OCTOBER 2012

AIRCURRENTS: TOP 10 HISTORICAL HURRICANES AND EARTHQUAKES IN THE U.S.: WHAT WOULD THEY COST TODAY

EDITOR'S NOTE: *For more than 25 years, AIR has been helping companies assess and manage the financial risk from infrequent, but potentially devastating natural and man-made catastrophes. To provide a sense of the potential impact, AIR has periodically published a list of the costliest historical U.S. hurricanes and earthquakes—were they to recur today. The rankings below correspond to AIR's most recent update to its U.S. industry exposure database, reflecting replacement values of properties insured against the hurricane and earthquake perils as of the end of 2011.*

It is commonly thought that as many as six of the top 10 historical insured hurricane losses in the United States occurred in 2004 and 2005, with Hurricane Ike in 2008 claiming its place among the top five. The rankings are based on reported insured losses at the time the events took place—and while they may be trended to today's dollars, they are not trended to today's exposures. The number and value of properties in the United States—and particularly in areas at risk—have increased dramatically in the past century, well beyond the rate of inflation. The more interesting question, then, is what the ranking would be if these historical hurricanes were to recur today.

Using property exposures current through the end of 2011, the only recent storm to rank among the top 10 is Hurricane Katrina. First on the list is a hurricane unknown to many: the 1926 Miami hurricane (hurricanes were not systematically named until 1953). This Category 4 storm made a direct hit on Miami but, at the time, Dade and Broward counties had a combined population estimated at roughly 135,000. With a combined population of more than 4 million today, that storm would likely result in insured losses exceeding USD 125 billion.

Similarly, when a series of three large earthquakes occurred in the central United States in the winter of 1811-1812, the largest nearby town—New Madrid, Missouri—was home to fewer than 500 inhabitants. A recurrence of those earthquakes today would cost the industry in excess of USD 110 billion.

The following charts show the estimated impact of the top ten historical U.S. hurricanes and earthquakes. For hurricanes, AIR simulated the meteorological characteristics of each storm using the AIR Hurricane Model for the United States. Similarly, the ground motion of historical earthquakes was simulated using the AIR Earthquake Model for the United States. The resulting estimates of insured losses represent what these events would cost the insurance industry today based on AIR's detailed industry exposure database as of the end of 2011 and peril-specific take-up rates.

The real purpose of catastrophe models is to prepare for potential large losses before they occur. To account for the full range of potential scenarios, the AIR U.S. hurricane and earthquake models contain many possible events that could result in even higher losses than those listed below.

Estimated Insured Losses for the Top 10 Historical Hurricanes Based on Current Exposures

DATE	EVENT NAME	CATEGORY	2011 INSURED LOSS*
September 18, 1926	Miami Hurricane	4	USD 125 billion
August 24, 1992	Hurricane Andrew	5	USD 57 billion
September 17, 1947	1947 Fort Lauderdale Hurricane	4	USD 53 billion
September 17, 1928	Great Okeechobee Hurricane	5	USD 51 billion
August 29, 2005	Hurricane Katrina	3**	USD 45 billion
September 9, 1965	Hurricane Betsy	3	USD 45 billion
September 9, 1900	Galveston Hurricane of 1900	4	USD 41 billion
September 10, 1960	Hurricane Donna	4	USD 35 billion
September 21, 1938	The Great New England Hurricane	3	USD 33 billion
September 5, 1950	Hurricane Easy	3	USD 23 billion

*Modeled loss to property, contents, and business interruption and additional living expenses for residential, mobile home, commercial, and auto exposures as of December 31, 2011. Losses include demand surge.

