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ANALYSIS OF FIRE SPRINKLER SYSTEMS PERFORMANCE IN THE NORTHRIDGE EARTHQUAKE

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United States Department of Commerce
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Notice

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Executive Summary

The performance of nonstructural building components in the January 17, 1994 Northridge earthquake has received a considerable attention, especially building mechanical systems. There has been much anecdotal information indicating less than satisfactory system integrity during and following the Northridge earthquake, which measured 6.8 on the Richter scale. Fire sprinkler systems are of special interest since they are expected to remain functional following earthquakes so as to address post-earthquake fire hazards, and because of the potential for significant water damage that can take place if the system is compromised in a building which otherwise remains structurally intact.

This project was recommended to include two parts:

1. An analysis of the performance of fire sprinkler systems in the Northridge earthquake in relation to the specific earthquake protection measures employed in their design and construction, and

2. Development of proposed changes to the national installation standard, NFPA 13, which would improve future system performance by bringing brace fastener details and other aspects of the protection rules up to current levels of technology.

To aid in the analysis, the two parts have been merged, with the subject matter divided into the following twenty subject areas:

1. Applicability of Earthquake Protection Provisions
2. General Intent of Earthquake Protection Provisions
3. Flexible Couplings - General Applicability
4. Flexible Couplings for Risers
5. Drops to Hose Lines and Sprinklers in Racks
6. Flexible Couplings for Expansion Joints
7. Seismic Separation Assemblies
8. Clearances
9. Sway Bracing - General
10. Sway Bracing - Loads
11. Sway Bracing - Longitudinal Bracing
12. Sway Bracing - Lateral Bracing
13. Sway Bracing for Excessive Flexibility
14. Short Hanger Exception to Bracing
15. Bracing / Restraint of Branch lines
16. Ceiling / Sprinkler Interaction
17. Sway Bracing - Brace Components
18. U-Hooks as Sway Braces
19. Sway Bracing - Fasteners to Structure

20. Hanger and Piping Restrictions in Earthquake Areas

For each subject area, a discussion is first presented with regard to the past progression of requirements of the NFPA 13 standard. Observations of system performance in the Northridge earthquake for that subject area are then discussed, including information on the nature of protection measures employed where applicable. Changes adopted in the 1996 edition of the standard (possibly as a consequence of observations from the earthquake) are presented in for each subject area, and finally additional suggestions for proposed changes to NFPA 13 that might be considered. These proposed changes are gathered from a variety of reports on the Northridge earthquake, from this analysis of the information, and from the recent activities of other groups active in the area of earthquake protection on nonstructural systems.

Work on this project was begun approximately two weeks after the earthquake, with a series of on-site inspections conducted by staff engineers from the National Fire Sprinkler Association working in cooperation with the Los Angeles Fire Department, the National Fire Protection Association, and the Fire Sprinkler Advisory Board of Southern California. In the months following the earthquake, a review was made of the damage survey forms collected through the Fire Sprinkler Advisory Board of Southern California (FSABSC). Additional forms that were not included in the FSABSC report were also included. Subsequent review was also made of Northridge-based studies and recommendations from the following groups:

California Office of Statewide Health Planning & Development (Ayres & Ezer Associates)
California State Fire Marshal's Office
Earthquake Engineering Research Institute
Factory Mutual Research Corporation
NIBS/BSSC Technical Subcommittee on Architectural and Mechanical Systems
FEMA/NEHRP Seismic Rehabilitation Guidelines Project - Nonstructural Team
Underwriters Laboratories

Information and analysis resulting from some of these sources was used as the basis of proposed changes which were incorporated into the 1996 edition of NFPA 13 - *Standard for the Installation of Sprinkler Systems*. However, the deadlines inherent in processing the 1996 edition of the standard precluded a full evaluation of the lessons learned from the earthquake.

It is not the intent of this analysis to decide appropriate earthquake protection features of sprinkler systems - those are determined through the consensus standards-development process of the National Fire Protection Association. However, it is the intent to ensure that the NFPA Committee on Automatic Sprinklers is aware of all subject areas that need to be addressed in subsequent changes to the earthquake protection requirements of NFPA 13.

Introduction

Earthquake protection provisions for fire sprinkler systems were first included in U.S. national installation rules in 1947, in what was then known as NBFU 13, "Standards of the National Board of Fire Underwriters for the Installation of Sprinkler Equipments as Recommended by the National Fire Protection Association." Appendix section A471 was entitled "Protection of Piping Against Damage Due to Earthquakes" and consisted only of the following few paragraphs:

> "**A471 Protection of Piping Against Damage Due to Earthquakes.** In locations where sprinkler systems would be subject to earthquake shocks, sprinkler piping should be installed in a manner to avoid damage from earthquakes. The following paragraphs indicate general recommendations. The inspection department having jurisdiction should be consulted for further details.
>
> "(a) One to two inches clearance should be provided around pipes where they pass through floors, including floors on the ground, and walls. Clearance holes around risers should be protected with metal collars which will act a fire stops and water stops if needed, but will not hold the pipe rigidly. A split ceiling plate or metal collar should be provided on the underside of the floor also, and space between upper and lower collars filled with rock wool or other suitable material. Holes through fire walls or fire partitions should be covered with split plates or metal collars on each side of the wall and space between filled with rock wool or other suitable material.
>
> "(b) Approved flexible couplings should be installed at one or more points in sprinkler system risers as recommended by the inspection department having jurisdiction.
>
> "(c) Feed mains and cross mains should be provided with some form of lateral and longitudinal bracing. U hooks will usually satisfy the requirements for lateral bracing but additional hangers will be required for longitudinal bracing. Hangers to provide longitudinal bracing must be stronger and more carefully installed than those for lateral bracing. Where a system is installed with single rods, it will be necessary to provide earthquake bracing in both directions by installation of special hangers. Branch lines do not require bracing. Hangers should be designed to resist motion producing either tension or compression. Attachments should be such as to develop the full strength of the hanger."

The 1950 edition of the document was published as NFPA 13 rather than NBFU 13, but the earthquake protection recommendations were unchanged.

The 1951 edition saw major changes, with criteria placed in of the text of the standard for placement of longitudinal and lateral braces, maximum slenderness ratio of brace members, and flexible couplings on risers. The intent was stated to laterally brace the piping to withstand a force of 50% of the weight of the piping, valve attachments and water. Figures were added for bracing locations and types of braces, along with a table indicating maximum lengths of angles, rods, flats and pipe to limit the slenderness ratio to 200. One longitudinal brace was required for each main, and lateral braces were to be located at intervals of 30 to 40 feet. This criteria remained basically the same for the next twenty years.

It has been noted (Ayres & Ezer) there were no major earthquakes in large population centers in the United States between 1939 and 1971, so the provisions of the NFPA document were not really tested until the Sylmar earthquake of February 9, 1991, located in the San Fernando Valley of California and measuring 6.6 on the Richter scale.

In the 1973 edition of NFPA 13, the standard was reorganized with the intent to separate the mandatory and advisory aspects of the document. All advisory material was moved to the appendix. Since earthquake protection provisions were not intended to be applicable to all systems, the criteria was moved to the appendix and retitled "Protection of Piping Against Damage Where Subject to Earthquakes". A new introductory paragraph was added to address the overall philosophy:

> "Protection of damage due to earthquake should be provided in some areas. The history, the intensity and the frequency of earthquakes should be considered in determining the need for protection of piping against earthquake damage. The authority having jurisdiction should be consulted relative to definite areas requiring protection."

In the 1980 edition, with no change of title, key aspects of the provisions were moved into the body of the standard to clarify that they were intended to be mandatory for areas subject to earthquakes. In the six editions of the standard from 1983 to 1994, there were additional refinements and improvements in the document. To some extent, these changes were due to increased attention to earthquake protection resulting from a series of earthquakes in the western states in the late 1970's and through the 1980's:

August 13, 1978	Santa Barbara	5.7 on Richter scale
October 15, 1979	Imperial Valley	6.7
May 2, 1983	Coalinga	6.7
April 24, 1984	Morgan Hill	6.2
October 1, 1987	Whittier	6.1

Following the Loma Prieta earthquake on October 17, 1989, the National Fire Protection Association, National Fire Sprinkler Association and Society of Fire Protection Engineers sponsored a hearing to gather information on the performance of fire sprinkler systems in that earthquake. Subsequent changes to the 1991 edition of the standard addressed the need to restrain branch lines where movement could damage sprinklers through impact against other building features.

