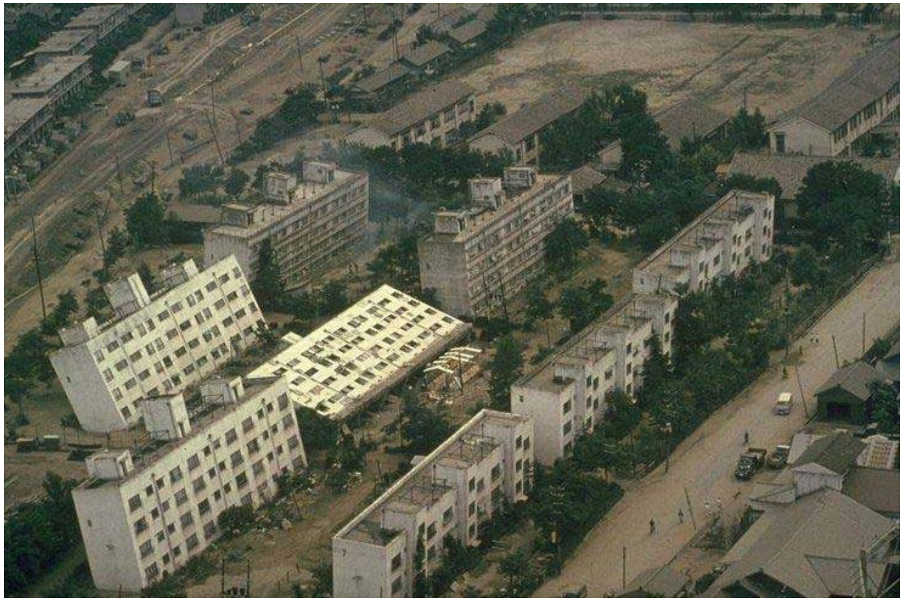
http://nisee.berkeley.edu/jpg/6317_3071_0971/IMG0100.jpg

Differential settlement is where not every point on the foundation settles the same amount.

Photo: Differential settlement at the base of a water tank in the Nippon Gatx complex. Kobe, Japan [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KG100)

Soil Liquefaction



http://www.ngdc.noaa.gov/seg/hazard/slideset/1/1_slides.html

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction and related phenomena have been responsible for tremendous amounts of damage in historical earthquakes around the world. Liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other.

(http://www.ce.washington.edu/~liquefaction/html/what/what1.html)

The Niigata earthquake, together with the Alaska earthquake also of 1964, brought liquefaction phenomena and their devastating effects to the attention of engineers and seismologists. A remarkable ground failure occurred near the Shinano river bank where the Kawagishi-cho apartment buildings suffered bearing capacity failures and tilted severely (left). Despite the extreme tilting, the buildings themselves suffered remarkably little structural damage.

(http://www.ce.washington.edu/~liquefaction/html/quakes/niigata/niigata.html)

Lateral Spreading

http://nisee.berkeley.edu/jpg/6324_3122_2969/IMG0083.jpg

Lateral spreading is generically used to describe lateral displacement of soil layers supported on liquefiable soils (once these supporting soils get weak enough due to liquefaction).

Photo: Soil settlement and lateral spread at east end of bridge Higashi Kobe cable-stayed bridge [Photo: Thewalt, Christopher R.]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KB323)

Lateral Displacement of Quay Walls

http://nisee.berkeley.edu/jpg/6317_3071_0971/IMG0041.jpg

http://nisee.berkeley.edu/jpg/6317_3071_0971/IMG0045.jpg

Left: Example of lateral displacement of older quay walls on Port Island. Port Island, Kobe, Japan [Photo: unknown]

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=KG41)

Right: Air view of damaged quay walls and port facilities on Rokko Island. Quay walls have been pushed outward by 2m to 3m with depressed areas called graben 3m to 4m deep forming behind the walls. Kobe, Japan [Photo: unknown]

Landslides (1992 Landers)

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647017/tif/64701714.tif

Landslides

This figure shows a view of the landslides along Highway 18 that connects Redlands to Big Bear in the San Bernadino Mountains. The strong shaking also caused landslides to occur along Highway 38. The steep slopes are white in color because of the white decomposed granite soil. Big boulders were embedded in the soil covered slopes. The dust clouds created by the landslides were similar to smoke clouds from forest fires. People thought that forest fires were occurring. Photo Credit: Lindie Brewer, U.S. Geological Survey

(http://www.ngdc.noaa.gov/seg/hazard/slideset/17/17_slides.html)

Landslides (1964 Alaska)

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647007/tif/64700709.tif

Landslides

This view of damage to Fourth Avenue buildings in downtown Anchorage shows the damage resulting from the slide in this area. Before the earthquake, the sidewalk in front of the stores on the left, which are in the graben, was at the level of the street on the right, which was not involved in the subsidence. The graben subsided 11 feet (3.3 m) in response to 14 feet (4.2 m) of horizontal movement of the slide block during the earthquake. Lateral spreading produced a fan-shaped slide 1,800 feet (545.5 m) across that covered about 36 acres (14.6 hectares) and moved a maximum of 17 feet (5.1 m). Movement on the landslide began after about 1 to 2 minutes of ground shaking and stopped when the shaking stopped. Photo Credit: NOAA/NGDC

(http://www.ngdc.noaa.gov/seg/hazard/slideset/7/7_slides.html)

