

**Annex 1**  
**Examples of Effects of Earthquakes**  
**on Pipeline Systems\***  
**(1969 - 1997)**

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\* Compiled by José Grases, Venezuela, 1997.

Place and Date	Intensity(M) Magnitude (MMI)	Reported Damage
<b>Santa Rosa, California, U.S.A. 1 October 1969</b>	5.7 (M)	Minor damage to storage tanks, pumping stations, and dams. Significant damage to distribution pipes.
<b>San Fernando, California, U.S.A. 9 February 1971</b>	6.6 (M)/ VIII–IX (MMI)	Damage to hydraulic structures were major impact of San Fernando earthquake in terms of supply sources and pipes. Pronounced fluctuations in water levels in wells occurred. The most important effects on the drinking water system occurred in the dams, reservoirs, water tanks, main tanks, pipes, and sewers. Van Norman Lakes and another series of reservoirs of the San Fernando Valley suffered severe damage. The lakes formed part of the Los Angeles aqueduct. The upper part of the Van Norman Lake dam fractured and the crest sank. One of the intakes was destroyed.
<b>Managua, Nicaragua. 23 December 1972</b>	6.25 (M) V–IX	The distribution system consisted of 16-inch cast iron pipes. Smaller pipes were 4-inch PVC. On 30 December there was pressurized water in the mains in areas beneath the city. Approximately 100 breaks were identified in the conduits. The eastern section of the city did not have water service on that date. The roofs of pumping stations collapsed. There was damage in the tank owing to differential settling and to breaks in the joints attached in the floor. The tank had to be emptied for inspection and later repair.
<b>Guatemala 4 February 1976</b>	7.5 (M)	Earthquake associated with the northeast edge of the Caribbean plate. Rupture of the Motagua fault at a length of some 250 km with an average lateral displacement of 100 cm. Damage occurred in numerous installations, although damage to pipes was not reported.
<b>Cotabato, Mindinao Island, Philippines. 17 August 1976</b>	7.9 (M)	The main supply to the city of Catabato was through an intake from the Dimapato River, 16 km away, with an elevation of 116 m, which remained in good condition. The pipelines consisted of 20 cm pipes for a total of 5.5 km followed by 26 cm pipes for 10.5 km. The 26 cm pipe broke when a bridge cover collapsed on top of it.

<p><b>San Juan and Mendoza, Argentina.</b> <b>23 November 1977</b></p>	<p>7.4 (M)</p>	<p>The earthquake caused damages of varying importance, the most serious was in the Cauçete, San Martín, and 25 de Mayo Departments.</p> <p>The water distribution system of the city of Cauçete had breaks along its entire length (approx. 40 km); this was aggravated by the high water table level and liquefaction.</p>
<p><b>Mexico.</b> <b>19 September 1985</b></p>	<p>8.1 (M) VIII–IX (MMI)</p>	<p>Mexico City operated and maintained some 72,000 km of pipes. Aquifers provided some 80% of the water supply, distributed to the city through aqueducts from the north, west, and south. The pipes were from 5 cm to 305 cm in diameter. Significantly, underground pipes suffered more damage than surface pipes.</p> <p>The majority of large diameter pipes were broken because of rigid joints in the system, such as T-connectors, cross connections, valves, and pipes connected to structures.</p>
<p><b>San Salvador, El Salvador.</b> <b>10 September 1986</b></p>	<p>5.4 (M)</p>	<p>Some 2,400 breaks were reported as a result of the earthquake, primarily in the drinking water supply system. The detection of the ruptures was fairly rapid because of reduced pressure. The length of the damaged pipeline was an estimated 80 km, 20% of the line's total length. An estimated 65 km of the sewerage system was damaged (22% of the total).</p> <p>San Salvador is located in a zone of volcanic ash deposits. The ruptures were attributed to differential settling and to deformations imposed by seismic waves. Failures occurred in the drinking water network, including in flexible steel piping.</p>
<p><b>Napo Province, Ecuador.</b> <b>5 March 1987</b></p>	<p>6.8 (M)</p>	<p>This earthquake in northeastern Ecuador, was preceded three hours earlier by a 6.1 magnitude earthquake with its epicenter near the Reventador volcano, in an area of complex geologic faulting. Avalanches and mudslides, owing to saturation from the rains prior to the earthquake, affected some 40 km of the trans-Ecuador oil pipeline. This conduit came from the deposits in Agrio Lake, particularly between Salado River and the San Rafael Falls. Some 17 km of oil pipeline disappeared as a result of this earthquake, and two bridges collapsed because of the large slides and/or backwater effects in the area.</p>