** This refers to Katrina's second landfall in Louisiana.

AIR

Estimated Insured Losses for the Top 10 Historical Earthquakes Based on Current Exposures

DATE	EVENT LOCATION	MAGNITUDE	2011 INSURED LOSS*
February 7, 1812	New Madrid, MO	7.7	USD 112 billion
April 18, 1906	San Francisco, CA	7.8	USD 93 billion
August 31, 1886	Charleston, SC	7.3	USD 44 billion
June 1, 1838	San Francisco, CA	7.4	USD 30 billion
January 17, 1994	Northridge, CA	6.7	USD 23 billion
October 21, 1868	Hayward, CA	7.0	USD 23 billion
January 9, 1857	Fort Tejon, CA	7.9	USD 8 billion
October 17, 1989	Loma Prieta, CA	6.3	USD 7 billion
March 10, 1933	Long Beach, CA	6.4	USD 5 billion
July 1, 1911	Calaveras, CA	6.4	USD 4 billion

**Modeled loss to property, contents, and business interruption and additional living expenses for residential, mobile home, commercial, and auto exposures as of December 31, 2011. Losses include demand surge and fire following earthquake. Policy conditions and earthquake insurance take-up rates are based on estimates by state insurance departments and client claims data.

HISTORICAL HURRICANES

MIAMI HURRICANE (1926)

The 1926 Miami hurricane was an intense storm that devastated Miami and caused extensive damage in the Florida Panhandle, Alabama, and the Bahamas. The storm developed off Cape Verde on September 6 and traveled toward St. Kitts and the Bahamas. On September 18 the hurricane made landfall south of Miami as what today would now be categorized as a Category 4 storm on the Saffir-Simpson scale; winds on the ground were reported at 125 mph and storm surges of 15 feet inundated the area.

The storm crossed Florida, entered the Gulf of Mexico, and made landfall again near Mobile, Alabama, on September 20 as a Category 3. The storm traveled westward over Alabama and Mississippi, eventually dissipating after entering Louisiana.

Heavy damage from wind, rain, and storm surge were reported along the Florida coast, but the greatest devastation was in Miami. It is estimated that between 25,000 and 50,000 people were left homeless, and nearly 370 people were killed.

HURRICANE ANDREW (1992)

Hurricane Andrew began as a tropical storm off the coast of Africa on August 14. The storm reached peak winds of 170 mph off the Bahamas, where it caused an estimated quarter-billion dollars in damage (1992 currency). At about 4:00 a.m., August 24, the eye of Hurricane Andrew passed over Elliot Key on the eastern edge of Biscayne Bay. The Fowley Rocks Buoy, located just to the east, recorded sustained winds of 141 mph with a peak gust of 169 mph as the eyewall passed. Data transmission ceased after that reading. Storm surges were recorded from Turkey Point in the south to as far north as Miami. The highest was 16.9 feet at the Burger King International Headquarters on the western coast of the bay. Andrew's eye made landfall just east of Homestead Air Force Base at about 5:00 a.m. The eye was about 15 miles in diameter and central pressure had fallen almost 45 millibars to an estimated 922 mb. Just before they were destroyed, instruments at the National Hurricane Center (NHC) in Coral Gables, at the northern edge of the eyewall, recorded a maximum sustained wind of 138 mph, with a peak gust of 164 mph. In 2002, the NHC reclassified the storm as a Category 5 hurricane, up from Category 4, making Andrew only the third Category 5 hurricane to strike the continental U.S. since 1900.

Andrew destroyed more than 25,000 homes in Dade County and damaged 100,000 more. About 90% of all mobile homes in south Dade County were destroyed. Twenty-six deaths were directly attributed to Andrew, with an additional indirect toll of about 65. Andrew briefly re-intensified over the Gulf of Mexico and made a second landfall in Louisiana, where storm tides, tornadoes, and winds up to 105 mph damaged crops and property. Insurance claims from the storm contributed to the bankruptcy and closure of 11 companies and drained excessive equity from some 30 more.

FORT LAUDERDALE HURRICANE (1947)

This intense storm, also known as the Pompano Beach Hurricane, affected the Bahamas, Florida, Louisiana, and Mississippi. It developed east of Cape Verde on September 4, and reached peak winds of 160 mph as it passed over the Bahamas. On September 19 it made landfall near Fort Lauderdale as what would later be rated a Category 4, with wind speed readings the highest ever recorded in the state of Florida (until Hurricane Andrew).

