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INFORMAL REPORT
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Performance of Fire Protection Systems Under Post Earthquake Conditions

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I.

ABSTRACT

Guidelines of the U.S. Nuclear Regulatory Commission stipulate that fire protection piping in nuclear safety related areas be designed and constructed so that failure thereof will not reduce the functioning of systems required for safe shutdown of the reactor in the event of a Safe Shutdown Earthquake (SSE) incident. Because of the need to install fire protection systems in safety related areas and because of the limited experience with such systems in nuclear power plants, a study was authorized by Division of Systems Safety, NRC, to investigate and present information on the performance of fire suppression and fire detection systems under post-earthquake conditions. NRC's main interest was indicated as being in those parameters which involve system hardware reliability, post-earthquake functional capability, and major types of failures which have been reported in recent earthquakes.

Numerous organizations and individuals who might have detailed, specific information on earthquake damage to fire protection systems and on special design recommendations were contacted during the course of the study. Literature searches were conducted, and a considerable amount of descriptive material, data, and design guidelines were collected and analyzed for applicability to this subject. Case histories containing descriptions of damage sustained by fire protection systems as a result of earthquakes were summarized for inclusion in the report on the study. Earthquakes included were those in San Francisco (March 1957), Alaska (March 1964), San Fernando (February 1971), and Point Mugu (February 1973). Damages were tabulated and analyzed.

As a result of this study, it was concluded that automatic sprinkler systems, installed in conformity with nationality recognized standards, which include special hanger and lateral bracing provisions for earthquake prone regions, will not suffer significant impairments in an earthquake, unless the piping is broken through major structural collapse or by falling walls. Some modifications to current rules are presented to further reduce potential loss of operating capabilities following an earthquake.

No special precautions are taken at the present time to prevent impairment of underground piping as a result of an earthquake. Fire mains installed in conformity with nationally accepted standards appear to withstand earthquake forces reasonably well, but with strong ground motions, breakage of cast iron and asbestos cement pipe and the pulling apart of slip joints can be anticipated. Adequate looping, the provision of sufficient means to isolate damaged sections of piping, and the provision of connections for temporary water supplies will reduce the probability of major impairments.

There was a general lack of documented case histories on the damage to fire detection and alarm systems due to earthquakes. This may be due to their satisfactory performance or to failure to document impairments at a time when other damage is of much greater and immediate importance, or both. However, the evidence suggests that impairments, if any, are minor if no severe structural damage occurs. "Seismic loops" have been suggested as a means of preventing failure of wiring where it crosses building joints where large, differential movement can be anticipated. Temporary impairments of fire alarm service immediately following earthquakes, due to actuation of many automatic transmitters simultaneously as a result of ground motion, can be expected and cannot reasonably be prevented.

No references were found as to the performance of special fire extinguishing systems in earthquakes. There are relatively few such systems (carbon dioxide, Halon, etc.), and while breakage or impairment may occur during an earthquake, the agent probably would not be discharged. Damage is likely to be minor, and restoration fairly simple. Standards covering these systems have no seismic provisions.

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II.

INTRODUCTION

This study was principally conducted by Mr. B.M. Cohen, senior vice president of Gage-Babcock and Associates, Inc., a consultant to Brookhaven National Laboratory under the direction of Mr. Robert E. Hall.

Numerous organizations and individuals who might have detailed, specific information on earthquake damage to fire protection systems and on special design recommendations were contacted. Literature searches were conducted, and a considerable amount of descriptive material, data, and design guidelines were collected and analyzed for applicability to this subject.

The organizations which were contacted during the course of this study included:

Insurance Services Offices in San Francisco and Los Angeles (formerly Pacific Fire Rating Bureau)

Factory Mutual System, Los Angeles and Norwood, Mass.

Industrial Risk Insurers (Factory Insurance Association), Los Angeles and Hartford, Conn.

California State Fire Marshal, Schoolhouse Section

National Automatic Sprinkler & Fire Control Association

Cast Iron Pipe Research Association, Sacramento

Defense Civil Preparedness Agency, Washington

National Science Foundation, Washington

Introduction

Publications of the following organizations were reviewed for applicability to seismic design requirements or guidelines for fire protection systems:

National Fire Protection Association (Pamphlets 10, 11, 12, 12A, 13, 14, 15, 17, 20, 22, 24, 70, 72D, 73E; Fire Protection Handbook)

Factory Mutual System (Loss Prevention Data Sheets, Handbook of Industrial Loss Prevention)

International Conference of Building Officials (Uniform Building Code, Uniform Plumbing Code, Uniform Fire Code)

American Insurance Association (National Building Code)

Building Officials & Code Administrators, Intl. (Basic Building Code)

Department of Defense (Seismic Design for Buildings)

Sheet Metal & Air Conditioning Contractors National Association (SMACNA) (Guidelines for Seismic Restraints of Mechanical Systems)

AIA Research Corporation (American Institute of Architects) (Seismic Design for Police & Fire Stations)

Applied Technology Council (Seismic Design Provisions for Buildings - 1976 Draft)

Veterans Administration (Earthquake-resistant design of nonstructural building elements)

In addition to the earthquake incident reports quoted in this report, a Pacific Fire Rating Bureau preliminary report on the Chilean Earthquakes (1960) and American Iron & Steel Institute reports on the earthquakes in Yugoslavia (1963) and Venezuela (1967) were reviewed for information pertinent to this study.

III.

DISCUSSION OF PROBLEM

Considerable attention has been directed in the design of nuclear power plants to prevent damage as a result of an earthquake which would jeopardize the safety of the facility. Even though present NRC fire protection guidelines do not classify the fire protection system as seismic Category I, the guidelines* functionally require that hose standpipes and hose connections which serve areas containing equipment required for safe plant shutdown should be capable of supplying water following a Safe Shutdown Earthquake (SSE). Further, NRC requires, similar to other non-seismic I systems in safety related areas, that the fire protection system should be designed and constructed so that an SSE will not reduce the functioning of other safety related systems in that area due to failure of the fire protection system.

At the present time, the numbers and types of fire suppression and detection systems in nuclear plants are being greatly expanded. Because of the limited experience to date, this report provides case history information and conclusions relative to performance of fire suppression and fire detection systems installed in commercial or public facilities under actual post-earthquake conditions.

A. RESPONSE OF NONSTRUCTURAL COMPONENTS TO EARTHQUAKES [1]

Building code requirements tend to deal with the structural integrity of a building. Little attention is given to the performance of nonstructural components during an earthquake, but with much improved structural design for seismic stability, building collapse has become less prevalent, and this in turn has made nonstructural elements more vulnerable to damage and a greater factor in life safety.

