# Fire Protection Failures During the Whittier, California and New Zealand Earthquakes

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## INTRODUCTION

This report examines two instances of seismically induced failures in fire protection systems, one during the March 1987 New Zealand Earthquake and the other during the October 1987 Whittier, California Earthquake. While the majority of fire protection systems affected by these two events performed well, the failures discussed in this paper emphasize the need for properly designed and detailed fire protection systems. Both facilities where these failures occurred were relatively fortunate in that few electromechanical equipment items were located in areas where the fire protection system failed; however, water damage was extensive and the cleanup costly.

### March 1987 New Zealand Earthquake

On March 2, 1987 a Richter magnitude 6.3 (M6.3) earthquake struck the eastern Bay of Plenty region of North Island, New Zealand. The main event was centered about 8 km northwest of the town of Edgecumbe, and produced Peak Ground Acceleration (PGA) values estimated from 0.30g to 1.0g. An average horizontal PGA of 0.26g was recorded approximately 11 km south of the main surface rupture, with strong motion accelerations on the order of 0.10g and greater lasting approximately 10 seconds. In addition, a M5.2 foreshock occurred about 7 minutes before the main event, and four aftershocks in the M5.0 to M5.5 range occurred in the subsequent seven hours. While the magnitude of the earthquake was moderate, local soil conditions and a shallow focal depth (about 12 km) contributed to very damaging ground motion.

The Caxton Paper Mill is a large forest products facility located about 20 km from the epicenter of the earthquake. This area is estimated by the New Zealand Department of Scientific and Industrial Research (DSIR) to have experienced a level of ground shaking equivalent to Modified Mercalli Intensity VIII. A map of Modified Mercalli intensities for the affected area is shown in Figure 2 (DSIR, 1987). The primary building structure at Caxton consists of an assemblage of three paper machine buildings, a large warehouse, and several smaller structures. The buildings housing the three paper machines are somewhat interconnected structurally and similar in design, being steel high bays atop basements formed of reinforced concrete shear walls. Paper Machine #1 (PM1) Building utilizes steel roof trusses and columns as the primary structural members. Roofing and siding consists of timber sheathing supported directly by the steel framework. The building is 90 by 12 m in plan and appears to have no true lateral load-resisting system of its own, relying instead on attached buildings for lateral stability. Paper Machine #2 (PM2) Building consists of a steel-frame high bay with corrugated metal siding and roof. Lateral support is provided by diagonal steel bracing. The building measures 20 m wide by 100 m long, and about 10 m high. Paper Machine #3 (PM3) Building measures 30 x 140 m, and is similar in construction to PM2 Building with the exception of non-load-bearing masonry walls rather than metal siding. The products warehouse is a large gabled frame structure with masonry infill shear walls and a roof of corrugated asbestos cement panels. Building dimensions are approximately 30 x 300 m.

The fire protection system used at Caxton is wet, and therefore solely dependent on piping pressure integrity and the fusible link sprinkler heads to control spray activation. Threaded cast steel pipe is used through most of the buildings, though problems with corrosion have led to the gradual replacement of cast steel with stainless steel. Typical system configuration for the buildings utilizes a laterally braced riser up to the level of the building eave, with feed and cross mains supported directly on the lower chord of roof trusses or rod hung from them. Branch lines are routed similarly.

System Performance. A great many failures in the fire protection system occurred as a result of the earthquake. Factors contributing to failure appear to have been the inertial loading of flexible systems, differential displacement of rigidly supported systems, and corrosion of piping and threaded fittings. Corrosion of steel lines was visible in some locations, and was probably a significant contributor to poor system performance. By the time the reconnaissance team had reached Caxton, damage to the fire protection piping had been repaired, and exact causes of failure were difficult to determine. Piping configurations were observed by the team, but actual failure locations were reported by plant personnel. The following list summarizes five typical examples of failure at Caxton.

- PM1 Building. A 10-cm diameter galvanized line routed across the bottom chord of the building's roof trusses failed at a threaded coupling. The line appeared to have no lateral or longitudinal bracing. As configured, the line would behave in much the same way as a rod-hung pipe. The damping effect of friction between the pipe and truss members would tend to improve the system response as compared to rod hangers, but the lack of a pendulum restoring force would tend to offset this effect.

- PM3 Building. Several rod hangers supporting a small diameter unbraced branch line failed. Although the system did not collapse completely, breaks occurred at threaded connections and resulted in water spray. While it is not uncommon for branch lines to be unbraced, the added effect of the unbraced feed and cross mains may have contributed to the failure.