In preparing the 1996 edition of NFPA 13, the Committee on Automatic Sprinklers dealt with 53 proposals to make modifications to its earthquake protection provisions, and 19 comments with regard to preliminary Committee action on those proposals. Many of the proposals were the result of observations of system performance in the Northridge earthquake. However, as has been noted in the Commentary to the proposed *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, very few buildings involved in the Northridge earthquake had sprinkler piping installed in accordance with the 1991 edition of NFPA 13, the edition that was current at that time. Of the estimated 1 to 2 percent of the buildings that failed in the area affected by the Northridge earthquake, two-thirds were built before 1976 (BOCA, 1994). But just as it is difficult to determine by what amount newer buildings are safer against earthquakes, so it is impossible to accurately assess the total effectiveness of newer NFPA 13 earthquake protection criteria. The Committee can only review case histories to determine what are the weak points in system protection, and try to judge if those weak points have been successfully addressed by successive changes to the sprinkler installation standard.

It is not the intent of this analysis to decide appropriate earthquake protection features of sprinkler systems - those are determined through the consensus standards-development process of the National Fire Protection Association. However, it is the intent to ensure that the NFPA Committee on Automatic Sprinklers is aware of all subject areas that need to be addressed in subsequent changes to the earthquake protection requirements of NFPA 13.

Review of Relevant Studies and Recent Activities

Since the Northridge earthquake, there has been a substantial amount of activity in the area of protecting nonstructural systems against earthquakes. Part of this activity relates to follow-up and damage assessment. Other activity is related to national programs working toward improved earthquake protection for new buildings and for existing buildings. A summary of some of those activities and programs is as follows.

Fire Sprinkler Advisory Board of Southern California (FSABSC)

The Fire Sprinkler Advisory Board, an industry-funded organization serving the greater Los Angeles area, distributed 2,000 survey forms following the Northridge earthquake to elicit information on the performance of fire sprinkler systems. Of this amount, they received 225 completed responses. Most of the forms were completed by fitters who did the actual repairs to damaged systems, although some were filled out by staff based on field inspections or telephone conversations with fire protection contractors and others. The Board noted that the City of Los Angeles Department of Water and Power has identified about 14,000 fire sprinkler system services, of which 3,300 are located within the San Fernando Valley where the earthquake took place.

The report acknowledged that system installation practices, including earthquake protection requirements, have changed considerably with successive editions of the installation standard. However, the survey form did not ask about the year of system installation, or the age of the building. This limited the amount of analysis which could be completed based on the survey results. In many cases, however, it was still possible to draw conclusions based on the nature of the failure in terms of the available information on the system configuration and hanging and bracing techniques and materials employed. This led to the development of a list of types of system damage with corresponding "cause" factors, reprinted in Table 1.

The report also noted that significant damage to the water distribution system resulted in approximately 3,000 leaks within the San Fernando Valley, dropping the water pressure to zero in some areas. On January 22nd, five days after the earthquake, between 40,000 and 60,000 customers were still without public water service, and another 40,000 were experiencing intermittent service.

Although recognizing that the question of sprinkler system damage relative to other mechanical systems would be the subject of debate, the report noted that "in most cases documented in this Report, the owners and/or owners' representatives stated almost without exception that their automatic fire sprinkler systems performed as well or better than the other mechanical systems."

Table 1
FSABSC Northridge Earthquake Survey Summary

DAMAGE	CAUSE
Approximately 2,200 feet of Schedule 40 Steel Pipe (up to 8" in size) fell down off the ceiling of a warehouse.	• C-clamps (no retainer straps) • Powder-driven studs (sway bracing) • Seismic bracing - Longitudinal bracing
Branch lines fell	• 3/8 coach screw rods pulled out of structural members • Piping breaks at threads
Underground ductile piping (6-inch) broken	• Backfill not clean (concrete rubble)
Upright sprigs moved downwards	• Joints leaking
2-inch pipe threads pulled out of coupling	• Piping material • Depth of threads cut into pipe
Powder-driven studs broke out of concrete	• Powder-driven studs • Quality control
U-bolts pulled off	• C-clamps
Broken hangers/broken pipe	• Seismic bracing - Lateral bracing - Longitudinal bracing • C-clamps • Mechanical fittings
Sway bracing pulled out	• Lag bolts • Seismic bracing - Longitudinal bracing
Fasteners on 4-way pulled out of wall	• Expansion shields • Seismic bracing - Longitudinal bracing
Overturning rack storage pulled down overhead piping	• Stability of rack storage units • In-rack fire sprinklers • Piping arrangement
Replaced recessed fire sprinklers	• Solid ceilings (stucco/sheetrock) sheared sprinklers • Ridge piping systems did not move with ceilings
Repaired riser mechanical coupling	• 6-inch and 8-inch couplings • Tolerance (depth of groove)
Replaced hangers	• Seismic bracing

	- Lateral bracing - Longitudinal bracing • Fasteners used on hangers • Spacing and types of hangers
Hangers failed	• Seismic bracing - Lateral bracing - Longitudinal bracing • Coach screw rods pulled out of dry "old" wood • Lags pulled out of wood - Lags hammered in, not screwed into pilot hole
Sprinklers pulled up through ceiling	• Seismic bracing attached to metal decking • Fasteners pulled out • Hangers damaged/broken
Piping material broke at threads	• Threadable thinwall piping materials • Tolerance (depth of cut threads • Rigidity of material
Broken armovers	• Movement of large ducts (HVAC) • Fastened to duct
Grooved coupling leaking	• Rubber gasket bridle (old and hard) • Seismic bracing - Lateral bracing - Longitudinal bracing
Broking piping	• Seismic bracing - Fasteners (powder-driven studs) - Clearance through floors and walls
Broken pipe hangers	• Powder-driven studs
Broken underground piping	• Post Indicator Valve (PIV) moved
Broken overhead piping	• Seismic bracing - Longitudinal bracing • Fasteners pulled out - Powder-driven studs
Sprig up sprinklers rolled	• Maintaining alignment
Broken overhead piping	• C-clamps without retaining straps • Seismic bracing - Lateral bracing - Longitudinal bracing
Broken fire sprinklers	• Clearance to objects - Installed ¼" to ½ " from wood beam

Ayers & Ezer Associates

The Ayers & Ezer Associates Report entitled "Northridge Earthquake Hospital Water Damage Study" was prepared for the California Office of Statewide Health Planning & Development, and involved subconsultants Hillman Biddison & Loevenguth Structural Engineers. Published in April 1996, the work was started in August 1995 and was based on hospital damage survey forms and available publications regarding nonstructural damage. The report included a review of failures in pressurized piping systems, including fire sprinkler, HVAC, and domestic water systems. The report reviewed water damage reports from 13 hospitals in the vicinity of the Northridge earthquake. Three of the hospital facilities were shut down in the aftermath of the Northridge earthquake: St. John's in Santa Monica, The Veteran's Administration Medical Center in Sepulveda, and the Psychiatric Hospital in the Los Angeles County / USC Medical Center Complex. Two other hospitals, Olive View and Holy Cross, were closed for a week after the earthquake because of nonstructural damage.

A summary of damage attributed to sprinkler systems in the report is as follows:

> Tarzana Medical Center (0.3 g) - No damage
>
> Cedars-Sinai Medical Center (0.4 g) - Sprinklers on 1-inch lines crossing a seismic separation on floors 4 through 8 were activated by striking other building components. The 90-degree offsets used on each side of the seismic separation did not allow sufficient flexibility. A below-grade 8-inch supply main also failed.
>
> Holy Cross Medical Center (0.4 g) - Short drops (6 to 10 inches long) failed at screwed tee when sprinklers struck the hard (rated) ceiling within 20 ft of a seismic separation. Other sprinklers were opened by impact against the ceiling. A reported 1220 sprinklers and 401 two-piece escutcheons were used in the replacement.
>
> Kaiser Panorama City Medical Center (0.45 g) - Main building not sprinklered. A few failures of screwed joints and sprinklers in newer wings.
>
> Los Angles County USC Medical Center (0.3 g) - Not sprinklered
>
> Olive View Hospital (0.9 g) - Heavy damage reported, especially on top (6th) floor. T-bar ceiling with 5/8 gypsum and flush sprinklers resulted in failures of screwed fittings at tops of drops. A main failed on the 2nd floor. In some places, concealed sprinklers damaged by impact against ceilings.
>
> Medical Center of North Hollywood (0.45 g) - No damage

Northridge Hospital Medical Center (0.5 g) - Three underground pipe failures only

Santa Monica Hospital Medical Center (0.6 g) - A 1-inch line failed at a tee by impact against a duct.