*These guidelines apply to nuclear plant construction permit application docketed after July 1, 1976. Older plants are considered on a case by case basis.

Discussion

Severe earthquake damage does not necessarily imply total destruction of the structural system. Damages suffered may amount to as much as 40% of the replacement value even though the structure remains standing. Such buildings may not be technically destroyed in the sense of structural collapse, but they are functionally inoperative due to damage to architectural components and disruption of services and utilities.

Earthquake induced ground failures in the form of landslides, settlement and liquification are particularly damaging to building support systems such as water lines, sewers, gas mains, and communication lines. Loss of these systems after an earthquake has serious effects on both health and life safety (causing fires and reducing the ability to fight them, for instance).

Nonstructural components necessarily must be properly integrated with or effectively isolated from the basic structural frame if excessive damage to the building is to be avoided. The horizontal displacement of basic building elements is usually most critical to nonstructural components. All floors do not drift at the same rate or time, and this action causes a horizontal displacement between floors; floors may move in opposite directions at the same time. This differential movement affects utility lines which run vertically through the building and can cause their failure even when little structural damage occurs.

The interaction between nonstructural components tends to be overlooked. Classic examples of failure in this include the tearing off of automatic sprinkler heads (which are rigidly fastened to the piping) where they pass through a non-laterally braced suspended ceiling, and the collapse of partitions which rely for lateral support on suspended ceilings, which collapse during the earthquake.

B. APPLICABILITY TO NUCLEAR POWER PLANTS

Industrial plants and large commercial establishments, which are the principal users of automatic sprinkler systems, tend to be relatively light construction which contrasts sharply with the heavy, reinforced concrete construction which predominates in the nuclear safety-related portions of nuclear power plants. Despite the light construction, installed sprinkler systems

have sustained very little damage in recent earthquakes, unless major damage occurred to the building, and the less flexible construction employed at the power plants should provide an increased margin of safety. There is no actual experience with sprinkler systems in power plants during earthquakes.

IV.

CASE HISTORIES

A. SAN FRANCISCO EARTHQUAKE, MARCH 1957[2]

The San Francisco earthquake of March 22, 1957 was a minor one in an area long known to be seismically active. Nevertheless, it was the strongest and most damaging shock San Franciscans have felt since the great earthquake of April 18, 1906. The epicenter was at the San Andreas fault southwest of San Francisco, at the Pacific Ocean. Principal building damage was to frame houses in the Westlake Palisades tract west of Daly City. Throughout San Francisco and the area adjacent to the south the prevailing maximum intensity based on criteria of the Modified Mercalli scale was 6. That is, the general pattern of effects included cracked plaster, broken dishes, fallen knickknacks, and shifted furniture.

Underground water lines were slightly damaged in the housing development near the epicenter, where one 6-in. transite line and two 2 in. galvanized lines broke. One of Daly City's aboveground reservoirs received a minor leak. In San Francisco, several leaks were reported in corrosion-weakened pipes, and a 12-in. pipe was severed by ground settlement. Similar minor damage was reported by other water utilities. The electric distribution system of the Pacific Gas & Electric Company suffered practically no damage, and no damage to telephone equipment occurred.

The most seriously damaged sprinkler piping was in an old two-story wood frame building located on filled ground in San Francisco. Actual damage was the cracking of the feed main on the second story where it rises and passes through the second floor. The sprinkler equipment did not conform to accepted earthquake-resistant construction practices.

One sprinkler system pipe leak was reported in South San Francisco. At the San Francisco Airport, one sprinkler head in each of two airline maintenance buildings was opened from contact with vibrating structural X-bracing in the roof trusses, and a 1 in. pipe broke at a cast iron fitting where it passed through a concrete block wall.

B. THE ALASKA EARTHQUAKE, MARCH 1964

1. NBFU/PFRB Report[3]

The most disastrous earthquake Alaska has experienced occurred on March 27, 1964. The Richter magnitude, estimated at 8.4, was greater than that of the 1906 San Francisco earthquake. The epicenter was in the Prince William Sound area about 75 miles east of Anchorage. The ground motion in that city tended to be of the long, rolling type, continuing for a duration of 1½ to 4 min., and as a result, the earthquake selectively damaged certain classes of construction while leaving other classes relatively undamaged. The ground motion resulted in larger earthquake forces in the taller or larger structures, which received more damage than did the small buildings. Earthslides and ground settlement triggered by the earthquake cause extensive damage.

Most of the principal buildings in Anchorage have been built since World War II. Currently, and during most of this period, the Zone 3 (most restrictive) earthquake requirements of the Uniform Building Code have been in force. Therefore, the bulk of the major buildings in Anchorage should have had earthquake resistive design and construction.

Except where buildings or parts of buildings collapsed, automatic sprinkler systems withstood the earthquake quite well. Systems incorporated earthquake bracing, flexible couplings, and other earthquake design features. All systems were inoperable during the period when the city water system was out of service. Of the 24 complete sprinkler systems in Anchorage and adjoining Spenard on which information could be obtained, 2 were destroyed with partial or total building collapse, one was damaged when the building was severely damaged, and 2 were slightly damaged by a falling chimney and by a dropped rear balcony. Two heads were broken and replaced in a high school, and one or 2 heads fused in a junior high school chemicals storage room.

Water supply was affected in a number of ways. Pumps were out of service due to disruption of electric power. Well casings shifted. Numerous breaks in the underground distribution piping caused an immediate jump in water consumption from a rate of 3.0 mgd to 11 mgd. Subsequent examination of pipes showed that in many cases the spigot end of cast-iron pipe was battered causing breakage of the bell, and that the rubber ring at the joints of asbestos-cement pipe was frequently displaced, causing leakage.

The municipal fire alarm system in Anchorage received damage to 2 of its 3 box circuits. Telephone facilities were completely disrupted. Emergency fire department communications continued by radio.

2. U.S. Department of Commerce Report[4]

Providence Hospital received moderate earthquake damage. Its tower portion is 5 stories high. Built in 1960-61, the buildings were designed to meet the requirements of the 1958 Uniform Building Code, including its seismic Zone 3 requirements. Principal damage was found in the walls of the east core tower, where an 8-in. thick reinforced concrete shear wall had broken concrete above doorways. Minor concrete and plaster cracking occurred elsewhere. The damage to the Providence Hospital is quite significant since it was one of the better designed and constructed buildings in Anchorage. The problem of ducts and other mechanical and electrical services piercing shear walls is a common one, and no doubt will give trouble to many presently constructed buildings in future earthquakes. One run of automatic sprinkler piping broke loose but did not release water. Property loss was about 2½% of replacement value.