- Warehouse. An 8-cm diameter riser rigidly attached to a block wall broke apart at threaded couplings in two locations. One failure occurred near the bottom of the wall where the line entered the building, and was probably caused by insufficient flexibility to accommodate differential movement between the buried piping and wall. The second failure occurred at a 90° elbow at the top of the riser. At this hard point in the system the connection failed, apparently from the seismically induced loads imposed by the unbraced feed main and branch lines.

- Warehouse. Bolts sheared off a flanged connection on a 18-cm diameter line supported on the lower chords of the steel roof trusses. Unlike many other lines routed similarly, this line was restrained in the lateral direction, and was loaded by unbraced sections of the system.

- Warehouse. A 20-cm diameter line in a workshop adjacent to the warehouse pulled apart by the failure of bolts at a flanged connection. The line was hung on rod hangers from the bottom chord of roof trusses. No lateral restraint was observable.

Summary. Differential displacement, inertial loading, and corrosion all contributed to fire protection piping failures at the Caxton Paper Mill. The most interesting aspect of the failures is that both restrained and unrestrained medium sized (8- to 20-cm) lines were damaged. High accelerations and displacements at the eave level of the high bays, and corrosion of threaded joints contributed to the poor performance of the flexible systems. Failures in the braced system were probably caused by the concentration of seismically induced inertial forces at locations of rigid support. It is likely that too few lateral restraints were utilized in these piping runs.

## October 1987 Whittier Earthquake

On October 1, 1987 a magnitude 5.9 (M5.9) earthquake occurred near the center of the greater Los Angeles area. A magnitude 5.3 aftershock occurred about 3 days after the main event, causing additional damage. The earthquake was the most damaging event in the Los Angeles area since the magnitude 6.6 San Fernando Earthquake in 1971; a Modified Mercalli Intensity map of the affected area is reproduced in Figure 3 (Leyendecker, 1988). Ground motion recordings indicate a peak horizontal ground acceleration of 0.40g to 0.50g.

The California Federal (CalFed) Data Processing Center is located about 2 km south of the epicenter in the town of Rosemead. Peak acceleration in the area is estimated at about 0.40g, but the duration of strong motion was limited to about 3 seconds. The United States Geologic Survey (USGS) assigned an Intensity VII to the Rosemead area, as shown in Figure 3. However, based on damage to the CalFed facility and other structures nearby, an intensity of VIII is probably more appropriate. The building is a four-story steel braced-frame structure containing floors of steel deck with concrete topping and precast concrete exterior panels. The structure was completed in 1982 and apparently designed to the 1979 *Uniform Building Code*. The ground and second floors contain large computer facilities, with offices located on the upper floors.

Water damage to the interior of the CalFed facility was one of the major causes of damage. The CalFed fire protection system is a pre-action system, requiring two conditions to actuate and release water. Initially, a detection signal causes a deluge valve to open and flood the system with water. This signal can originate from loss of air pressure in the piping system, loss of off-site power, etc. Secondly, the piping pressure boundary must be breached, normally through the activation of fusible link sprinkler heads (line breaks in this case). Each floor in the CalFed facility has its own separate pre-action system fed from one vertical riser. The fire protection system consists of a single deluge valve which feeds 6-in (18-cm) diameter and 4-in (10-cm) diameter main headers. 1-1/2-in (4-cm) diameter pipes 3 to 4 ft (about 1 m) long vertically connect to 2-in (5-cm) diameter branch lines. 1-1/2-in diameter drops connect sprinkler heads to the branch lines. The piping is typical cast steel Sch 40 pipe with cast-iron threaded fittings used on the branch lines. The piping system is supported with standard National Fire Protection Association (NFPA) type rod hangers, with lateral sway bracing on the 4- and 6-in diameter main headers. Lateral bracing is typically spaced at 40-ft (12-m) centers. A sketch of a typical piping configuration is shown in Figure 3.

The sequence of events which led to the release of fire water follows. Loss of off-site power caused the deluge valves to actuate, flooding the piping system. Breaks in the piping lines at several locations, including at several sprinkler heads, caused the water to leak and spray. These water releases occurred on the second and fourth floors only, due to breaks and loss of pressure in the lines on these floors. As a result of these failures, large amount of water poured into the upper floors of the building immediately following the main shock. Water collected in cable troughs recessed in the floors and flowed through penetrations to the floors below. The computer center escaped serious damage because it is served by a halon system. However, water from the upper floors dripped into the damaged ceiling above the computer area. Plastic was used to protect the equipment from water damage. The piping system failures are summarized below.