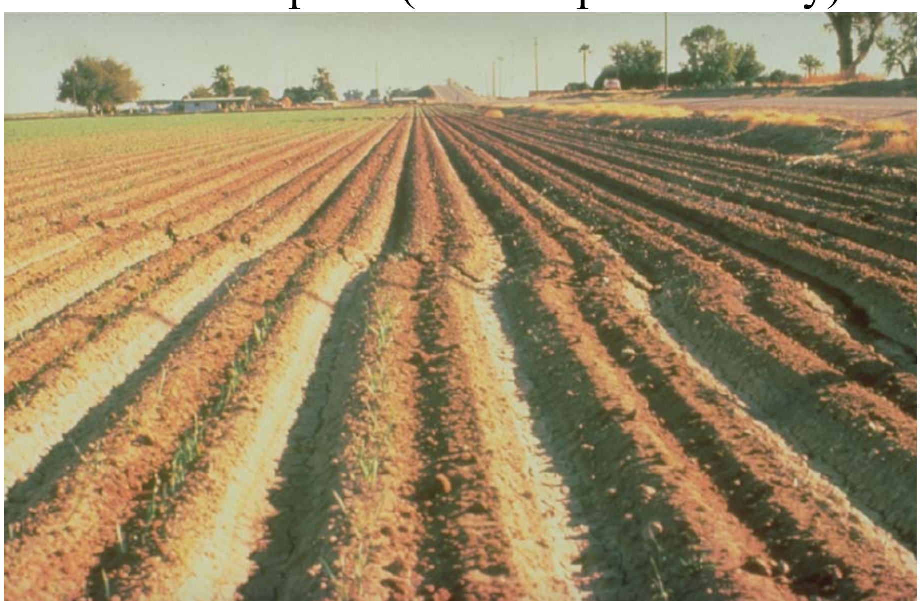
Tsunami Damage (1964 Alaska)

http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647007/tif/64700719.tif

This slide shows tsunami damage to the north end of Resurrection Bay near Seward. The first wave arose after a waterfront and submarine slump developed within minutes of the beginning of the earthquake. A large mound of water rose in the fiord. This wave and other waves washed into the town of Seward destroying buildings, docks, railroad facilities, and small boats. About twenty minutes later the first wave from the major tsunami arrived. The maximum runup was between 30 and 38 feet (9.1 -11.5 m) above mean low water. Waves continued for more than eight hours after the quake. Photo Credit: U.S. Dept. of the Interior

(http://www.ngdc.noaa.gov/seg/hazard/slideset/7/7_slides.html)

Surface Rupture (1979 Imperial Valley)



http://www.ngdc.noaa.gov/seg/image/geohazards_v2/images/647008/tif/64700806.tif

Earthquake of October 15, 1979, Imperial Valley, California.

A fault trace crosses a cultivated field near El Centro. The surface rupture on the Imperial Fault extended from about 2.5 miles (4 km) north of the International Border to about 2.5 miles south of Brawley. Maximum lateral displacement was about 22 inches (55 cm) in Heer Dunes and the maximum vertical displacement was 7.5 inches (19 cm) southeast of Brawley. Photo Credit: University of Colorado

(http://www.ngdc.noaa.gov/seg/hazard/slideset/8/8_slides.html)

Fault scarp (1999 Chi-Chi)

http://www.ngdc.noaa.gov/seg/image/high_res/g0211501.tif

Chi-Chi, Taiwan Earthquake, September 21, 1999

Fault scarp on street with four meters of vertical offset. Note the height of the basketball hoop. Note apparently undamaged structures on the left on the raised portion of the fault.

(http://www.ngdc.noaa.gov/seg/hazard/slideset/47/47_slides.html)

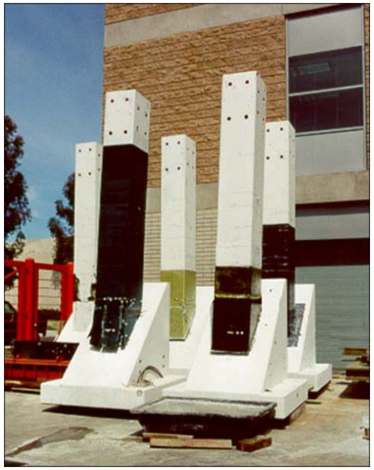
http://nisee.berkeley.edu/jpg/2350_1031_1035/IMG0019.jpg

Toppling

Statue of Agassiz thrown from its niche above arches, Stanford University. Palo Alto, California [Photo: Branner, J.C.] 1906 San Francisco

(http://nisee.berkeley.edu:8080/images/servlet/EqiisDetail?slide=S3024)

Seismic Retrofit



http://structures.ucsd.edu/Research/Welded.shtml

http://structures.ucsd.edu/Research/BixbyCreek.shtml

Left: The Bixby Creek Bridge, located on Highway 1, 18 miles south of Carmel in Monterey County, California, was built in the early 1930's and has been evaluated by Caltrans and external consultants for seismic retrofit. One of the main deficiencies identified was the low ductility capacity in the lap splice reinforced spandrel columns. Because this bridge is designated as a historic structure, the rectangular cross-section must be maintained. This eliminates the possibility of elliptical steel jackets and leaves the options of either complete reconstruction, or using advanced composite jacketing on the rectangular column geometry. The purpose of this test program was to (1) assess the performance of non-perpendicular spandrel column/arch rib connections, and (2) establish a comparison between various advanced composite jacketing systems based on seismic performance, time required for installation, cost, and visual impact.

(http://structures.ucsd.edu/Research/BixbyCreek.shtml)

Right: Following the widespread brittle fracture near or at the beam flange-to-column flange welded joints in the January 17, 1994 Northridge Earthquake, the research project was initiated to investigate the effectiveness of different schemes for seismic retrofit of existing welded steel moment frame connections.

(http://structures.ucsd.edu/Research/Welded.shtml)

Additional Information

The National Information Service for Earthquake Engineering (NISEE)

http://nisee.berkeley.edu

National Geophysical Data Center

http://www.ngdc.noaa.gov/seg/hazard/slideset/earthquakes/