Granada Hills Community Hospital (0.8 g) - No significant damage except for some C-clamp failures

Kaiser Foundation Hospital Woodland Hills (0.35 g) - A "few" sprinklers reported opened

Motion Picture & Television Hospital (0.4 g) - One or two slow leaks at screwed fittings

St. Francis Medical Center (0.2 g) - No damage

In the discussion of damage, the report states the following:

> "The fire sprinkler system sustained less damage than other piping systems in the buildings. Typical failures were broken C-type clamps, sheared or loosened lag bolts, fractured cast iron fittings, and a few pipe failures. In some buildings, sprinkler heads were damaged or activated when they pounded against adjacent objects and ceiling elements. The outstanding performance of fire sprinkler systems can be attributed to the installation requirements detailed in NFPA Standard 13."

One of the tasks addressed in the methodology was to evaluate the 1994 edition of NFPA 13 as a potential standard for corrective work.

Specific conclusions from the report dealing with fire sprinkler systems were the following:

> "1. Components failed when differential movements occurred at hard ceilings and walls, where heads struck other building components, and where lines crossed seismic separations.
>
> "2. Penetrations through rated corridor or non-rated hard ceilings with inadequate space for movement around the branch pipe, caused significant damage to threaded pipe joints.
>
> "3. Bracing failures (specifically one-sided C-clamps used for gravity hangers) contributed to the pipe movement and failures at screwed joints."

Many of the general recommendations in the report relate to items already addressed within NFPA 13, such as avoiding crossing of seismic separations and avoiding attachment to two structural systems that can move independently. Other recommendations are addressed within the particular subject area.

Earthquake Engineering Research Institute

Supplement C to Volume 11 of *Earthquake Spectra*, the journal of the Earthquake Engineering Research Institute (EERI), contained a Northridge Earthquake Reconnaissance Report which focused on damage from the earthquake, including observations on fire sprinkler system performance gathered from EERI investigators. Most of these observations report damage, but without specific information on the nature of the failure. Among the observations and recommendations in that report are the following:

-The latest version of the industry and code standard, NFPA 13, is too recent (1991) to have affected many buildings.

-The least common but most disruptive and dangerous type of failure was falling of pipes, including a 12-inch pipe that fell at the Fallbrook Mall in West Hills, demolishing a kiosk.

-Incompatible motions of sprinkler piping and other ceiling or ceiling plenum components was a common cause of damage.

-There is a possibility that the motions in some buildings were more severe than even well-designed, properly installed systems could withstand without some leakage.

-Suggestions for preventing leakage in essential facilities include zoning systems into smaller areas to allow damaged zones to be shut off, using automatically or remotely controlled shut-off valves, and more rigorous training of designated personnel in shut-off techniques.

-The desire to shut off systems following an earthquake to avoid water damage must be balanced against the need to have systems operational immediately after an earthquake when there is a higher chance of ignitions as well as less availability of fire department resources.

-The scientifically preferable way to decide what types of ceilings, sprinkler systems, or storage racks perform best or worst is to collect and analyze comprehensively collected data on a large and representative sample, rather than limited observations combined with judgment.

-The EERI nonstructural damage report form was little used and data collected were insufficient to support statistically valid statements.

California State Fire Marshal's Office

The Office of the State Fire Marshal in California commissioned a report on sprinkler system performance in the Northridge earthquake. The report led to a number of amendments to the 1994 edition of NFPA 13 as it was adopted for official use in the state:

Section 4-6.4.3.5.13 (C-type clamps) Delete "or other approved means to prevent movement." Add a second sentence:

> "The retaining strap shall be listed for use with a C-type clamp, or shall be a steel strap of not less than 16 gauge thickness and not less than 1 inch wide for pipe diameters 8 inches or less and 14 gauge thickness for pipe diameters greater than 8 inches. The retaining strap shall wrap around the beam flange not less than 1 inch. A lock nut on a C-type clamp shall not be used as a method of restraint. A lip on a "C" or "Z" purlin shall not be used as a method of restraint."

Section 4-6.4.3.5.3 (Sway brace components) Add a sentence after the first sentence:

> "Where pipe is used for sway bracing, it shall have a wall thickness of not less than Schedule 40."
>
> Also, delete the portion of Table 4-6.4.3.5.3 related to Schedule 10 pipe.

Section 4-6.4.3.5.15 (Brace fasteners) Revise as follows:

> "<u>Lag screws</u> or powder-driven fasteners shall not be used to attach braces to the building structure."
>
> (Exception to be deleted)
>
> Also, delete the portion of Table 4-6.4.3.5.4 related to lag screws.

Table 4-6.4.3.5.4 (Through bolts) Add a note to the table as follows:

> "A flat washer shall be provided at each end of the through bolt. The diameter of the hole shall be not greater than 1/16 inch greater than the diameter of the bolt."

A-4-6.4.3.5.1 (Appendix forms) Add new appendix section:

"The following forms are provided to assist in the layout, plan review, installation, and inspection of seismic braces. This form is not required to be used for every brace. A worst case brace calculation is considered acceptable."

All of these items were reviewed by the NFPA Committee on Automatic Sprinklers and most incorporated in the changes to the 1996 edition of NFPA 13.

Factory Mutual

As an organization representing several large insurance companies, Factory Mutual Research Corporation publishes its own earthquake protection standards for fire sprinkler systems. Based on its review of the performance of sprinkler systems in the Northridge earthquake, the Factory Mutual System released a new edition of Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*, dated August 1996. The new data sheet represents a substantial increase in severity of earthquake protection measures beyond those detailed in NFPA 13. In fact, many of the changes in the data sheet were proposals that Factory Mutual had unsuccessfully made to change the 1996 edition of the NFPA sprinkler standard. The most significant departures from NFPA 13 are the following:

1. Sway bracing is recommended to consist of either two opposing diagonal braces or one diagonal brace and one vertical brace. If opposing diagonal braces are used, each can be designed for one-half the normal brace load. If a vertical brace is used, it can be a hanger if it is located within 6 in. of the point of attachment of the brace and meets the following additional requirements:

(a) The hanger must be able to resist the vertical resultant force V_F, determined as

$$V_F = (H) / \tan \alpha$$

where α is the angle between the vertical hanger and the brace, and H is the horizontal design load.

(b) The slenderness ratio of the hanger does not exceed 200, which can be achieved by means of a rod stiffener.

(c) The hanger is attached to the structure through a positive means of mechanical attachment, such as through bolts, lag screws or concrete anchors which are properly sized for the load.

(d) The hanger attachment to the fire protection system is snug and concentric, with no more than1/2-inch between the top of the piping and the hanger so that excessive movement cannot occur.

NFPA 13 requires the resultant vertical force to be addressed where horizontal force factors are high, but does not specify the arrangement.

2. Omission of lateral sway bracing for piping supported by hanger rods less than 6 in. long is not be acceptable as it is in NFPA 13.

3. The maximum slenderness ratio l/r is limited to 200 to minimize buckling concerns. NFPA 13 permits a maximum of 300 with correspondingly reduced loads.

4. The maximum distance of lateral and longitudinal braces from the ends of the mains being braced is limited to 6 ft and 40 ft respectively. NFPA 13 requires only that the last length of pipe be provided with a lateral brace, and permits up to 80 ft of main to be braced with a single longitudinal brace at one end.

5. The zone of influence method, whereby the actual weight of the piping is considered in the selection of braces and fasteners, is to be used in all cases. NFPA 13 permits the alternate use of a very conservative assigned load table.

6. Wrap-around U-hangers are not permitted as sway braces, except for gridded system branch lines provided the U-hangers meet specific size, orientation and fastening criteria. NFPA 13 permits U-hangers to be used as lateral braces provided the legs are bent out at least 30 degrees and the size meets the minimum requirements for rods used as braces.

7. Powder-driven fasteners are not permitted to attach either pipe hangers or sway braces. NFPA 13 permits powder-driven fasteners for use with hangers in low-risk earthquakes areas, but permits them for use with braces and with hangers in high-risk earthquake areas only when specifically investigated and listed for such purposes. To date, there are no such listings.

8. The data sheet includes a figure which showing attachment of the 4-way brace at the top of the riser to a wall rather than the roof structure, which is shown to be preferred in the NFPA 13 appendix figure. The data sheet requires, however, that the attachment be to a structural element as opposed to as lightweight wall panel.

9. Storage racks and suspended ceilings with sprinklers are both recommended for seismic design. NFPA 13 cannot address these items within its scope.

10. The possibility of listing a tension-only cable bracing system is not recognized. NFPA 13 permits this by means of a special listing.