- Several failures of 1-1/2-in diameter Sch 40 riser nipples occurred near to where they connected to the main headers. "T" couplings connecting the tops of the riser nipples to the branch lines also failed. The failures occurred where the riser nipples connected the branch lines to the main headers near the midpoint between lateral bracing of the main lines. Although the mains were laterally braced at 40-ft spacings, deflections near midspan were probably substantial.

- A sprinkler head sheared off when the piping system displaced and the branch line impacted an adjacent wall. The wall was an interior partition wall and was not laterally braced at the top.

- Several sprinkler heads penetrating the ceiling hardboard sheared off. The attached branch lines were connected to a long section of unbraced main header. Displacement of the header caused the branch lines and sprinkler heads to act as inadvertent support points due to the stiff restraint provided by the heads penetrating the ceiling.

- Several branch lines also broke where large HVAC ducting displaced and impacted the piping, shearing the lines at the threaded connections. The piping in these areas were routed down, underneath, and up the other side of the HVAC duct. The HVAC duct was supported by vertical straps with no lateral bracing.

- One piping sway brace was also damaged. An unanchored electrical panel rocked during the earthquake, pulling attached conduit with it. The conduit impacted and damaged the sway brace. The conduit also loaded the pipe sufficiently to pull several pipe hangers out of the ceiling. The piping itself did not collapse.

- Locations were found where piping had ovaled and crushed dry wall through which it penetrated. Several branch lines failed due to this occurrence.

Discussion. The fire protection system at the CalFed facility appears to have been designed and detailed according to NFPA guidelines. Risers and mains were braced at the recommended spacings, flexible couplings were used where appropriate, and proper hardware was installed. Failures at CalFed seem to be related to two separate phenomena. Interaction failures occurred where flexibly supported sprinkler lines impacted rigid items, or other items impacted the piping, both well known and predictable failure modes. The other failures, however, all seem to result from large lateral deflections near the midpoint of braced fire protection headers, causing the branch lines to act as inadvertent support points where the sprinkler heads penetrate the stiff ceilings. The majority of failures seen at CalFed are related to the headers' midpoint deflection driving the rest of the system. Branch lines and sprinkler heads, where they were restrained at relatively stiff penetrations, etc., then became supports for the system and failed under the imposed loading. Although the building used a dry system, the deluge valve activated and flooded the piping, spraying water wherever the piping had failed.

## CONCLUSIONS

Failures of fire protection systems could have serious consequences in structures containing spray-sensitive equipment. The performance of fire protection piping at the Caxton Paper Mill and at the CalFed Data Processing Center illustrates the need to properly design and detail fire protection piping. Guidelines such as those suggested in NFPA 13, which have provisions specifically for the seismic protection of fire protection piping, have resulted in effective system designs.

However, the failures at both CalFed and Caxton also emphasize the need to evaluate piping systems individually, and not rely solely on general guidelines. These failures demonstrate that factors not addressed in codes such as NFPA 13 can limit the performance of piping systems. Hard spots in flexible systems, interference, and impact hazards are not explicitly covered by these codes, yet were major contributors to poor system performance at Caxton and CalFed and need to be accounted for in the design and analysis of fire protection systems.

## REFERENCES

Leyendecker, E. V. et al. February 1988. "Early Results of Isoseismal Studies and Damage Surveys." *Earthquake Spectra*. Vol. 4, No. 1. Earthquake Engineering Research Institute.

New Zealand Department of Scientific and Industrial Research (DSIR), Geophysics Division. n.d. Map of Modified Mercalli Intensity for the March 2, 1987 Earthquake.