C. THE SAN FERNANDO EARTHQUAKE, FEBRUARY 1971

1. Pacific Fire Rating Bureau Report[5]

The San Fernando, California earthquake of February 9, 1971, is of major insurance importance and significant public interest because of its distinctive characteristics. It was one of the few domestic earthquakes having its epicenter adjacent to a highly concentrated center of pupulation. It was caused by the movement of a little known "thrust" fault, rather than one of the large, famous faults which have been suspect for decades.

Case Histories

While partial damage was widespread, total and near total destruction of structures was confined to very narrow bands within the shaken area. On the other hand, considering the amount of exposed property, the percentage of damage throughout the shaken area was comparatively small.

The earthquake inflicted severe damage and major losses along the foothills of the San Gabriel Mountains and along a narrow east-west band of faulting on the valley floor. Overall strong motion lasted about 12 seconds. Its epicenter was in the San Gabriel Mountains about 5 miles north of the San Fernando Valley, much of which is a north-western section of Los Angeles. Rated at a Richter magnitude of 6.6, the earthquake released its energy along a thrust fault which was much closer to heavily populated regions than indicated by the epicenter.

Earthquake forces in the heaviest shaken area of the valley far exceeded building code earthquake requirements and were considerably beyond those anticipated by engineers and scientists. Under these circumstances, modern earthquake resistive structures collapsed or were severely damaged. However, this highest intensity zone was confined to the area above the thrust fault block. Outside of this area, the intensity was within expectable limits.

In the area over the wedge of the thrust fault, 876 breaks were found in water lines, 380 in natural gas lines, and 1155 in sewer lines. It is important to recognize that these pipe breaks coincided with the areas having the heaviest dwelling damage.

Generally, if a sprinklered building fared well, so did the sprinkler system. Out of 973 sprinklered risks contained in Pacific Fire Rating Bureau files and located in the affected areas, 68 were indicated as possibly suffering damage. These 68 were surveyed, resulting in the assessment shown in the table following:

SPRINKLERED BUILDING SURVEY

	Buildings Damaged		Sprinkler System Damage		Sprinkler Leakage Loss	
Damage	No.	%	No.	%	No.	%
None	6	9	30	44	40	59
Slight	25	37	16	24	12	18
Moderate	13	19	9	13	7	10
Severe	24	35	13	19	9	13
Totals	68	100	68	100	68	100

2. Fulton Compilation

A study of case histories of automatic sprinkler system performance during the San Fernando earthquake was performed by John C. Fulton, PE, at our request. Data describing damage to buildings and to its installed fire protection equipment had been obtained by him shortly after the incident and were compiled for this report. These case histories are included in summary form as Appendix A.

For the 55 buildings, or building complexes, reported by Fulton, damage to the buildings correspond to damage of the sprinkler system in all but seven instances -- five where sprinkler damage was less and two where it was more severe. For the 48 cases where there was no damage to the building or the damage was minor, there was moderate damage to the sprinkler systems in two instances. On the other hand, in five cases where moderate damage was reported to the building, sprinkler system damage was slight. There were two cases of moderate building and moderate sprinkler damage and one case of severe building and severe sprinkler damage.

Fulton reports that a survey of 13 sprinkler companies indicated that they responded to 192 locations to make repairs following the earthquake. Most incidents were to replace leaking rubber gaskets in flexible couplings. Other commonly reported problems included earthquake braces pulled out of concrete or wood members, sprinklers bent or broken from contacting objects or construction members, leaking threads, broken fittings, and pipes cemented solid.

3. Industrial Risk Insurers Experience

The earthquake loss experience of Industrial Risk Insurers (Factory Insurance Association) for the San Fernando Earthquake was transmitted to us by J. E. Troutman, Assistant General Manager & Manager of Engineering. Of the industrial facilities insured by this organization, damage to fire protection equipment was reported at only eight locations. At Rye Canyon, a 12-in. inlet valve to a 277,000 gal. water storage tank broke, emptying the contents, and there were several small breaks in sprinkler systems. At Sylmar, sprinkler pipe drops through suspended ceilings resulted in 52 breaks. The remaining failures involved breakage of one or two pipe fittings or the separation of a pipe from an earthquake clamp. No information is available on the construction of the buildings or of the structural damage sustained.

D. UNDERGROUND PIPING

1. General Experience[6]

The general history of underground fire mains in recent years has been good when they have been installed in conformance with National Fire Protection Association standards (NFPA #24), with specific attention paid to the installation of thrust blocking and rodding. The damage that has resulted has greatly depended on the type of soil, type and age of pipe, and proximity to the major shock area. NFPA #24 sets forth no special requirements for earthquake resistance -- see also Section V.

2. San Fernando and Managua Earthquakes[7]

In the 1971 San Fernando earthquake, where a magnitude of 6.6 on the Richter scale was recorded, ground displacements measured 6 ft. reverse and 6 ft. left lateral slip. It was noted that both compression and extension occurred in many areas as some blocks were shortened by 5 ft. and some elongated by about 2½ ft. In cases of extreme compression on clay sewer pipes, bells were broken away from the pipes. Separated joints were very evident in areas experiencing extension or elongation.

Damage occurring to large-diameter water and gas welded steel pipe was more prevalent on welded bell and spigot type joint than on butt-welded. Some failures were attributed to excessive water hammer surges induced by ground movement during the earthquake.

Water distribution mains in the area included welded steel, riveted steel, cast iron and concrete cylinder pipe. There was a small amount of asbestos-cement, which suffered extensive crushing failure, and a small amount of ductile iron pipe, which was not damaged. There was no plastic pipe.

Joint eccentricity was a critical problem. Most of the failures resulted from horizontal ground motion which developed tension, disengaging welded and caulked joints. Some of the failures resulted from compressive action of the spigot within the bell. Frequent failures occurred when the earthquake motion loosened the caulking material in the joint. Lead-caulked and rubber-gasketed joints on cast iron mains survived earth movements much better than did cement-caulked joints.

Case Histories

In the Managua earthquake (6.2 on the Richter scale), damage to underground piping was somewhat different. The system contained 200 miles of asbestos cement pipe and 51 miles of older cast iron pipe in sizes up to 12 in. Above 12 in., the system contained mostly ductile iron pipe with some older cast iron, totaling 19 mi. In the smaller sizes, there were 391 breaks in the asbestos cement and 90 in the cast iron (about in direct proportion to the amount in use). The asbestos cement pipe was mostly affected by ruptures caused by pipe ends colliding with the coupling; breaks due to shearing stress in the body were also frequent. In the larger diameter piping, failures were not in the pipe but due to separation of rubber-gasketed push-on joints.