In conformance with FM proposals to NFPA 13, earlier drafts of the data sheet suggested a minimum horizontal force of 1.2 times gravity, but the final version states a "minimum 'g' factor of 0.5, or a higher 'g' factor if required by local authorities per the building code for the location involved." This avoids a problem as to application of the data sheet in low-risk seismic zones. The data sheet states that it is intended to apply to areas designated by Factory Mutual as "earthquake zones 150 or less" as shown in FM Data Sheet 1-2S, *Maps of Earthquake Zones*. Unlike NFPA 13, the FM data sheet provides no modifier which would permit the same basic protection measures to be applied using reduced loads in areas that are considered subject to earthquake, but to a lesser degree than California. By referencing requirements of building codes, the data sheet avoids conflicts with the currently-changing building regulations.

The data sheet reports that the 1994 Northridge, 1989 Loma Prieta and 1987 Whittier earthquakes combined to produce a total of 144 sprinkler leakage losses for the Factory Mutual System, for a total gross loss in 1995 dollars of $30 million, or an average of $212,000 per loss. Water damage losses from pumps, tanks and reservoirs were reported to be relatively insignificant.

NIBS/BSSC 1997 NEHRP Revisions

With funding from the Federal Emergency Management Agency, the Building Seismic Safety Council has been developing the 5th edition of the *National Earthquake Hazard Reduction Program (NEHRP) Provisions.* These 1997 *Provisions* are expected to form the basis of the earthquake protection rules of the consolidated model building code expected to be adopted in 1999 by the three current model building code groups in the United States.

Structural design under the proposed 1997 *NEHRP Provisions* is controlled through limits on two basic parameters: lateral structural strength and lateral structural stiffness. A design ground motion is specified, and the effect of this motion on the structure is determined through elastic response spectrum analysis or through a simplified approximation to this approach, the elastic lateral force technique. Expected forces can be large, especially in zones of high seismicity. Observation of the performance of structures in earthquakes has shown, however, that structures with inherent ductility in their load paths and connections can withstand strong ground shaking which would be expected to exceed their lateral strength capacities. The *NEHRP Provisions* therefore permit design for lateral strength reduced by a factor R, selected from a table based on the type of lateral force resisting system. It is recognized that structures so designed will respond to the design earthquakes in an inelastic manner, and will experience lateral drifts that are much greater than would be obtained from the reduced lateral loading.

The *NEHRP Provisions* changed from a working stress basis to a strength basis with the publication of the 1994 edition. The *Provisions* assume that the structure will yield, but that it will not deform beyond a point of "significant yield".

Drift control is obtained through a two-step process. Interstory drifts are computed based on the design force levels. Drifts are then amplified by a factor C_d to obtain an approximate estimate of the real drift. The C_d values are also taken from a table and are based on the system. They account, approximately, for differences in elastic and inelastic response. Upper limits are placed on the permissible real drift, based on the structural type and desired performance.

For the 1997 edition of the NEHRP Provisions, a joint effort of the BSSC, the Federal Emergency Management Agency (FEMA), and the U.S. Geological Survey (USGS) was conducted to develop new earthquake motion maps and a new design procedure, to take advantage of advances made in the 20 years since the existing maps were developed. In a departure from past practice, the new maps:

1. Define the maximum considered ground motion for use in design procedures.

2. Provide approximately uniform protection against collapse for ground motions in excess of the design levels in all parts of the country.

3. Are based on both probabilistic and deterministic seismic hazards.

4. Are response spectra ordinate maps and reflect the differences in the short-period range of the response spectra for the areas of the United States with different ground motion attenuation characteristics.

For the 1997 *Provisions*, 50 years has been used as the useful life of buildings, and the design earthquake is that which has only a 10 percent chance of exceedance in 50 years. In other words, a return period of about 500 years. The degree of conservatism in the provisions is based on a minimum margin of 1.5 times the design earthquake.

The Maximum Considered Earthquake (MCE) will be approximately equal to a 2500 year event in the East, but will be deterministically defined for the West. To bring it down to a design level, the MCE will be multiplied by 2/3.

It has been recognized that anchorage provisions are inconsistent among the various chapters of the *NEHRP Provisions,* and this is a subject of continuing discussion. The 1997 *NEHRP Provisions* are not expected to address component anchorage for the various building materials in a manner adapted to the new inelastic limit design approach.

The technical subcommittee in charge of mechanical and architectural systems (TS8) made a number of proposals for changes in the 1997 edition of the *NEHRP Provisions*. Some of those changes were later amended at the November 18-20, 1996 meeting of the

Provisions Update Committee. One of the most significant changes concerns the basic proposed formula for seismic forces F_p. As presently proposed, the formula will be:

$$F_p = \frac{0.4\, a_p\, S_{DS}\, W_p}{R_p / I_p} (1 + 2x/h)$$

although F_p need not be taken as greater than:

$$F_p = 1.6\, S_{DS}\, I_p\, W_p$$

and F_p shall not be taken as less than:

$$F_p = 0.3\, S_{DS}\, I_p\, W_p$$

where

F_p = seismic design force

S_{DS} = Spectral acceleration, short period

a_p = Component amplification factor relative to the fundamental period of the structure (1.0 for piping systems)

I_p = Component importance factor (1.5 for life-safety components required to function after an earthquake and for all components in essential facilities)

W_p = Component operating weight

R_p = Component response modification factor, representing both the overstrength and ductility of the component's structure and attachments (2.5 for piping systems employing ductile materials and ductile attachments)

x = Height in structure of highest point of attachment of component (x = 0 for items at or below grade)

h = Average roof height of structure relative to grade elevation

The seismic design force equations originated with a study and workshop sponsored by the National Center for Earthquake Engineering Research (NCEER) with funding from the National Science Foundation (NSF) (Drake and Bachman, 1994). Recorded acceleration data in response to strong earthquake motions was examined, with the objective to develop a "supportable" design force equation that considered actual earthquake data as well as component location in the structure, component anchorage ductility, component importance, the safety hazard posed by the component if separated from the structure, the response of the structure, the site conditions, and the seismic zone. Additional studies (Bachman and Drake, 1995 and 1996) revised the equation to its present form. Final adjustments were made to make the provisions consistent with the 1997 edition of the *Uniform Building Code.*

Two significant changes from past codified requirements are:

1. The inclusion of site soil conditions in the determination of S_{DS}.

2. The inclusion of an amplification factor for components on top floors of structures.

S_{DS} is determined by multiplying the response acceleration parameters by site coefficient F_a, designated in tables based on the soil types and the spectral acceleration S_S, taken from a map corresponding to BSE-1.

$$S_{DS} = Fa\ S_S$$

Mapped values of S_S, based on reference site material with 760 m/s shear wave velocity, go as high as 300% g in some parts of the west coast, up to 40% g in the New Madrid fault area, and up to 10% g in the New York City area. This corresponds to a Class B soil condition, designated as rock. For other soil conditions, multipliers must be used from the table below, which yields values of Fa as a function of site class and mapped short-period spectral response acceleration S_S :

Values of F_a as a Function of Site Class and S_S

Site Class	**$S_S < 0.25$**	**$S_S = 0.50$**	**$S_S = 0.75$**	**$S_S = 1.00$**	**$S_S > 1.25$**
A (hard rock)	0.8	0.8	0.8	0.8	0.8
B (rock)	1.0	1.0	1.0	1.0	1.0
C (dense soil or soft rock)	1.2	1.2	1.1	1.0	1.0
D (stiff soil)	1.6	1.4	1.2	1.1	1.0
E (soft clay)	2.5	1.7	1.2	0.9	*
F (peats, high plasticity clays, etc.)	*	*	*	*	*

* Requires site-specific geotechnical investigation and dynamic site response analyses.

The soil types are more precisely described within the guidelines, with standard blow counts and undrained shear strength values assisting in the soil classification system.

The height amplification factor is based on recorded in-structure acceleration data in large California earthquakes that showed a reasonable maximum value for the roof acceleration is four times the input ground acceleration (Drake and Bachman, 1995 and 1996). The maximum design equation is intended to bound 84 percent of the recorded data.

Using the default equation for maximum load, with $S_S = 50\%$ and site class B,

$$S_{DS} = Fa\ S_S = 0.5$$

so

$$F_p = 1.6\ S_{DS}\ I_p\ W_p = 1.6\,(0.5)\,(1.5)\,W_p = 1.2\ W_p$$

Compared to current values such as those used in the Uniform Building Code (see Appendix A), this represents a sizable increase in loads, and yet the site class and S_S values selected were far from worst case.