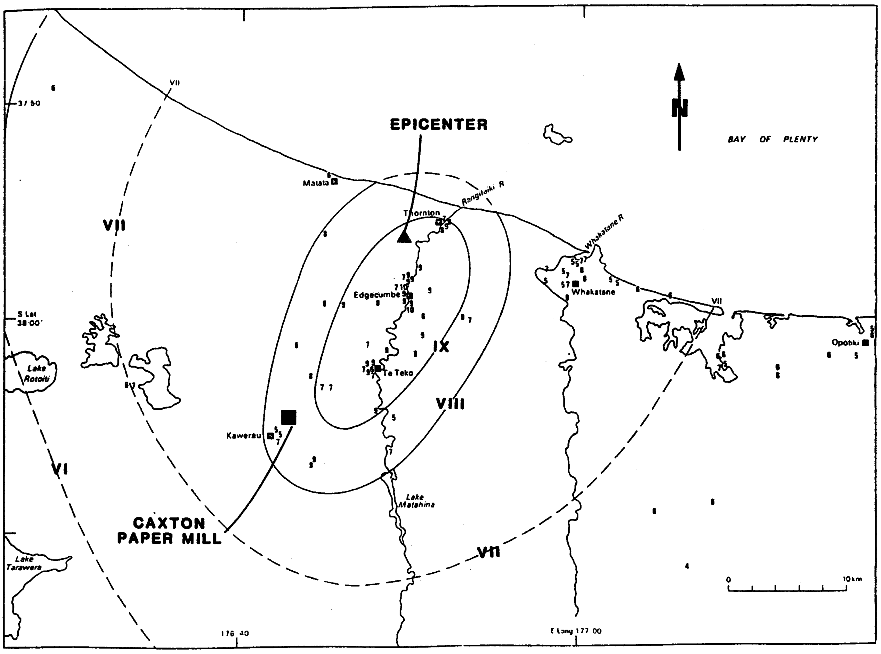

Figure 1: The map of Modified Mercalli Intensities published by DSIR rates the area around the Caxton Paper Mill as Intensity VIII.

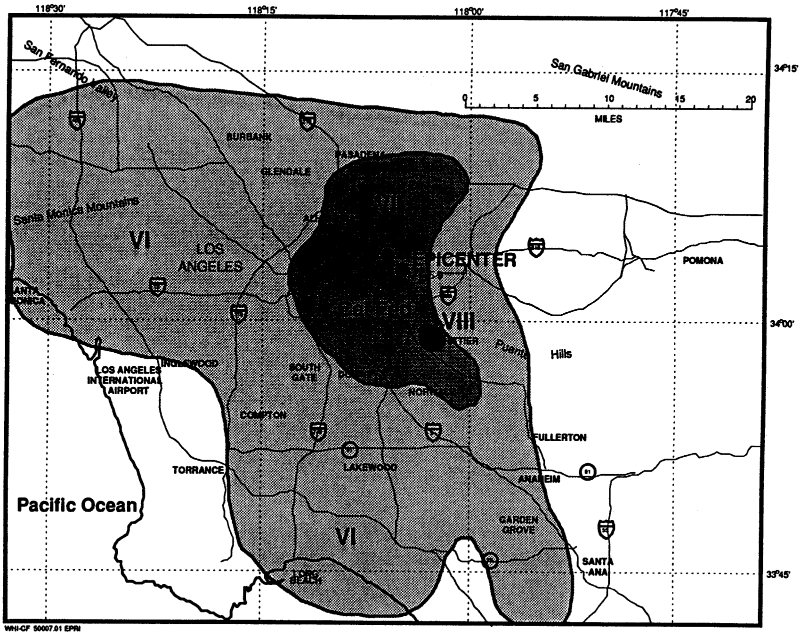

Figure 2: A map of Modified Mercalli Intensity for the Los Angeles area, illustrating the average effects by area of the October 1 earthquake, was developed by the United States Geological survey (USGS). While the area near the CalFed facility was rated Intensity VII, level VIII is probably more appropriate based on observed damage.

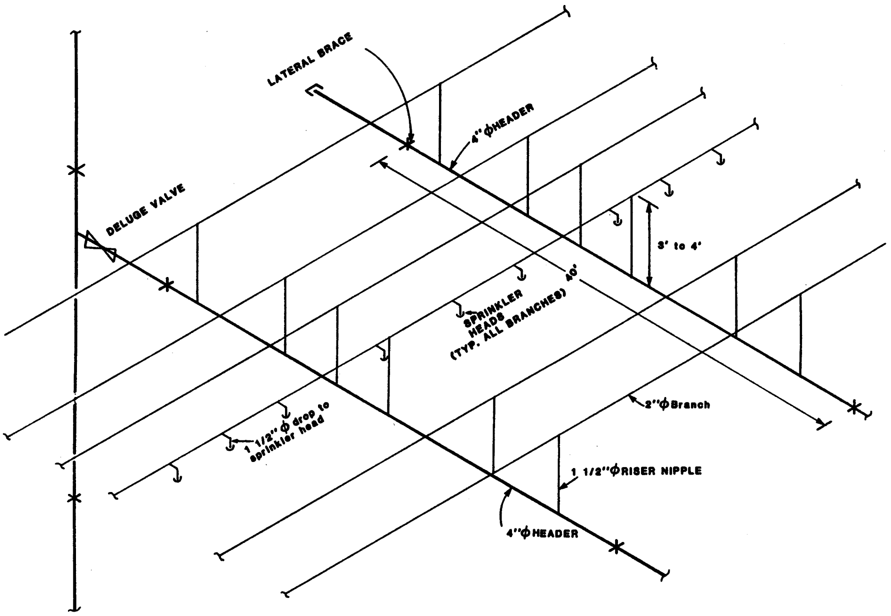

Figure 3: Typical fire protection piping configuration at CalFed.