<p><b>Spitak and Leninakan, Armenia.</b> <b>7 December 1988</b></p>	<p>6.8 (M) VIII (MMI)</p>	<p>The water source for Lininakan was located some 32 km north of the city and transported to the city through three pipes. Two of the sources originated in the mountains and were not treated before being distributed to the city. Pipes that were 500–600 mm in diameter, one of steel and the other of a mixture of steel and cast iron, transported water for industrial use. The three pipes passed through a slope some 7 km north of the city. Approximately 1 km of pipe was buried in this slope. A rock slide some 4.5 km wide covered and damaged pipes located along a river.</p>
<p><b>Loma Prieta, California, U.S.A.</b> <b>17 October 1989</b></p>	<p>7.1 (M) VI–VIII (MM)</p>	<p>Interruptions in the electrical power system affected treatment plants and pumping stations. Portable electrical plants were used in operation centers and pumping stations. The water mains in the area of the canals of the Calaveras fault, constructed in the 1950s, 4 and 6 inches thick, and of cast iron with bell and spigot connections suffered significant damage. There were many breaks in residential connections. Many pipes located in uncompacted fill and in alluvial soils were damaged. Damage to pipes in compacted soils was less frequent.</p>
<p><b>Limón, Costa Rica.</b> <b>22 April 1991</b></p>	<p>7.4 (M) VIII (MMI)</p>	<p>Serious damage occurred in the Banano River basin, through surface soil slides, causing turbidity of 100,000 UNT. In the drinking water pipe system, four types of failure were observed: cracks in intermediate segments in the body of the pipe; in joints between two segments of pipe; in the joints owing to separation by tension; and in the joints from "telescopic" compression.</p>
<p><b>Erzincan, Turkey.</b> <b>13 March 1992</b></p>	<p>6.8 (M) VIII (MMI)</p>	<p>There were approximately 250 km of distribution piping in the city. Asbestos-cement pipes of 80 cm were damaged in certain places. The distribution pipes were primarily of 60 cm cast iron; there were also 8 to 12.5 cm PVC pipes and 20 to 25 cm asbestos-cement pipes. Damage was reported in settling tanks and in the pumping stations, but did not affect their operation. A simple break was found in the connection of an 80 cm steel transmission pipe. In the water mains 25 ruptures were reported. Breaks were found in the joints of the PVC and asbestos-cement pipes.</p>

<p><b>Northridge, Los Angeles, California, U.S.A.</b> <b>17 January 1994</b></p>	<p>6.7 (M)</p>	<p>Los Angeles water was provided by two aqueducts from a valley. Aqueduct no. 1 suffered damages in four places, but it was operated using low levels of pressure for four weeks after the earthquake while repairs were made in Aqueduct no. 2. There were breaks in concrete pipes of 54–77, 78–85, and 120 inches.</p> <p>The tunnels were inspected and did not have major damage with the exception of some small breaks around Terminal Hill. These cracks were sealed with urethane resin.</p> <p>To the north of Terminal Hill a 77-inch steel pipe suffered damage through compression.</p> <p>Simi Valley, 20 km west of the epicenter, receives water from the Jensen treatment plant. Water is diverted to two large storage tanks east of Simi Valley. The tunnel was not damaged, but pipes of 78 and 51 inches split. The main damages in the distribution pipes occurred because of vibrations and intense movements. Pipes with the most damage were those of iron with rigid joints and signs of corrosion.</p> <p>In the area of Newhall, six of the seven tanks inspected had to be taken out of service because of broken and damaged valves. In the area of Valencia, one of the tanks suffered a total collapse as a result of tearing of the material in the bottom of the tank. Spillage from this tank damaged the adjacent tank.</p>
<p><b>Kobe, Japan.</b> <b>17 January 1995</b></p>	<p>7.2 (M) IX-X (MMI)</p>	<p>Approximately 75% of the drinking water in Kobe was supplied from the Yodo River through two mains which were out of service after the earthquake, leaving more the 1.5 million inhabitants without water supplies. Twenty-three breaks occurred in the 1.25 m water main, apparently of concrete. The underground water pipes suffered severe damage. A pump station and treatment plant also failed.</p>
<p><b>Cariaco, Venezuela.</b> <b>9 July 1997</b></p>	<p>6.9 (M)</p>	<p>An earthquake occurring along the southeast border of the Caribbean Plate caused a rupture along some 50 km of the El Pilar fault with lateral displacement to the right of 40 cm. Buried pipe and waste water treatment installations suffered damage.</p> <p>A drinking water supply pipe that crossed the fault at an angle of 30° to 35°, 5 km from Cariaco, failed as a result of bending compression forces.</p>