Based on experience gained from these earthquakes, recommendations were proposed for special couplings to be used where pipelines cross active faults. The coupling provides for restrained expansion, has enough flexibility to withstand displacements, and facilitates prompt repair. Other recommendations are for the laying of pipe in the fault zone and for the use of ductile iron pipe because of its well-known ability to bend without fracturing.

No other design recommendations are presented for geologically hazardous situations. Means for mitigating the effects of broken mains due to an earthquake include alternate loops and sufficient valving, both to isolate the damaged section and to shut off noncritical usage. Proper location of valves, hydrants and blow-off valves help make it possible to bypass broken mains with temporary piping materials, such as fire hoses, etc.

E. GROUND SUCTION TANKS

1. General Experience[6]

The use of ground suction tanks as a suction source for fire pumps installed in private protection fire systems has been good, providing adequate design has been done in regards to the tank foundation, seismic design, and anchorage.

In conjunction with this design, the use of swing joints and flexible couplings in the pump suction feed allows for movement of the tank and pump or pumps during an earthquake. The past history of ground suction tanks and fire pumps installed in this manner has been very good, with minimum damage resulting in recent earthquakes. The above types of installations conform with the

applicable NFPA standards (NFPA #20 and #22), which are being used by the Insurance Services Office of California as design requirements. These two pamphlets incorporate some special earthquake precautions -- see Section V.

2. Fulton Compilation

Several of the complexes for which Fulton provided case histories (see Section Iv.C.2) have private water supplies for fire protection. In each instance, the minor damage to the structures at the complex correlated with minor damage to the water supply installation. For Case No. 5, as detailed in Appendix A, there was an installation consisting of a 300,000 gal. ground storage tank and two fire pumps. There was no damage to the tank, foundation, piping or pumps.

The complex described in Case No. 10 has a 2-million gallon tank, which was unaffected, but a 277,000 gal. tank rotated, causing breakage of a valve flange and discharge of the contents. Settlement of a 250,000 gal. steel tank at the glass manufacturing plant (Case No. 13) caused leakage at a flexible coupling and at a cast-iron 6x4 reducer but the supply to the fire pump was not disrupted during the emergency.

Settlement of 3 in. occurred at another fire pump suction tank (Case No. 25), causing some leakage from this 150,000 gal. installation from one coupling. An elbow on the tank fill line also was cracked. There was no other damage.

F. FIRE ALARM SYSTEMS

1. General Experience

While ground motion during an earthquake triggers the operation of fire (and burglar) alarm systems, there is little evidence of the failure of components of the systems as a result of an earthquake, except where collapse of a portion of the building occurs. Devices such as waterflow transmitters and low water level alarms are actuated by water surges in pipelines and by water sloshing in tanks, and the multiplicity of such signals received by central station fire/burglar alarm offices tends to completely overwhelm these facilities. (See particularly extract from report on San Fernando earthquake, below.

There are accounts of battery racks (at telephone exchanges and for emergency generators) collapsing, and undoubtedly, similar failures would occur where fire alarm systems are powered by wet-cell batteries. Instances have been reported where fire pumps start automatically during an earthquake, apparently due to the closing of mercury switch contacts as a result of ground motion, and it can be assumed that similar incidents will trigger fire alarm systems, as relays and switches operate as the building shakes.

Contact was made with Phil Leung, resident expert on fire alarm systems for Northern California, Nevada and Alaska in the Insurance Services Office, San Francisco. He stated that he had never seen nor heard of any damage to any part of the fire alarm system as a result of an earthquake. Although he is not directly knowledgeable with the San Fernando earthquake, he stated that he would have heard of any serious incidents involving fire alarm systems.

It is possible that substantial damage occurs which is not documented. Disruption of the fire alarm system in a building which has received earthquake damage probably would not be considered to be of significance, nor would repairs have a high priority, particularly since in most instances, such systems do not provide a first line of defense against fire incidents or for life safety. Broken water lines tend to receive more immediate attention than a broken conduit making a fire alarm system inoperative.

2. San Fernando Earthquake[5]

The San Fernando earthquake produced a confusing pattern of unreadable signals on receiving equipment of central station services supervising fire alarm and burglary equipment at protected premises. Water level devices in storage tanks were activated, foil was broken on intrusion-protected windows, contacts were opened on doors, detection light beams were disturbed, and transmitters were tripped by severe shaking. Leased telephone circuits were impaired and there was general power failure. In one central station, over 200 alarm registers started printing signals at one time.

As in previous earthquakes, some communication systems were vastly overloaded, failed in one instance, and were not coordinated in some cases. One central telephone office was destroyed

due to equipment toppling. Emergency communications by telephone were immediately ineffective after the quake and were on a reduced basis for 39 days. Signaling services for sprinkler systems, fire, police, etc., such as those provided by private central stations, did not function well immediately after the shock due to unreadable signals, equipment overload, destroyed lines, and insufficient staffing for catastrophe conditions. Radio communications generally functioned, but the lack of monitoring of other frequencies or otherwise coordinating these radio links caused significant problems during the first few hours.

V.

SEISMIC PROVISIONS OF CODES AND STANDARDS

A. DESIGN REQUIREMENTS, AUTOMATIC SPRINKLERS

1. Pamphlet #13 Requirements and Experience[8]

National Fire Protection Association (NFPA) Pamphlet #13, Standard for the Installation of Sprinkler Systems , is the nationally recognized design and installation guide for automatic sprinkler systems and is universally used in the United States. Sections 3-9.3 and 3-9.4 and similarly numbered sections in the appendix provide rules and supplementary guidance for protection of piping against damage where subject to earthquakes. These special requirements for seismically active regions are being applied in California, Nevada, Alaska, and other states by the authorities having jurisdiction.

The experience with systems incorporating earthquake protection has been very good, as observed in the Eureka earthquake, Daly City earthquake of 1957, and the San Fernando earthquake of 1971. Observations of sprinkler systems installed with earthquake bracing design and installed in accordance with the NFPA #13 edition in effect at the date of installation showed no loss of sprinkler systems, with the exception of those installed in buildings to which major structural damage occurred, such as collapse or loss of structural members which supported the piping.

Flexibility of the systems was noted after the Eureka earthquake. The 45° braces and A braces were pulled from the supporting structural members, with the sprinkler systems remaining intact. This was particularly true in buildings where systems were predominantly hung by the use of U hooks (in wood joists). In the San Fernando earthquake, where a wrap-around U hook had been placed at the end of branch lines, the sprinklers were prevented from hitting the ceiling and breaking sprinkler heads.