The hurricane was unusually large, with hurricane-force winds extending outward to an estimated 120 miles from the center. Eleven-foot storm surges along the coast caused extreme flooding and washed out large stretches of highway between Palm Beach and Boynton Beach. Records for single month rainfall were set in some areas. The hurricane traveled in a northwesterly direction into Louisiana and Mississippi, where storm surges and heavy rains caused extensive crop and property damage. In total, 51 people lost their lives.

A NOTE ABOUT THE SAFFIR-SIMPSON SCALE

The Saffir-Simpson Intensity Scale was developed in the early 1970s to warn coastal residents in harm's way of the destructive potential of an approaching hurricane. It was motivated by the 150 fatalities that resulted when Hurricane Camille (one of three Category 5 landfalls in the U.S.) roared ashore near Biloxi, Mississippi, in 1969.

Historically, the five categories of the Saffir-Simpson Hurricane Scale had been defined by three factors: central pressure, wind speed, and storm surge. In 2010, the NHC revised the scale to use wind speed only and it was renamed to the Saffir-Simpson Hurricane Wind Scale.

Note that while the five discrete categories defined by the Saffir-Simpson Scale are a useful convention for characterizing individual events for the public, because hurricane damage increases non-linearly with wind speed, a spectrum of continuous intensity is used when modeling hurricane risk.

GREAT OKEECHOBEE HURRICANE (1928)

The 1928 Great Okeechobee hurricane, the first recorded hurricane to reach what is now considered Category 5 status in the Atlantic basin, is one of the 10 most intense storms documented to make landfall in the United States. It currently remains the only storm of Category 5 intensity to have made landfall in Puerto Rico. The hurricane, first observed east of Guadalupe on September 10, caused heavy crop and property damage when it passed over the Leeward Islands on September 12. The hurricane struck Puerto Rico on September 13 as a Category 5, with winds up to 160 mph. After crossing the Bahamas as a Category 4, the hurricane then made landfall in southern Florida on September 16 with maximum sustained winds near 150 mph and a central pressure of 929 mb. Coastal damage in Florida was catastrophic; however, the most extreme destruction occurred inland at Lake Okeechobee. Strong winds generated storm surges that breached the dike around the lake, and the resulting flood was 20 feet deep in some places and covered hundreds of square miles. The Great Okeechobee Hurricane left thousands homeless and more than 4,000 dead. The storm is the second deadliest natural disaster in U.S. history.

HURRICANE KATRINA (2005)

Hurricane Katrina formed as a tropical depression over the Bahamas on August 23 and became a Category 1 storm only two hours before it made landfall in southern Florida on August 25. The storm weakened over land but quickly regained strength and nearly doubled in size as it crossed the Gulf of Mexico.

On August 29 the storm made landfall in southeastern Louisiana, where it caused massive property damage and severe loss of life. A storm surge led to 53 different levee breaches in greater New Orleans, resulting in roughly 80% of the city being submerged under flood waters. A third U.S. landfall occurred at the Louisiana/Mississippi border at Category 3 intensity. Storm surges, high winds, and heavy rains caused billions of dollars of damage (2005 currency). The effects of Katrina were widespread.

As the hurricane traveled inland and toward the northeast, its outer bands spawned some 62 tornadoes, causing damage in eight states. Tropical storm strength gusts were recorded as far north as Kentucky, and high winds downed trees in the state of New York. Significant rainfall occurred in 20 states and regions of Ontario, Canada. In the U.S., an estimated 1,800 people lost their lives in the hurricane. Estimates of total economic losses from Hurricane Katrina vary, but most are considerably more than double the estimated insured loss.