The proposed 1997 *NEHRP Provisions* also address sprinkler/ceiling interaction. In Seismic Design Categories D, E, and F, except where rigid braces are used to limit lateral deflections of ceilings, sprinklers and other penetrations will be required to have a 2-inch (50 mm) oversize ring, sleeve, or adapter through the ceiling tile to allow for free movement of at least 1 inch (25 mm) in all horizontal directions. Alternatively, a swing joint that can accommodate 1 inch (25 mm) of ceiling movement in all horizontal directions may be provided at the top of the sprinkler drop. In Seismic Design Categories B and C, sprinklers will be required to have a minimum of 1/4 inch (6 mm) clearance on all sides.

The *NEHRP Provisions* address other components that can affect sprinkler system protection criteria. For steel storage racks, for example, the proposed NEHRP provisions are calling for an assumed total relative displacement to adjacent or attached components and elements of at least 5 percent of the height above the supporting floor unless a smaller value is justified by test data or analysis.

The 1997 *NEHRP Provisions* will reference the 1996 edition of NFPA 13 as follows:

> "3.3.11. **Fire Protection Sprinkler Systems.** Fire protection sprinkler systems designed and constructed in accordance with Ref. 3-12 (NFPA 13 -1996) shall be deemed to meet the force, displacement, and other requirements of this section provided that the seismic design force and displacement used, multiplied by a factor of 1.4, is not less than that determined using these *Provisions*."

The factor of 1.4 is intended to accommodate the fact that the *NEHRP Provisions* are based on strength design rather than working stresses, whereas NFPA 13 is considered to be based on allowable working stresses.

BSSC Rehabilitation Guidelines

In 1994, President Clinton issued a directive under which all federally-owned or leased buildings are required to meet standards of Safety for Existing Federal buildings. While those standards call for an evaluation of nonstructural features, the evaluation is aimed at "major mechanical items suspended from the ceiling without bracing", as well as elevators, external building cladding, and other architectural appendages. In other words, things that might actually fall, resulting in injury or death. Sprinkler systems are generally not included as a subject of concern.

The most ambitious effort to date in addressing seismic rehabilitation is being funded by the Federal Emergency Management Agency through the National Institute of Building Sciences (NIBS), the American Society of Civil Engineers (ASCE), and the Applied Technology Council (ATC). Since 1991, the NIBS Building Seismic Safety Council (BSSC) has served as program manager for a 6-year $10 million effort to develop a set of nationally applicable guidelines for the seismic rehabilitation of existing buildings.

The project has produced the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings,* which is currently being balloted, and which is expected to achieve consensus approval during 1997. A chapter of the *Guidelines* is devoted to architectural, mechanical and electrical components, and includes fire sprinkler systems.

For buildings in general, the *Guidelines* recognize several possible objectives: complete rehabilitation, partial rehabilitation, or reduced rehabilitation. Partial rehabilitation would address some but not all potential modes or aspects of failure. Reduced rehabilitation is a complete rehabilitation but at a level less than standard. The Guidelines recognize various performance levels as well: collapse prevention level, life safety level, immediate occupancy level, or operational level.

There appears to be a consensus that buildings should have two basic earthquake protection design points. They should be able to maintain life safety level performance when subjected to the ground motion associated with a traditional design earthquake, the Basic Safety Earthquake 1 (BSE-1), which has a 10 percent chance of exceedance in 50 years. In other words, the 500-year earthquake. They should also provide collapse protection against the large rare earthquake event designated the Maximum Considered Earthquake (MCE) or BSE-2. This is an earthquake with a 2 percent chance of exceedance in 50 years, or the 2500-year earthquake. Considering inherent structural safety factors, the structural community is calling for new buildings to be designed, with traditional design rules, for two-thirds of the MCE ground motion values. The same is to be included for existing buildings in the *Guidelines*.

Performance levels of nonstructural components are separate from the structural performance. For nonstructural systems, the design earthquake is that with a 10 percent probability of exceedance in 50 years. The MCE is not considered, since the goal of preventing building collapse does not presume integrity of nonstructural systems.

For fire sprinkler systems, the proposed *Guidelines* are a bit more simple. Compliance with the 1996 edition of NFPA 13 is recognized as providing life safety level protection, and the *Guidelines* simply note that higher (immediate occupancy) level compliance criteria "are similar to those for life safety". As submitted for balloting, the *Guidelines* would suggest seismic rehabilitation for fire sprinkler piping only in areas with high seismic risk..

Determine the areas of high seismic risk is not as simple as traditional codes have suggested, with their national maps designating seismic zones. Maps are still proposed for use, but the soil conditions of the site also play a role.

Zones of high seismicity are defined in the *Guidelines* as those for which the 10%/50 year design short-period response acceleration S_{DS} is equal to or greater than 0.5g, or for which the 10%/50 year design one-second period response acceleration S_{D1} is equal to or greater than 0.2g.

S_{DS} and S_{D1} are determined by multiplying the response acceleration parameters by site coefficients F_a and F_v, designated in tables based on the soil types and the spectral accelerations S_s and S_1 corresponding to BSE-1 and BSE-2.

Working backwards, high risk sites would be those with the following approximate soil/response acceleration combinations:

	S_s	S_1
Class A soil (hard rock with shear wave velocity over 5,000 ft/s)	>0.62g	>0.25g
Class B soil (rock with moderate shear wave velocity)	>0.50	>0.20
Class C soil (dense soil or soft rock)	>0.40	>0.10
Class D soil (stiff soil)	>0.35	>0.08
Class E soil (more than 10 ft soft clay layer in profile)	>0.20	>0.05
Class F soil (highly-sensitive clays, peats, or other weak soils)	Req. specific eval.	

The soil types are more precisely described within the guidelines, with standard blow counts and undrained shear strength values assisting in the soil classification system. Where insufficient data is available for classification, a Class E profile is assumed.

Even with hard rock, the classification of high risk site would include almost all of California and the west coast, the New Madrid area near St. Louis and Memphis, and the area near Charleston, South Carolina. With soft soils, it also includes almost everything west of Denver, and substantial parts of New England, the mid-Atlantic, and some mid-western states as well.

It appears therefore that a consensus is forthcoming that sprinkler systems should be protected against earthquakes in many parts of the country. As systems are installed on a retrofit basis in these areas, they should use the earthquake protection criteria of NFPA 13.

Underwriters Laboratories

Underwriters Laboratories, along with Factory Mutual Research Corporation, serves to provide quality control for equipment used in fire sprinkler systems. Generally, equipment that is considered critical to successful system performance is required within NFPA 13 to be "listed". Under the NFPA standards, "listed" is defined as "equipment, materials or services included in a list published by an organization acceptable to the authority having jurisdiction and concerned with evaluation of products or services that maintains periodic inspection of production of listed equipment of materials or periodic evaluation of services, and whose listing states either that the equipment, material or service meets identified standards or has been tested and found suitable for a specified purpose." Since Factory Mutual is also an authority having jurisdiction, its listing automatically implies FM "approval". Underwriters Laboratories listings are almost universally acceptable to other authorities having jurisdiction throughout the United States. UL, as a policy, lists fire sprinkler equipment in accordance with the stated intent of NFPA 13.

Working with the NFPA 13 Committee's Earthquake Protection Task Group, UL revised its standard 203A for rigid earthquake braces, with an effective date of November 27, 1996. The revised standard helps organize brace equipment, defining a "sway brace assembly" as follows:

> "Sway Brace Assembly - A structural system, consisting of a sway brace fitting attached directly to the sprinkler system pipe and one end of a sway brace, and a structure attachment fitting attached directly to the building structure and the other end of a sway brace, intended to connect sprinkler system piping to a building structure to provide resistance to relative horizontal movement between the building and the sprinkler system during an earthquake."

The UL standard defers to NFPA 13 for maximum slenderness ratio of the sway brace, but notes that a sway brace is not required to be supplied by the sway brace fitting manufacturer or the structure attachment fitting manufacturer. Lateral sway brace components and longitudinal sway brace components must be individually designated and investigated for use. Maximum loads per fastener hole are designated for structure attachment fittings. Static testing is used to determine maximum loads without permanent deformation or slippage, and a safety factor of 1.5 is applied to obtain a published load rating for the brace assembly or fitting. The test loads are applied in both compression and tension, and in directions both perpendicular to the building structure and parallel to the building structure. As part of the listing, each sway brace fitting and structure attachment must be marked with the sprinkler system pipe size(s) intended for use, and a minimum rated load is designated for each pipe size as shown in the table below. The load values represent one-half the weight of an 80 ft length of water-filled Schedule 40 steel pipe (schedule 30 for 10 and 12-inch), although the values for 2 and 2-1/2-inch pipe are the minimums from the assigned load table of NFPA 13.