2. Specific Provisions

Several changes are being proposed by the sectional committee on sprinkler systems for inclusion in the next edition of the standard, which is scheduled to be voted on at the November 1978 meeting of the National Fire Protection Association. These revisions are as follows:

> *Existing Section 3-9.3.2 (a). Add a new second sentence as follows:* "The mechanical grooved coupling at the top of the riser shall be installed below the four-way sway brace installed at the top of the riser as specified in 3-9.3.4.1."
>
> *Revise existing Section 3-9.3.4.1, the first sentence, to read as follows:*
>
> **3-9.3.4.1** Feed and cross mains shall be braced to withstand a force equal to 50 percent of the weight of water-filled piping, using a two-way sway brace.
>
> *Revise existing Section 3-9.3.4.6 to read as follows:*
>
> **3-9.3.4.6** Piping shall not be fastened to building sections that would move differentially.

Factory Mutual System[9] has adopted as guidance for its insured properties essentially all of NFPA #13, which has been reproduced in its Loss Prevention Data sheet 2-8N with the mandatory text of NFPA #13 intermixed with the recommended appendix sections of that standard. Special FM guidelines have been added. Additional guidance for the sprinkler system designer is contained in Factory Mutual Data sheet 1-2, Earthquakes, as follows:

> *"It is advisable to allow piping to accommodate itself to building vibration and to its own inertia forces with a minimum of stress. A certain amount of damping, however, is desirable. This can be achieved by anchors on the feed mains. The branch lines can then be left free to adjust themselves to the racking effects of building movement. A certain degree of flexibility is also desirable, especially on bulk mains where flexible couplings should be provided about every 20 to 40 ft. Since building walls will lean inward and outward while oscillating, it is advisable to provide flexible couplings at the base and top of sprinkler risers to accommodate this deflection. Couplings at the top and bottom of each floor in multi-story buildings, and also where passing horizontally through walls of separate buildings will help minimize damage to the sprinklers. Clearance where risers and feed*

mains pass through floors, walls and foundations would be helpful. Loose fitting sleeves fitted with asphalt mastic can be provided around the pipes.

"Riser fittings, such as drain pipes and fire department pumper connections, may fail if they are cemented solid in walls."

Another requirement is now in committee but was not included in that proposed text for the next edition of NFPA #13. However, it will probably be required in new sprinkler systems in California and Nevada. This will be the installation of an additional brace at each point on all horizontal piping where a flexible coupling is used in lieu of threaded or flanged couplings. It is anticipated that the 24-inch rule will apply where two or more couplings are close together. As a whole, the use of flexible couplings in sprinkler system risers in conjunction with the correct installation of earthquake bracing is considered to have been a major factor in increasing the effectiveness of earthquake bracing in general and the integrity of the sprinkler system.

3. Seismic Qualification of Sprinkler Systems

Results of studies performed by the State of California on seismic qualification of hangers and sway bracing for sprinkler system piping was provided by William R. Goss, P.E., Executive Coordinator, Western States - National Automatic Sprinkler and Fire Control Association. He states that following the 1971 San Fernando earthquake, the California legislature passed SB 519, which created a new State Building Safety Board, whose purpose was the development of updated seismic standards and requirements for the construction, equipping, and remodeling of hospitals. Goss served on the Mechanical and Electrical subcommittee, along with Leon Stein, supervising structural engineer in the Office of the State Architect.

The subcommittee's role was to examine and review installation requirements and methods for all types of mechanical systems as to their adequacy for seismic performance. Stein has long been associated with seismic design performance requirements in connection with California's Field Act, passed to improve school earthquake safety.

During this period of time, SMACNA (Sheet Metal & Air Conditioning Contractors' National Association) conducted tests on the seismic effectiveness of the installations of mechanical systems,

including hangers and sway bracing, as required for earthquake protection by NFPA #13-1974. These tests indicated that the NFPA #13 provisions met the seismic specifications, with the following notations:

1. The seismic values for shot studs used for securing hangers and bracing should be checked.

2. Lag screws should not be used in glue laminated beams.

3. C-clamps on I-beams should always be strapped.

4. Stress factors and approved locations should be verified when fastening hangers and bracing to prefabricated truss assemblies.

In 1976, Ayres & Hayakawa, energy management consultants, received a contract from the State of California to further review the seismic requirements for high life hazard construction. It has been learned from K. L. Marz, earthquake research engineer for A & H, that the automatic sprinkler system piping hanger and sway bracing provisions of NFPA #13-1974 have been approved as meeting the seismic requirements of the State of California.

SMACNA design recommendations are contained in the booklet, "Guidelines for Seismic Restraints of Mechanical Systems," prepared for Sheet Metal Industry Fund by Hillman, Biddison & Loevenguth, structural engineers, and approved by the Structural Safety Section, Office of the State Architect, State of California, in 1976. According to a representative from the Schoolhouse Section, California State Fire Marshal's Office, NFPA #13 earthquake protection requirements parallel and will meet the SMACNA guidelines.

B. DESIGN REQUIREMENTS, OTHER SYSTEMS[8]

Other National Fire Protection Association standards cover the design and installation of special fire suppression systems, water supply components, and fire detection and alarm systems. NFPA #11, Foam Extinguishing Systems, and NFPA #15, Water Spray Fixed Systems for Fire Protection, refer back to NFPA #13 for provisions relating to the installation of interior piping; thus by inference, the earthquake hanger and bracing requirements of the sprinkler standard apply to these systems, also. None of the other standards which would govern the installation

of special extinguishing systems at nuclear power plants contain any reference whatsoever to the need for earthquake protection. This includes #12, Carbon Dioxide Systems; #12A, Halon 1301 Systems; #14, Standpipe and Hose Systems; and #17, Dry Chemical Systems.

NFPA #20, Standard for the Installation of Centrifugal Fire Pumps, covers the whole gamut of special installations and protection with one sentence: "The fire pump, driver, and controller shall be protected against possible interruption of service through damage caused by explosion, fire, flood, earthquake, rodents, insects, windstorm, freezing, vandalism, and other adverse conditions."

Recognition of the need for special earthquake protection as warranted by local conditions is given by NFPA #22, Standard for Water Tanks for Private Fire Protection. Both tanks and towers are required to meet local code requirements for resisting earthquake damage; some additional design guidance is provided.