HURRICANE BETSY (1965)

Hurricane Betsy formed east of the Windward Islands and moved northwestward across the Atlantic, at one point making a complete loop. The storm looked to be heading towards the Carolinas, but instead made a second loop and passed over the Bahamas. Betsy made landfall in Key Largo, Florida, on September 8 as a Category 3 storm. Winds up to 155 mph were recorded as the storm gained

intensity while crossing the Gulf of Mexico. On September 9 the storm made landfall in Grand Isle, Louisiana, just west of the mouth of the Mississippi River.

Betsy, which killed approximately 76 people, destroyed nearly every building in Grand Isle and caused extensive flooding of the Mississippi River and nearby lakes. It was the first hurricane to cause over a billion dollars (1965 currency) in damages, thus earning it the nickname "Billion Dollar Betsy." Devastation from the storm included 164,000 flooded homes and the destruction of eight offshore oil platforms. At the time, Betsy was the costliest hurricane to make landfall in the United States.

GALVESTON HURRICANE (1900)

The city of Galveston is situated on Galveston Island, where the highest elevation is 8.7 feet. In 1900 Galveston was the largest city in Texas, a prosperous, booming metropolis of some 40,000 people. It was the state's chief trading port and, with more than 70% of the national cotton crop passing through it, the chief port for the lucrative cotton trade.The hurricane that struck Galveston on September 8, 1900, is the deadliest natural disaster in the history of the United States, with an estimated 8,000-12,000 losing their lives. The storm made landfall with 135 mph winds, a Category 4 storm on the Saffir Simpson scale. The highest gust wind speed recorded was 150 mph and the lowest central pressure was 936 mb.

The greatest damage stemmed from the 15-foot storm surge that washed over the low-lying harbor town, which destroyed more than 3,600 homes and wiped out bridges and telegraph lines. On September 12 the storm tracked to New York City, where 65 mph winds were recorded. By the time it dissipated over the Atlantic, the storm had caused over USD 20 million (1900 currency) in damage across the United States.

THE GREAT NEW ENGLAND HURRICANE (1938)

By far the most severe hurricane to have struck the northeastern United States since 1900 was the Great New England Hurricane of 1938, otherwise known as the Long Island Express. The storm made landfall in Suffolk County, Long Island, on September 21, and continued through Connecticut, Massachusetts, and into Vermont and even Canada. Maximum sustained winds of 121 mph, with peak gusts of 184 mph, and a central pressure reading of 946 mb were recorded. Even though the affected area was far less populated than it is today, the cost of the 1938 storm was immense for the time. Heavy winds and storm surges resulted in approximately 680 deaths, 700 injuries, and the damage or destruction of 57,000 homes throughout the Northeast. Significant structural damage occurred far inland, as photos taken in Worcester, Massachusetts, some 140 miles from the point of landfall, show. So much damage so far inland was possible because the storm was travelling at a forward speed of 50 miles per hour, covering 600 miles in just 12 hours. The hurricane destroyed power lines, automobiles, boats, and trees, killed thousands of cattle and chicken, and wiped out half of the region's apple crop. Rainfall and surges submerged communities along the coast in flood waters that were measured up to 13 feet high

HURRICANE DONNA (1960)

Hurricane Donna holds the record for the longest-lasting major hurricane in the Atlantic, where it ambled for a total of 17 days. For nine of those days, Donna consistently maintained wind speeds of at least 115 mph. Donna finally made landfall in Key Marathon, Florida, as a Category 4 on September 10, 1960. Gusts up to 180 mph were recorded and 13-foot storm surges destroyed coastal properties. In southwestern Florida, 30% of the grapefruit, 10% of the orange and tangerine, and nearly all of the avocado crops were lost.

The storm continued up the East Coast, landing first in North Carolina and then Long Island, New York, on September 12. In the Carolinas, Donna uprooted trees, downed power lines and blew roofs off of homes. Sustained winds of 105 mph were reported in Long Island and Rhode Island. Storm surge in New York Harbor reached 11 feet. Blue Hill Observatory in Massachusetts reported gusts exceeding 145 mph. In all, damaging winds from Donna affected every state from South Carolina to Maine. A total of 364 people lost their lives during the storm, 50 of them in the United States.