Sprinkler System Pipe Size (in.)	**Minimum Rated Load (lb.)**
2	380
2-1/2	395
3	435
3-1/2	540
4	655
5	935
6	1265
8	2015
10	2765
12	3740

Working with Underwriters Laboratories, the Power-Actuated Tool Manufacturers' Institute (PATMI) has proposed a draft of a new UL 203B, *Standard for Power-Driven Fasteners for Attaching Hangers and Sway Braces for Fire Protection Service in Seismic Areas*. Intended to supplement UL 203 and 203A, the draft standard contains both a hanger seismic test procedure and a sway brace fastener test procedure. For hangers, the draft standard calls for fasteners to be installed in the base material, and to be connected to a 1 meter long rod of 3/8 in. diameter. The free end of the rod is cycled 10 times at one Hz through a in-plane horizontal movement of 8 in. to each side of vertical. The fasteners are then tested in tension to failure to compare the ultimate capacity of the cycled fasteners to those tested simply in tension under the provisions of UL 203. Average ultimate capacities of the cycled fasteners are proposed to be at least 90 percent of the ultimate capacities of the non-cycled fasteners. The load rating is proposed to be the minimum assigned load for the pipe size per the Assigned Load Table of NFPA 13.

For sway brace fasteners, the draft calls for fasteners to be tested at 10 cycles of one Hz of an alternating shear (lateral) load at 2 times the proposed load for which the fastener is to be rated. The rating may be determined from static shear tests to determine the shear capacity or from the following table, which is intended to represent one-half the weight of an 80-ft length of water-filled Schedule 40 steel pipe:

Sprinkler System Pipe Size (in.)	Minimum Rated Load (lb)
2	380
2-1/2	395
3	435
3-1/2	540
4	655
5	935
6	1265

Analysis of System Performance and Recommendations for Proposals to NFPA 13

In addition to on-site observations following the earthquake, the various information sources cited above were examined for information and opinions with respect to system performance in the earthquake in the individual subject areas of concern:

1. Applicability of Earthquake Protection Provisions
2. General Intent of Earthquake Protection Provisions
3. Flexible Couplings - General Applicability
4. Flexible Couplings for Risers
5. Drops to Hose Lines and Sprinklers in Racks
6. Flexible Couplings for Expansion Joints
7. Seismic Separation Assemblies
8. Clearances
9. Sway Bracing - General
10. Sway Bracing - Loads
11. Sway Bracing - Longitudinal Bracing
12. Sway Bracing - Lateral Bracing
13. Sway Bracing for Excessive Flexibility
14. Short Hanger Exception to Bracing
15. Bracing/Restraint of Branch Lines
16. Ceiling/Sprinkler Interaction
17. Sway Bracing - Brace Components
18. U-Hooks as Sway Braces
19. Sway Bracing - Fasteners to Structure
20. Hanger and Piping Restrictions in Earthquake Areas

For each area of concern, historical changes in the treatment of this item within NFPA 13 are first reviewed, arranged by the year of edition of the standard. Observations regarding performance of systems in each category are then discussed, along with identification of the source. Any changes adopted as part of the 1996 edition of the standard are presented, and recommendations for additional changes are noted for possible consideration by the NFPA Committee on Automatic Sprinklers.

1. Applicability of Earthquake Protection Provisions

1974 - Where subject to earthquakes

1996 - When ...(required) to be protected against damage from earthquakes

Observations from Northridge Earthquake:

Applicability of the NFPA 13 earthquake protection criteria to sprinkler systems in the area involved in the Northridge Earthquake was never in question. However, the specific edition of NFPA 13 used in the protection of individual systems is believed to have played a major role. NFPA 13 protection provisions have been strengthened through the years, especially since 1987, when brace and fastener load tables first appeared in the document to provide guidance in that area.

Adopted changes to 1996 Edition of NFPA 13:

In response to a request for clarification from the U.S. Department of Energy, the Committee revisited the issue of whether the standard intends to require earthquake protection of sprinkler systems. DOE pointed out that wording of NFPA 13 providing criteria "where subject to earthquakes" was being interpreted as a mandate for earthquake protection of systems in most seismic zones in both the western and eastern United States.

Section 4-14.3.4.1 was revised to read: "When sprinkler systems are to be protected against earthquakes, the requirements of Section 4-14.3.4 shall apply."

Proposed additional changes to NFPA 13:

FM proposed updating the appendix maps to latest versions of NEHRP or ASCE-7, and the Committee took the opportunity to again clarify that the maps are examples only, since NFPA 13 does not determine when seismic protection is required.

The DOE also proposed deletion of the term "dynamic" in the exception to the general applicability section, noting that equivalent static methods and beam formulas are usually used to seismically evaluate piping systems as an alternate to dynamic analysis. Additionally, DOE urged that the piping system seismic capacity not be linked to building seismic capacity. The Committee held these proposals for further study. DOE is suggesting that simpler less costly alternatives are available, and has pointed to upcoming publication by the Pressure Vessel Research Council (PVRC) of a Bulletin on equivalent static loads for seismic analysis of piping (Antaki et al, 1996).

The use of a Maximum Considered Earthquake in addition to a design earthquake in the 1997 NEHRP Provisions and proposed Rehabilitation Guidelines make it obvious that the design basis of a nonstructural system is not intended to be the same as the structure.

Therefore, while the 1996 change helps clarify that the NFPA 13 earthquake protection rules only apply when some authority having jurisdiction has made that determination, the Committee may want to consider revising the exception to clarify that the alternate approach does not have to be based on a dynamic analysis, nor does the sprinkler system performance need to match that of the structure itself.

2. General Intent of Earthquake Protection Provisions

1983 - Minimize or prevent pipe breakage

1991 - Prevent pipe breakage

Observations from Northridge Earthquake:

In general, system performance involving even minor pipe breakage or opening of sprinklers was considered unsatisfactory.

Adopted changes to 1996 Edition of NFPA 13:

None

Proposed additional changes to NFPA 13:

The stated intent of the provisions, "to prevent pipe breakage" should be clarified in two ways. One is that inadvertent operation of sprinklers is considered as equivalent to pipe breakage. The other is with regard to the operational readiness of the system. The other unstated intent is that, if the building remains occupiable and the water supply source is intact, the fire sprinkler system should be fully operational.

3. Flexible Couplings - General Applicability

1983 - For piping 3½ in. or larger

1994 - For piping 2½ in. or larger

Observations from Northridge Earthquake:

To determine the general effectiveness of present requirements for flexible couplings, a review of incident reports was made to determine if broken overhead or riser piping was reported in the absence of inadequate bracing which resulted in severe shifting or falling of mains. Most of the reports of broken piping involved such shifting or falling. Only a couple of others were reported:

-At the Panorama Towers high rise, an underground ductile iron main cracked, reportedly due to pressure of shifting earth pushing against a piece of concrete rubble.

-At the Ragu Foods Warehouse in North Hollywood, 3-1/2 and 4-inch pipe required repairs, although no hanger or brace problems were reported.

Flexible couplings were not without their problems. At the Lucky Store in Hermosa Beach, a 6-inch grooved joint required repair despite no reported problems with hangers or braces. At George Rice & Sons Printers in Los Angeles, grooved couplings required replacement due to hardened gaskets. At least a half dozen warehouses were reported to have experienced leaks from grooved couplings when the gaskets would not seat properly after being disturbed by earthquake motion. Repairs at another warehouse involved the need to reinstall an 8-inch grooved coupling that had pulled out of the groove.

Adopted changes to 1996 Edition of NFPA 13:

None

Proposed additional changes to NFPA 13:

The DOE proposed that the standard address the issue of allowable loads, displacements and rotations of all mechanical couplings, but this was rejected by the NFPA 13 Committee on the basis that there have been no reports of failures of these devices. DOE has performed additional work in this area (Antaki et al, 1996), and the results of that study should be reviewed by the Committee to ensure that product listing standards are appropriate for anticipated earthquake loads under current hanger and brace spacing rules.

There also needs to be a clarification with regard to requirements for piping passing through walls. Section 4-14.4.3.2(c) currently calls for a flexible coupling on one side of concrete or masonry walls within 3 ft (0.9 m) of the wall surface. An exception to this section states that the flexible coupling is not required if clearance around the pipe is provided in accordance with 4-14.4.3.4. However, within that section, the clearance is waived only if flexible couplings are provided within 1 ft (0.3 m) of both sides of the wall. The standard is therefore inconsistent as to the level of flexibility that can substitute for the required clearance.