No special earthquake protection is required for underground yard piping supplying automatic sprinkler systems or other fire suppression equipment (NFPA #24, Standard for Outside Protection). Nor does the Uniform Building Code or Uniform Plumbing Code contain provisions to limit earthquake damage to underground fire mains, and inquiries to insurance and fire officials in California also revealed that any underground piping system acceptable in non-earthquake prone areas would be accepted in that state.

Likewise, no special seismic provisions appear to exist in nationally recognized codes and standards for fire alarm systems or for electrical systems, in general. These standards include NFPA #70, National Electrical Code; NFPA #72D, Proprietary Signaling Systems (fire alarm, sprinkler supervisory service, etc.); and NFPA #72E, Automatic Fire Detectors.

The general lack of special earthquake damage prevention measures for most fire protection systems, except sprinkler systems, might be due to the improbability of the need for such systems during or immediately after earthquakes. Unlike most sprinkler systems, where a pipe break can cause substantial property damage, a pipe or wiring break in the majority of the other systems has no immediate, adverse effect on life safety or conservation

of property. Despite the general disruption of gas and electric utility lines, there tend to be few fires immediately following an earthquake, and insofar as fire detection and alarm systems are concerned, the earthquake itself alerts the people to the emergency situation. In cases where substantial damage to fire protection systems coincides with substantial damage to the structure, the loss of the protective system is immaterial. However, these arguments do not appear to be valid when applied to the lack of earthquake provisions for underground fire mains, whose disruption can nullify the effectiveness of otherwise intact sprinkler systems for long periods of time.

VI.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded as a result of this study that automatic sprinkler systems, which have been installed in conformity with the rules of the nationally recognized National Fire Protection Association Standard #13 -- including its special provisions for seismically active regions -- will not suffer significant impairments to the interior piping, provided that there is no major damage to the building, such as structural collapse or falling walls. This conclusion is based on the observations of many persons who have direct knowledge of the installation requirements and the post-earthquake performance. Many case histories were obtained which confirmed this conclusion.

Some weaknesses in the performance of the piping systems have been documented and, consequently, some modifications to the current rules have been proposed by the authorities involved and by NFPA Sectional Committee on Automatic Sprinkler Systems. These modifications are presented herein to further reduce the potential loss of operating capabilities following an earthquake.

Many times the damage sustained by a sprinkler system when there was little damage to the building was of sufficiently minor nature (leakage at a fitting or a sprinkler head knocked off) that the system was still functional. However, water leakage normally dictates that the system be shut off until repairs are effected. Impairments such as this can be lessened by using pre-action sprinkler systems, which require a double failure to cause accidental water discharge (such as, short-circuiting of the detector wiring and a break in the piping).

No special precautions are taken at the present time to prevent impairment of underground piping which supplies automatic sprinkler systems, standpipe and hose systems, and certain special hazard extinguishing systems. Reports on the post-earthquake

performance of underground piping systems are mixed. Extensive outages and hundreds of breaks have been reported in municipal water distribution systems following an earthquake, but fire protection yard mains are reported to have good survivability. Since public and private systems follow essentially the same material specifications and installation practices, the difference in performance most likely is due to the insignificant amount of private mains in an urban area. It is concluded that ordinary installations of cast iron and cement asbestos fire mains are subject to major impairments when ground motion is severe. Slip joints, which do not require rodding to prevent separation from internal water pressure, tend to separate from extensive earth movement.

There was a general lack of documented case histories on the damage sustained by automatic fire detection systems and fire alarm systems. This lack of data could be due to the overall satisfactory performance of these systems, or it could be due to the failure of people to document the impairments because of the more serious structural damage or damage to water mains occurring at the same time, or both. However, the evidence and the observations of persons familiar with the performance of these systems suggest that impairments, if any, are minor if no severe structural damge occurs. Typically, there is a temporary, area-wide impairment of fire alarm service immediately following an earthquake, due to actuation of many automatic pressure and water-level sensors simultaneously as a result of ground motion; this type of impairment is difficult, if not impossible, to prevent without material degradation of the sensors.

No references were found as to the performance of special fire extinguishing systems in earthquakes. There are relatively few such systems (carbon dioxide, Halon, etc.), and while it is likely that the installations are prone to the same type of failures sustained by mechanical and electrical systems in general, the failure has no immediate serious consequences. Discharge of the extinguishing agent probably would not occur. Damage is likely to be minor, and restoration fairly simple. The National Fire Protection Association standards covering the design and installation of these systems have no seismic provisions.

The following recommendations are offered as a result of this study for application to installed fire protection systems for safety-related areas of nuclear power plants in seismically active regions of the U.S.:

1. Automatic sprinkler systems should comply with the current rules of NFPA #13, including the earthquake hanger and bracing requirements. These rules should be supplemented with the amendments to Section 3-9.3 which have been proposed for adoption (see Section V of this report).

2. Fire detection and alarm systems should comply with current rules of the applicable NFPA standard if loss of functional capability in the period immediately following an earthquake is acceptable. Otherwise, the system should be seismically qualified. In all cases, seismic loops should be provided for wiring crossing building seismic or expansion joints.

3. Piping for hose standpipes and hose connections serving plant areas containing equipment required for safe plant shutdown should continue to be designed in accordance with NRC fire protection guidelines to maintain the capability of supplying water following a postulated safe shutdown earthquake.

4. Other fixed fire extinguishing systems in the interior of the building should comply with current rules of the applicable NFPA standard, provided that a single failure in the mechanical or electrical portions of the system will not create an unacceptable condition in the period immediately following an earthquake. If such condition could exist, seismic qualification should be required.

5. In situations where accidental discharge of water in sprinkler piping can lead to particularly dangerous consequences, the use of a pre-action type of sprinkler system should be considered.

6. Seismic Category I water supplies should be capable of being connected to fire protection systems. Also, yard mains and other non-seismic portions of the supply system should be sufficiently sectionalized that impaired portions can be isolated, provided that alternate means are available to supply water to the interior systems in such an emergency (such as laying hose lines or aboveground piping). Lead-ins from yard mains to the building interior should be provided with shut-off valves both on the exterior and on the interior of the building.

7. Batteries, fuel tanks and similar ancillary equipment for vital fire protection systems should be secured and braced to resist earthquake forces.

8. Sprinkler head drops through suspended ceilings should be avoided.

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Appendix A

AUTOMATIC SPRINKLER SYSTEM DAMAGE AS RELATED TO BUILDING DAMAGE

SAN FERNANDO EARTHQUAKE, FEBRUARY 9, 1971
(Partial List)

1) Auto repair garage, San Fernando. All-steel, 65x200'
BLDG DAMAGE: Structure, none. Partitions, moderate.
SPKLR DAMAGE: None.