HURRICANE EASY (1950)

The fifth named storm of the 1950 season, Hurricane Easy formed in the western Caribbean Sea and strengthened steadily to Category 1 status before making landfall in Cuba on September 2, with winds of 80 mph. After exiting Cuba, the storm re-intensified, ultimately achieving 125 mph wind speeds. Easy tracked parallel to the Florida coast, subjecting coastal exposures along the length of Florida to hurricane force winds and dangerous tides. When the storm reached about 80 miles west of Tampa, steering currents weakened, causing Easy to make a slow counterclockwise loop. Easy then traveled northeast and made landfall in Cedar Key, Florida, on September 5 before making a second loop over land. The storm reemerged in the Gulf of Mexico briefly before making a second Florida landfall north of Tampa at Homosassa Springs. The storm's unusual track is attributed to its interaction with another hurricane to its east in a phenomenon known as the Fujiwhara Effect.

Hurricane Easy's Category 3 wind speeds wreaked havoc in the Cedar Key area, with half of the houses destroyed or rendered uninhabitable. In Florida, Hurricane Easy was responsible for three deaths, dozens of injuries, and USD 3.3 million in damage (1950 currency). The damage was no doubt moderated by the region's then sparse population.

HISTORICAL EARTHQUAKES

NEW MADRID REGION (1811-1812)

Between December 16, 1811, and March 15, 1812, a series of devastating earthquakes struck the interior of the continental United States. The series defined the New Madrid Seismic Zone, named after New Madrid, Missouri, which was the town closest to the epicenter of the earthquake sequence. During the three-month period, the area was shaken by over 100 earthquakes, among them a cluster of very large events: an earthquake with a magnitude of 7.2 on December 16, 1811, another with a magnitude of 7.1 on January 23, 1812, and the largest with a magnitude of 7.7 on February 7, 1812.

In an area sparsely populated at the time, most of the destruction was done to the landscape, which still shows evidence of uprooted forests, massive landslides, sand blows, and fissures covering an area of about 232,000 square miles. Shaking was felt throughout much of the United States and even as far away as Quebec—an area more than five times larger than the area affected by the 1906 San Francisco earthquake.

The earthquake generated huge waves along the Mississippi River, throwing boats onto the banks, which in turn collapsed back into the river. Elsewhere along the river, whole islands disappeared. According to records, the only life that was claimed was in the town of New Madrid, due to falling buildings.

SAN FRANCISCO, CALIFORNIA (1906)

The magnitude 7.8 earthquake that struck San Francisco on April 18, 1906, remains one of the most devastating earthquakes in the history of California. It caused an estimated 3,000 deaths and USD 524 million in property loss (1906 currency), due to both shake damage and resulting fires. Shaking was felt throughout California and in parts of Nevada and Oregon. In San Francisco, the effects were felt for about one minute from the main shock, which was followed by several aftershocks.

The earthquake created the longest fault rupture ever observed in the continental United States, extending nearly 300 miles along the northern San Andreas Fault. Horizontal displacement was observed in many areas with the largest at 21 feet near Point Reyes Station in Marin County. Indeed, the displacement caused by this earthquake, and the strain of the rupture, led to the elastic-rebound theory of earthquakes.

In San Francisco, pavements buckled, houses of ordinary brick and frame construction were destroyed, sewers and water mains were broken, and streetcar tracks were torn and bent out of shape. Pipelines were broken, and roads were impassable, shutting off water supply to the city, which in turn made it impossible to fight the fires that ignited due to overturned stoves and broken gas lines. At least 50-60 fires burned in the city for four days.

MEASURING EARTHQUAKE INTENSITY

The severity of an earthquake can be measured by the damage it inflicts on the earth's surface or by the energy released at the point of rupture below the surface. Earthquake magnitude characterizes the total energy released by an earthquake, while earthquake intensity refers to the resulting level of ground shaking at a particular location and the observed effects of an earthquake on people, buildings, and other features. While the magnitude of an earthquake is a characteristic of the earthquake as a whole, intensity varies from place to place.