4. Flexible Couplings for Risers

1983 - At the top and bottom of risers and at the ceiling of each intermediate floor.

1994 - Within 12 in. above and below the floor in multistory buildings such that the flexible coupling below the floor is below the main supplying that floor.

Observations from Northridge Earthquake:

Very few problems were reported with flexible couplings on risers. The exception was the Sears store in the Northridge Fashion Center, where a broken grooved coupling was reported at the riser.

Adopted changes to 1996 Edition of NFPA 13:

None

Proposed additional changes to NFPA 13:

None

5. Drops to Hose Lines, Sprinklers in Racks, and Portions of Systems

1983 - Fittings with flexible joints at the top of drops to hose lines (all sizes).

Swing joints assembled with flexible fittings on drops to racks over 3 in.

1987 - Flexible couplings at the top of drops to hose lines (all sizes).

Swing joints with flexible fittings on drops to racks (all sizes).

1989 - Flexible coupling at the top of drops to hose lines, rack sprinklers and mezzanines (all sizes).

Flexible coupling at the top of drops exceeding 15 ft. to sprinklers or portions of systems (all sizes).

1991 - Flexible coupling within 24 in. of ceiling at top of drops to hose lines, rack sprinklers and mezzanines (all sizes).

Flexible coupling within 24 in. of ceiling at top of drops exceeding 15 ft. to portions of systems supplying more than one sprinkler (all sizes).

1994 - Same as 1991 but delete “of the ceiling”.

> “Flexible listed pipe coupling” defined as “a listed coupling or fitting that allows axial displacement, rotation, and at least 1 degree of angular movement of the pipe without inducing harm on the pipe” (minimum 0.5 degrees for 8-in. and larger).

1996 - Add “at top and bottom”

Observations from Northridge Earthquake:

While there were no significant reports of problems with drops to hose lines or portions of systems, drops to sprinklers in racks were cited as a frequent problem. Much of this, however, was considered due to collapse or severe distortion of the rack structures.

Adopted changes to 1996 Edition of NFPA 13:

The degree of required flexibility was enhanced considerably by the requirement for flexible couplings at the bottom of the drops as well as the top. The Committee agreed that considerable flexibility is needed, particularly to connections to free-standing racks which move independently of the structure.

Proposed additional changes to NFPA 13:

There is a presumption in the standard that the piping at the bottom of the drop is anchored to the building structure in some manner. However, it should be noted that these provisions also apply, in subsection (f), to drops exceeding 15 ft in length to portions of the system supplying more than one sprinkler. This is being interpreted in the field to include drops to branch lines which are suspended more than 15 ft below the mains that serve them. In such a case, the concept of providing basic alignment of branch lines by means of bracing the cross mains is invalid. Even where this additional flexibility is not provided, the standard needs to address the limits associated with transference loads from the branch lines to the mains.

For racks, the proposed NEHRP provisions are calling for an assumed total relative displacement to adjacent or attached components and elements of at least 5 percent of the height above the supporting floor unless a smaller value is justified by test data or analysis. This 5 percent displacement exceeds the expected allowable displacement offered by two flexible couplings on a drop from a roof main, especially if the drop is relatively short. A requirement for additional flexibility in drops to free-standing racks should be considered.

6. Flexible Couplings for Expansion Joints

1983 - On one side of building expansion joints.

1987 - At or near building expansion joints (Seismic separation assembly needed for seismic separation joints).

Observations from Northridge Earthquake:

No specific reports

Adopted changes to 1996 Edition of NFPA 13:

None

Proposed additional changes to NFPA 13:

None

7. Seismic Separation Assemblies

1987 - Swing joints assembled with flexible fittings required where piping crosses seismic joints. Figure added to appendix.

1989 - Adds "regardless of size".

1991 - Designated as "seismic separation assembly".

Observations from Northridge Earthquake:

No specific reports

Adopted changes to 1996 Edition of NFPA 13:

None

Proposed additional changes to NFPA 13:

The requirement for seismic separation assemblies is fairly new and considered fairly conservative in that it requires the use of six flexible couplings in combination. Based on field reports, better guidance is needed for sizing the seismic separation assembly for various combinations of pipe diameter and separation distance. Guidance is also needed with regard to support of the assembly itself, and bracing requirements for the piping on either side of an assembly. A common question is whether the first piping downstream of a seismic separation assembly requires 4-way bracing like the top of a riser.

8. Clearances

1983 - Clearance through walls, floors, platforms and foundations 1 in. all sides through 3½-in pipe, 2 in. all sides 4-inch and larger.

Exception added to permit pipe sleeves of nominal diameter 2 in. larger through 3½-in. pipe (4 in. larger for 4-inch and larger pipe).

Exception added for pipe passing through gypsum board or equally frangible construction not required to have a fire-resistance rating.

1985 - Flexible joints permitted to substitute for clearance for pipe entering a basement wall with ground water conditions.

1987 - Flexible couplings or swing joints within one foot of both sides permitted to substitute for clearance in any wall.

1994 - Flexible coupling within 1 ft. of each side accepted as alternative for walls, platforms and foundations.

1996 - Flexible coupling within 1 ft. of each side accepted as alternative for floors as well as walls, platforms and foundations.

Clearances based on overall hole size, not clearance on all sides

Observations from Northridge Earthquake:

Insufficient clearances to objects were cited by both the FSABSC and Ayers & Ezer reports as a cause of broken sprinklers and piping. Some, such as the Northridge Hospital, involved lack of clearances around pipe passing through floors and walls, despite long-standing requirements of NFPA 13 for such clearances. Others involved gray areas. At the Sears store in North Hollywood, damage resulted from inadequate clearance from ducts. At the Arcs Mortgage facility in Calabasas, damage resulted from inadequate clearance to the lower edge of wood beams.

Adopted changes to 1996 Edition of NFPA 13:

The second paragraph of the section on clearances, 4-14.4.3.4.1, was totally rewritten in 1996. Basic to the rewrite is the clarification that clearance is required in terms of the diameter of the hole compared to the diameter of the pipe. Formerly, the section was written to require clearance on all sides of the pipe, which led some to question whether the pipe was required to be suspended as when supported by holes through concrete beams.

A new provision within the section requires a minimum clearance of 2 inches (50 mm) from structural members not required, individually or collectively, to support the piping.

As noted above, floors were added to the list of structural members for which flexible couplings on both sides can substitute for clearances.

Proposed additional changes to NFPA 13:

The simplification of clearance criteria to overall diameter size solves the question of suspending the pipe in the middle of successive holes through structural members, but open the door to the possibility that the clearances in such a case could be on alternate sides of the pipe in alternate openings, resulting in no real clearance at all. This should be rewritten to require clearance on all sides, but to permit the pipe to rest at the bottom of successive holes when such holes are permitted as the means of piping support.

With flexible couplings now permitted to substitute for clearances through virtually all types of members, it is likely that this option will be used more, and clearances provided less often. This is because of increased building code requirements for proprietary penetration sealants to be used where clearances are provided. For the cost of the couplings, coordination efforts with an additional subcontractor can be avoided.

The new clearance requirement of 2 inches from structural members not used, collectively or individually, to support the piping should be given additional analysis to determine its suitability for avoiding damage to piping when considering expected building deflections and typical system flexibility.

The Ayers & Ezer report recommended clearance space for differential movement between sprinklers and hard ceilings and walls, with larger than normal escutcheon plates. This is addressed in the section on ceiling/sprinkler interaction.

9. Sway Bracing - General

1983 - Piping to be tied to the structure for minimum relative movement, but allowing for expansion, and differential movement within and between structures.

Tops of risers secured against drifting in any direction using 4-way brace.

1994 - System piping to be supported to resist both lateral and longitudinal horizontal loads.

1996 - System piping to be supported to resist both lateral and longitudinal horizontal loads and vertical loads.

Each run of pipe between a change in direction to be provided with both lateral and longitudinal bracing. Exception for runs less than 12 ft. in length supported by braces on adjacent runs.

Observations from Northridge Earthquake:

In general, the lack of bracing or inadequate bracing was cited as a major factor of the most significant failures of fire sprinkler systems. The same was reported true for fire sprinkler systems in the subsequent January 17, 1995 earthquake in Kobe, Japan, where "breakage and leakage of fire sprinkler lines in manufacturing facilities...resulting in extensive damage to manufactured goods, stock and machinery...(can) virtually all ...be attributed to the failure of unbraced or inadequately braced piping." (EQE Summary Report, 1995).