2) Warehouse, San Fernando. Tilt-up concrete, wood roof, 100x190'
BLDG DAMAGE: Some floor cracks.
SPKLR DAMAGE: None

3) Department Store, San Fernando. Tilt-up concrete, plywood roof, 75,000 sq.ft.
BLDG DAMAGE: Minor structural damage.
SPKLR DAMAGE: 3 small cast-iron fittings broken at drops thru suspended ceiling.

4) Garment manufacturing, San Fernando. Brick walls, wood roof, 15,000 sq.ft.
BLDG DAMAGE: Minor; wood mezzanine platform shifted.
SPKLR DAMAGE: 1-1/4 in. riser broken where passing thru mezzanine floor. 1 sprinkler head broken on contact with wall.

5) Retail store, San Fernando. Reinf. brick walls, board on joist roof, 14,000 sq.ft.
BLDG DAMAGE: Structural, minor. Moderate to plaster ceilings.
SPKLR DAMAGE: None.

6) Grocery warehouses, Pacoima. 4 large, tilt-up concrete bldgs, wood diaphragm roofs.
BLDG DAMAGE: Structural, slight. 21' high warehouse racks toppled.
SPKLR DAMAGE: None.

7) Metalworking plant, Pacoima. Several large tilt-up concrete bldgs, metal deck roofs.
BLDG DAMAGE: Not reported.
SPKLR DAMAGE: 1 small line broken.

8) 6 medium-sized industrial facilities, Pacoima.
BLDG DAMAGE: Not reported.
SPKLR DAMAGE: None.

9) Occupancy not reported, Sylmar. Tilt-up concrete, plywood roof, 41,000 sq.ft.
BLDG DAMAGE: Structural, moderate.
SPKLR DAMAGE: Numerouse broken fittings.

10) Aerospace R&D center, Saugus. 7 major bldgs. Mostly tilt-up concrete, concrete or steel deck roofs.
BLDG DAMAGE: Structural, slight to minor.
SPKLR DAMAGE: None.

11) Electronics plant, Saugus. Tilt-up concrete, plywood roof, 35,000 sq.ft.
BLDG DAMAGE: Minor.
SPKLR DAMAGE: None.

12) Hardware store, Saugus. Reinf. brick walls, plywood diaphragm roof, 24,000 sq.ft.
BLDG DAMAGE: Structural, minor, mostly at roof beam-brick pilaster connections (supported sprinkler mains).
SPKLR DAMAGE: 4 in. el broke at base of riser from main in area of structural damage. 4 in. tee at supply to exterior canopy broken.

13) Glass manufacturing, Saugus. Numerous steel on steel frame bldgs.
BLDG DAMAGE: Very minor.
SPKLR DAMAGE: To 7 systems. 1x1-1/2 in. el broken by impact with falling object. Leakage at 8 in. el at top of main riser. Broken 3-1/2 in. fitting on cross main. Two fittings at supply to exterior canopy broken. 1 sprinkler head broken in contact with hanger.

14) Grocery store, Granada Hills. Tilt-up concrete walls, plywood diaphragm roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

15) Department store, Granada Hills. Tilt-up concrete walls, plywood diaphragm roof, 24,000 sq.ft.
BLDG DAMAGE: Structural, none. Substantial to suspended acoustic ceiling.
SPKLR DAMAGE: None.

16) Department/grocery store, Granada Hills. Reinf. brick and tilt-up concrete walls, plywood diaphragm roof.
BLDG DAMAGE: Structural, none.
SPKLR DAMAGE: 1 leaking fitting.

17) Grocery store, Granada Hills. Steel frame, brick filled, plywood diaphragm roof.
BLDG DAMAGE: Structural, slight. Moderate to suspended ceiling.
SPKLR DAMAGE: None.

18) Department store, Granada Hills. Reinf. brick walls, plywood diaphragm roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: Minor leaks at 2 flexible couplings.

19) Grocery store, Granada Hills. Reinf. concrete frame, brick panel walls, wood truss roof.
BLDG DAMAGE: Structural, minor
SPKLR DAMAGE: None.

20) Instrument manufacturing, Sunland. Tilt-up concrete walls, plywood roof.
BLDG DAMAGE: Structural, minor.
SPKLR DAMAGE: None.

21) Grocery store, Sunland. Concrete frame, brick panel walls, plywood diaphragm roof.
BLDG DAMAGE: Structural, minor to moderate. Exterior wall deflection; partial roof diaphragm failure and roof deflection.
SPKLR DAMAGE: Bulk main sagged 2 ft., no leaks.

22) Machine shop, Chatsworth. Tilt-up concrete walls, plywood roof.
BLDG DAMAGE: Slight.
SPKLR DAMAGE: None.

23) Hardware store, Simi. Tilt-up concrete walls, plywood roof.
BLDG DAMAGE: Minor.
SPKLR DAMAGE: None.

24) Grocery store, Reseda. Reinf. brick walls, plywood roof.
BLDG DAMAGE: Minor.
SPKLR DAMAGE: None.

25) Grocery warehouse, Northridge. Tilt-up concrete walls, plywood roof, 276,000 sq.ft.
BLDG DAMAGE: None reported.
SPKLR DAMAGE: 1 leaking 5 in. elbow. 2 sway braces pulled loose.

26) Grovery store, Canoga Park. Reinf. brick walls, plywood roof.
BLDG DAMAGE: None.
SPKLR DAMAGE: None.

27) Grovery store, Canoga Park. Tilt-up concrete walls, plywood roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

28) Aerospace R&D complex, Canoga Park. 8 major bldgs. Tilt-up concrete or reinf. brick walls, steel deck and plywood roofs.
BLDG DAMAGE: Slight.
SPKLR DAMAGE: 1 sprinkler head leaked when struck by object. 1 head opened when struck by vibrating pipe.

29) Aerospace R&D facility, Canoga Park. 4 major bldgs. of reinforced concrete construction.
BLDG DAMAGE: Extensive minor cracking of concrete structural elements.
SPKLR DAMAGE: None.

30) Department store, Canoga Park. 2 stories, reinf. concrete frame, tilt-up concrete exterior walls, 170,000 sq.ft.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

31) Department store, Canoga Park. 2 stories, reinforced concrete floors and roof on steel frame. Reinf. brick walls 1st, tilt-up concrete walls 2nd. Partial basement.
BLDG DAMAGE: Structural, slight. Architectural, extensive.
SPKLR DAMAGE: Slight leak at one 4 in. fitting.