An earthquake's intensity at different locations can be described using the Modified Mercalli Intensity (MMI) scale, which was first developed in in 1902. The MMI at a particular location is based on human judgment and the observed post-event damage. Today, instruments called seismographs directly measure ground motion intensity, which can be characterized by physical parameters such as peak ground acceleration (PGA) and spectral acceleration (Sa).

CHARLESTON, SOUTH CAROLINA (1886)

On September 1, 1886, Charleston, South Carolina was struck by a magnitude 7.3 earthquake, one of the largest shocks on record for eastern North America. Craters and fissures from this earthquake were observed over an area of 500 square miles. More than 50 miles of railroad track was severely damaged and the track four miles northwest of Charleston formed S-shaped curves in places where they were formerly straight.

Sand boils were widespread in the area, and formed craterlets as wide as 20 feet. Some of these craterlets spewed water spouts as high as 15-19 feet. Fissures more than a yard wide appeared along

canals and stream banks. Wide cracks appeared along the banks of the Ashley River and as the banks collapsed, large trees were uprooted and carried into the river along with the sand.

The earthquake damaged or destroyed most of the buildings in the city of Charleston and killed 60 people. Structural damage was reported as far away as central Alabama, Ohio, eastern Kentucky, Virginia, and West Virginia. Shaking was reported as far away as Boston and Chicago.

SAN FRANCISCO, CALIFORNIA (1838)

In late June of 1838 (the exact date is uncertain), a long segment of the San Andreas Fault ruptured, causing intense shaking from Monterey to San Francisco as well as in the East Bay. Hundreds of aftershocks, some of them damaging, continued for three years. The magnitude of the mainshock is estimated at about 7.4 and the visible rupture, 10 to 12 feet wide as described by a local resident, extended 38 miles from near San Francisco to near Santa Clara.

Approximately 50 miles south of Santa Clara in Monterey, the shaking intensity was strong (possibly stronger than during the 1906 San Francisco earthquake), suggesting that the rupture extended farther south to the San Juan Batista area, as it did during the 1906 rupture did. Estimates of the total rupture length range from 60 to 100 miles. Predating the Gold Rush and California's secession to the United States, the Bay Area in 1838 was dotted with a few Spanish missions and was sparsely populated by settlers. There were no reports of casualties from the earthquake, but there were numerous accounts of violent shaking and damage. Eyewitnesses reported that the earth undulated in waves and cracked, trees swayed and snapped, and stream beds were displaced. Crockery and glassware broke, and houses and walls, often constructed of adobe, cracked. A house collapsed in San Jose, and the Mission Dolores in San Francisco was heavily damaged.

NORTHRIDGE, CALIFORNIA (1994)

On January 17, 1994, a magnitude 6.7 earthquake shook the Northridge area of southern California. The earthquake claimed the lives of 60 people, injured over 7,000, and left 20,000 homeless. Throughout the greater Los Angeles area, across several counties, more than 40,000 buildings and structures, including Anaheim Stadium, were damaged.

The earthquake affected several freeways when the columns supporting the overpasses collapsed, causing those portions of the freeway to fall onto the freeway beneath. Overpasses collapsed occurred on the Santa Monica, Simi Valley, and the Golden State freeways, among others.

Most of the buildings that were damaged were multi-story wood frame buildings, especially those with a "soft" ground floor, (e.g., those with parking areas or other large open spaces on the ground floor). Eleven hospitals had to be shut down due to heavy damage, which caused other hospitals to be overburdened with incoming patients injured from the earthquake. School buildings, for which earthquake reinforcement is mandatory, notably survived fairly well. As a result of this event, many insurers stopped offering earthquake insurance, or only offered it at a restricted level. In response, the California Earthquake Authority was created by the California Legislature to make minimal earthquake insurance available on a broad scale.