32) Department store, Canoga Park. 3 stories, reinf. concrete frame, steel deck roof, concrete block exterior panel walls, 240x350'. Adjoining 2-level reinf. concrete mall and 3-story atrium.
BLDG DAMAGE: Structural, slight. Architectural, extensive.
SPKLR DAMAGE: None in store. 1 leaking coupling on 6 in. main in mall.

33) Department store, Canoga Park. 2 stories, reinf. concrete frame, steel deck roof, 132,000 sq.ft.
BLDG DAMAGE: Structural, slight. Architectural, extensive.
SPKLR DAMAGE: 2 heads leaking after contact with objects. 2 earthquake sway braces pulled loose.

34) Aircraft manufacturing plant, Burbank. Numerous bldgs. of heavy construction (mostly concrete wall, steel deck roof).
BLDG DAMAGE: Structural, minor to some bldgs.
SPKLR DAMAGE: None to 50 systems, except 1 head opened above a suspended ceiling, 1 slight leak in a riser, and several earthquake braces bent.

35) Aircraft manufacturing plant, Burbank. Numerous bldgs., mostly wood frame construction, including several large aircraft hangars of pre-earthquake code vintage.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

36) Aircraft manufacturing, Burbank. Numerous bldgs., steel frame, mostly steel panel walls, steel deck on wood plank on steel truss roofs.
BLDG DAMAGE: Minor.
SPKLR DAMAGE: 1 head opened. 1 minor leak at a hose drop. 5 additional minor leaks at fittings.

37) Aircraft engine overhaul, Burbank. 4 major bldgs., steel or wood frame walls, wood roofs on 3 bldgs., tilt-up concrete and plywood roof on 4th
BLDG DAMAGE: Minor
SPKLR DAMAGE: Leaks at 2 flexible couplings.

38) Warehouse, Burbank. Concrete block walls, wood roof.
BLDG DAMAGE: Architectural to brick veneer.
SPKLR DAMAGE: Major leakage from 6 in. flexible coupling. (Waterflow alarm not received by central station service.)

39) Aircraft parts manufacturing, Burbank. Numerous bldgs, heavy steel frame, concrete or steel panel walls, mostly wood planks on joists floors and roofs.
BLDG DAMAGE: Structural, minor
SPKLR DAMAGE: Breakage of 3-1/2 in. cross main and 1-1/2 in. drop to hose station. Breakage of 2 in. branch line in machine shop, probably when hit by vibrating building cross-bracing rod.

40) Department store, Panorama City. Reinf. concrete construction.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

41) Department Store, Panorama City. Concrete construction, steel deck roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

42) Hardware store, Panorama City. Tilt-up concrete walls, wood roof.
BLDG DAMAGE: Structural, minor.
SPKLR DAMAGE: None.

43) Grocery store, Panorama City. Tilt-up concrete walls, plywood roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

44) Hardware store, Panorama City. Concrete block walls, plywood roof.
BLDG DAMAGE: Structural, none.
SPKLR DAMAGE: None.

45) Grovery store, Panorama City. Steel frame, concrete block walls, plywood roof.
BLDG DAMAGE: Structural, none.
SPKLR DAMAGE: Minor leaks from 3 flexible couplings on bulk main.

46) Electronics manufacturing, Panorama City. Reinf. brick walls, plywood roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None.

47) Helicopter manufacturing, Panorama City. Steel frame, mostly wood walls, mostly plank on wood truss roof.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: None to numerous systems.

48) Automobile manufacturing, Panorama City. Numerous bldgs of heavy construction, steel frame, steel deck roofs.
BLDG DAMAGE: Structural, slight to minor.
SPKLR DAMAGE: 8x8x6 tee at top of exterior riser broke where entering 2nd floor. 5 leaks at fittings, all in 2nd story of buildings.

49) Department store, North Hollywood. 4 stories, reinf. concrete construction, 450,000 sq.ft. Adjoining 1-story mall.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: Leak at branch line in penthouse.

50) Office building, Los Angeles. 4 stories under construction, steel frame, reinf. concrete block walls, concrete floors, suspended acoustic ceilings.
BLDG DAMAGE: Structural, slight.
SPKLR DAMAGE: Numerous breaks at drops through cast rosettes at junctions of T-bar ceiling grids, which were not laterally braced.

51) Printing plant, Los Angeles. 5 bldgs, 2 and 3 stories, unreinf. brick walls, wood floors and roofs.
BLDG DAMAGE: Structural, moderate. Brick wall around stairway penthouse collapsed.
SPKLR DAMAGE: 1-1/4 in. branch line broken by falling bricks. (System designed without earthquake protection.)

52) Furniture warehouse, Los Angeles. Multi-bldg complex, reinf. concrete and unreinf. brick walls, wood floors and roofs.
BLDG DAMAGE: Structural, minor to moderate. Brick parapets fell in several locations, breaking thru wood roofs.
SPKLR DAMAGE: 4 branch lines broken by falling bricks.

53) Department store warehouse, Los Angeles. Tilt-up concrete walls, plywood roof.
BLDG DAMAGE: None.
SPKLR DAMAGE: Slight leak around threads of a 4 in. fitting.

54)-58) 5 industrial plants, Vernon. Only locations with damage to sprinkler systems reported by fire department. No construction details available.
BLDG DAMAGE: Not reported.
SPKLR DAMAGE: 54) and 55) Deteriorated pipe broke. 56) 1 head broke on contact with purlin. 57) 2 in. tee broke at cross main. 58) 3 lag bolts on earthquake braces pulled loose; no leakage.

59) Machine shop and warehouse, Sylmar. Steel column and wood beam frame, tilt-up concrete walls, plywood roof. A special study was made of the damage to this building because the sprinkler system received extensive damage. The 240 ft. x 160 ft. building was located near Bradley Ave. and Oswald St., 10 mi. southwest of epicenter but only 1-1/4 mi. south

of the nearest surface fault trace. Peak ground acceleration was estimated at about 30%G. Except for a 2-story office section, the building was 1 story in height.

BLDG DAMAGE: Structural, severe; collapse of 23% of roof area attributed in part to placement of air conditioners on roof.

SPKLR DAMAGE: Severe. In addition to damage occasioned directly by the collapse of the roof, two 8 in. flexible couplings broke apart, causing 86 ft. of 8 in. pipe to fall; an 8 in. cast iron el impacted with a wall and shattered; a circumferential fracture occurred in an 8x6 reducer, a 6 in. flexible coupling broke without dropping the pipe, and two 1 in. hose drops broke at the connection to the main. Many hangers pulled loose.

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