HAYWARD, CALIFORNIA (1868)

On the morning of October 21, 1868, a 6.8 magnitude earthquake struck the San Francisco Bay Area. It was the strongest in the region since written recordkeeping began in 1776 and was called the "Great San Francisco Earthquake" until the more damaging 1906 quake occurred. A 20-mile segment on the southern end of the Hayward Fault, a right-lateral strike-slip fault, ruptured the surface, roughly from Fremont to San Leandro. The deep rupture beneath the surface likely extended north another 15 miles to the Berkeley area. The average horizontal strike-slip displacement of the fault was around six feet, while the crack that opened at the surface averaged six inches wide. Although the area was sparsely populated at the time, the earthquake remains one of the most destructive in California history, causing damage as far away as Napa to the north and Hollister to the south (some 130 miles apart). The East Bay towns immediately above the fault suffered extensive damage. In Hayward, a town then of about 500 residents, almost every building was severely damaged; most were knocked off their foundations and rendered uninhabitable. Nearby San Leandro and Fremont, north and south of Hayward, experienced slightly milder shaking. Still, many brick, adobe, even some wood-frame structures were severely damaged.

Farther away in the much larger cities of Oakland and San Jose, many chimneys toppled and some brick buildings were damaged. Shaking was intense across the Bay in parts of San Francisco, which suffered an estimated USD 350,000 in property damage (1868 currency)—by far the highest concentration of both exposure and loss. Buildings constructed on reclaimed landfill in the Bay fared especially poorly. In total, 30 people were killed.

According to the USGS's Uniform California Earthquake Rupture Forecast, there is about a 30% probability of a magnitude 6.7 or greater earthquake occurring on the Hayward Fault in the next 30

years, the highest for any single fault in the Bay Area. The expected magnitude is between 6.8 and 7.0, although a 7.2 quake is possible if the rupture extends into the Rodgers Creek Fault, north.

FORT TEJON, CALIFORNIA (1857)

The biggest earthquake in California's historical record occurred on January 9, 1857, at approximately 8 a.m. A continuous segment of the San Andreas Fault from the San Benito county line to the San Bernardino area, measuring over 220 miles, ruptured at the surface, traces of which can still be seen today. The average slip of the right-lateral strike-slip event was 15 feet, and the maximum slip was around 30 feet.

The magnitude of the 1857 earthquake is estimated to be approximately 8.0, but the epicenter is uncertain. The strongest reported shaking was located in Fort Tejon, giving the earthquake its name. However, evidence of foreshocks to the earthquake suggest an epicenter closer to Parkfield, over 60 miles northwest of Fort Tejon. The duration of the event is estimated at one to three minutes, and aftershocks continued to shake the area for over a year.

Fortunately, the large area affected by the quake was very sparsely populated at the time, and there were very few reported deaths. The tremor was felt from Marysville, over 30 miles north of Fort Tejon, to San Diego, about 180 miles south, to Las Vegas, 220 miles east. Fort Tejon experienced the most severe damage, with many adobe buildings collapsed or rendered uninhabitable. In Ventura, the mission was badly damaged, and a house collapsed in Gorman. In Los Angeles, damage was limited to superficial cracks in walls and buildings. Evidence of ground fissures, sandblows, and liquefaction was reported over a wide area. Several streams and springs were reported to have reversed their flow, and many rivers overflowed their banks.

One issue of concern for a recurrence of an 1857-type event is the performance of modern high-rise buildings in Los Angeles. Even though Los Angeles is at a significant distance from the fault, tall structures are particularly susceptible to long-period ground motion generated by large earthquakes. Additionally, the area closer to the fault that will likely experience strong ground motion is much more highly populated than in 1857.

LOMA PRIETA, CALIFORNIA (1989)

On October 17, 1989, a magnitude 6.9 earthquake struck Nisene Marks State Park in the Santa Cruz Mountains, rupturing a section of the San Andreas Fault about 62 miles south of San Francisco. The earthquake was the largest to occur along the San Andreas Fault since the 1906 San Francisco earthquake. It caused the deaths of 63 people and injured nearly 4,000 others. Damage occurred throughout the greater San Francisco-Oakland area. In Monterey Bay, liquefaction broke underground pipes and caused significant and widespread damage to buildings, bridges, highways, and port facilities. Liquefaction occurred in San Francisco's Marina District where the soil conditions (loose sandy fills above deep soil deposits) amplified the ground shaking. In San Francisco and Oakland, reinforced concrete viaducts collapsed, resulting in heavy damage to U.S Highway 101 and Interstate 280 in San Francisco; and to Interstate 880 in Oakland. Traffic was also disrupted for many weeks due to landslides near the earthquake's epicenter in the Santa Cruz Mountains.

The earthquake is sometimes referred to as the "World Series" earthquake, since it occurred at 5:04 p.m. during a World Series game taking place in San Francisco, and consequently became the first earthquake to be broadcast live on television. It is believed that rush hour traffic was much lighter than usual that day due to people leaving work early or staying in town for the game (both teams were from the area), and that the death toll might have been much higher otherwise.

LONG BEACH, CALIFORNIA (1933)

On the evening of March 10, 1933 a moderate quake occurred about one mile offshore of Huntington Beach in Southern California. The magnitude 6.3 event ruptured a 15-mile segment of the Newport-Inglewood Fault, causing approximately 10 to 15 seconds of ground shaking. The quake, the first significant one in Southern California since rapid settlement began, caused widespread damage estimated at USD 45 million (1933 currency) and 120 fatalities— the second highest human toll in California's recorded earthquake history.

The communities of Long Beach and Compton sustained the most severe damage as a result of poor construction and unfavorable geological conditions (many coastal areas were built over landfill or deep alluvial deposits). Chimneys toppled, and walls, parapets, cornices, and building ornaments fell onto the sidewalks below. Roads and bridges were damaged, and several gas lines ruptured. The most catastrophic damage occurred to unreinforced masonry buildings, which collapsed in large numbers.

The lasting legacy of the Long Beach earthquake was the passing of the Field Act just one month later. Because so many school buildings collapsed during the quake (fortunately, after school hours) the California State Legislature mandated that all schools in California be earthquake resistant. The Long Beach earthquake also brought about the end of unreinforced masonry construction in California.

CALAVERAS, CALIFORNIA (1911)

On July 1, 1911, a magnitude 6.5 earthquake ruptured on the Calaveras Fault in the San Francisco Bay Area. Called the Morgan Hill earthquake based on its epicentral location, the quake shook the Santa Clara Valley region and caused substantial damage in towns like Morgan Hill, Gilroy, Los Gatos, San Jose, and Santa Clara. Achieving a maximum Modified Mercalli Intensity (MMI) of VIII, the quake was felt as far away as Carson City in Nevada, and aftershocks were felt for several months. No surface fault ruptures were observed.

The earthquake knocked down chimneys and water tanks and caused masonry walls to crack. Minor building damage was reported as far away as San Francisco, some 60 miles away. This quake is notable because it occurred surprisingly soon after the 1906 San Francisco earthquake, which is believed to have relieved stress on major parallel faults of the San Andreas Fault, one of which is the Calaveras Fault. The 1911 event is the only one of magnitude >6 to occur in the Bay Area in the 75 years after 1906. A magnitude 6.1 earthquake occurred on an overlapping segment of the Calaveras Fault in 1984.

ABOUT AIR WORLDWIDE

AIR Worldwide (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 90 countries. More than 400 insurance, reinsurance, financial, corporate, and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, detailed site-specific wind and seismic engineering analyses, agricultural risk management, and property replacement-cost valuation. AIR is a member of the Verisk Insurance Solutions group at Verisk Analytics (Nasdaq:VRSK) and is headquartered in Boston with additional offices in North America, Europe, and Asia. For more information, please visit **www.air-worldwide.com**.