The other surprising lesson of the Northridge earthquake was the potential for strong upward forces. Vertical accelerations in excess of 1.0 g (such as at the Cedar Hill Nursery in Tarzana, 7 km from the epicenter, where a 1.18 g upward vertical acceleration was recorded or the 2.31 g vertical acceleration recorded at the roof of the Sylmar County Hospital) defied conventional wisdom that expected upward accelerations would be offset by gravity. As a result, many sprinklers were damaged when branch lines moved upward, pulling sprinklers through the ceiling with them, then pushing the sprinklers back through a substantial ceiling. This was observed at the Henry Radio in Los Angeles (plaster ceiling), Northridge Fashion Mall (plaster ceiling), Northridge Hospital Medical Center (rated ceilings) and elsewhere. In other locations, such as the Atlantic Optical warehouse in Pacioma, vertical forces on the lines caused direct damage to the sprinklers against the roof structure.

Adopted changes to 1996 Edition of NFPA 13:

Section 4-14.4.3.5.1 was rewritten to address vertical loads. The new wording states that the "system piping shall be braced to resist both lateral and longitudinal horizontal seismic loads and to prevent vertical motion resulting from seismic loads."

New section 4-14.4.3.5.4 states: "Where the horizontal force factors used exceed 0.5 W_p and the brace angle is less than 45° from vertical, or where the horizontal force factor exceeds 1.0 W_p and the brace angle is less than 60° from vertical, the braces shall be arranged to resist the net vertical reaction produced by the horizontal load."

Section 4-14.4.3.5.1 also now calls attention to the need for the structure to have the necessary inherent strength: "The structural components to which the bracing is attached shall be capable of carrying the added applied seismic loads."

Proposed additional changes to NFPA 13:

FM submitted a comment to suggest redrawing the appendix figures to accurately reflect spacing of braces. This was held for further study by the NFPA Committee on Automatic Sprinklers.

Although the 1996 changes to NFPA 13 begin to address vertical forces, it is only as a resultant of a strong horizontal force. Furthermore, there is no guidance on the arrangement of braces or reinforcement of hangers to resist such vertical loads. It has been suggested that both of these areas require further study.

10. Sway Bracing - Loads

1983 - Sway bracing to withstand a force in tension or compression equivalent to not less than half the weight of water-filled piping.

1989 - Assigned load table added. Alternative permitted for zone of influence method:

For lateral braces - all branch lines and mains within zone.

For longitudinal braces - all mains within zone.

1994 - Multipliers permitted for horizontal force factor $F_p = 0.5\ W_p$ where use of other force factors required or permitted by AHJ.

1996 - "When the horizontal force factor used exceeds 0.5 W_p and the brace angle is less than 45° from vertical or when the horizontal force factor used exceeds 1.0 W_p and the brace angle is less than 60° from vertical, the braces shall be arranged to resist the net vertical reaction produced by the horizontal load."

Observations from Northridge Earthquake:

Horizontal accelerations as high as 1.82 g were recorded in the Northridge earthquake, far surpassing those anticipated by the applicable model building code (See Appendix A) or the baseline 0.5 g of NFPA 13. By comparison, the maximum horizontal accelerations recorded in the Loma Prieta and Whittier earthquakes were 0.54 g and 0.62 g respectively.

Adopted changes to 1996 Edition of NFPA 13:

None.

Proposed additional changes to NFPA 13:

FM proposed that the appendix map showing effective peak velocity-related accelerations be updated to reflect the higher accelerations experienced in the Loma Prieta and Northridge earthquakes, but the Committee clarified these values come from other sources such as the Authority Having Jurisdiction, not from NFPA 13. Although FM proposed increasing the assigned horizontal accelerations to 0.9 g in Zone 3 and 1.2 g in Zone 4, the Committee reaffirmed its intent to use 0.5 g as baseline criteria, with Exception 2 to Section 4-14.4.3.5.3 permitting the other factors to be used as required or permitted by the Authority Having Jurisdiction.

The DOE suggested the standard also address a net upward vertical load, equal to 2/3 of the horizontal force, in all cases. The Committee, while giving some support for the concept, rejected the comment on the basis that practical considerations would be introduced. These included the need to revisit the tables for assigned loads, braces and fasteners, and substantial demands of the building structural systems. The rejection included the statement: "It is the opinion of the committee that the magnitude of this change is well beyond what a minimum standard should be addressing. The experience of the NFPA 13 seismic design criteria over the last 10 years has indicated that pipe failures attributed to vertical forces is practically non-existent. Acceptance of this criteria would make the braced system nearly failproof. This may be necessary for a critical, important structure but is excessive for most buildings."

It has been suggested that NFPA 13 may want to consider dropping its long-standing assumed load of half the weight of the water-filled piping. Building codes are now more commonly addressing the question of loads, and NFPA 13 can simply provide guidance on how to apply those loads in the determination of bracing details. With the probability of site-specific load determinations and loads incess of 1.0 g, the baseline of 0.5 g within NFPA 13 may serve no useful purpose.

11. Sway Bracing - Longitudinal Braces

1983 - Brace for feed and cross mains. Lateral braces may act as longitudinal if within 24 in. of center line of piping braced longitudinally.

1987 - Longitudinal bracing required at maximum 80 ft. on center.

1994 - Omission of longitudinal braces permitted for pipes supported by rods less than 6 in. long.

1996 - Delete 6-in. exemption for longitudinal braces.

Observations from Northridge Earthquake:

At the Gillette Co. (Paper-Mate) manufacturing facility in Santa Monica, the only longitudinal braces were the 4-way braces installed at the tops of risers. The earthquake forces pulled these braces loose from the brick exterior wall, permitting the bulk main to shift and break a tee at the opposite end..

Adopted changes to 1996 Edition of NFPA 13:

None.

Proposed additional changes to NFPA 13:

FM proposed that the maximum distance of a longitudinal brace to the end of a main be 40 ft, but the Committee rejected the proposal, stating that precise location of the brace is not important, only the ability of the brace to support its assigned load.

12. Sway Bracing - Lateral Braces

pre-1968 - Last length of pipe at end of feed or cross main to be provided with lateral brace.

Appendix figures show lateral braces "about 40 ft".

1985 - Lateral bracing at maximum 40 ft centers.

1989 - Maximum spacing to 50 ft when building primary structural members exceed 40 ft on center.

1996 - Distance between last brace and end of pipe limited to 20 ft (25 ft where braces up to 50 ft o.c.) Longitudinal braces permitted to serve as lateral braces when within 24 in. of piping braced laterally.

Observations from Northridge Earthquake:

There were no reports of piping breaking between lateral braces spaced in accordance with the standard at maximum 40 ft intervals.

Adopted changes to 1996 Edition of NFPA 13:

The limitation on the distance of the last brace from the end of the pipe was based on basic structural support considerations. The additional wording allowing longitudinal braces to also serve as lateral braces was considered a simple extension of the long-standing practice of permitting lateral braces to also serve as longitudinal braces.

Proposed additional changes to NFPA 13:

None.

13. Sway Bracing for Excessive Flexibility

1983 - A sway brace required within 24 in. of flexible couplings used other than for earthquake protection.

1989 - A lateral brace required within 24 in. of every other (such) coupling, but not more than 40 ft. on center.

Observations from Northridge Earthquake:

There were no reports of problems resulting from excessive numbers of flexible couplings between earthquake braces.

Adopted changes to 1996 Edition of NFPA 13:

For purposes of cross-reference, a new sentence was added to section 4-14.4.3.2 as follows: "Systems having more flexible couplings than required here shall be provided with additional sway bracing as required in 4-14.4.3.5.10, Exception No. 4."

Proposed additional changes to NFPA 13:

None.

14. Short Hanger Exception to Bracing

pre-1968 - Sway bracing may be omitted when hanger rods less than 6 in. long are used.

1985 - Moved to become exception to requirement for lateral bracing.

1994 - Exception extended to longitudinal as well as lateral bracing.

1996 - Deleted as exception for longitudinal bracing. Maintained for lateral bracing.

Observations from Northridge Earthquake:

No reports singled out the omission of earthquake braces on piping hung with short rods as the reason for a failure. However, there is more attention being paid to the development of moments for certain types of hanger arrangements. The proposed 1997 *NEHRP Provisions*, for example, still permit elimination of seismic supports for piping (other than fire protection sprinkler systems) supported by rod hangers "provided that all hangers in the pipe run are 12 in. (305 mm) or less in length from the top of the pipe to the supporting structure and the pipe can accommodate the expected deflections. Rod hangers shall not be constructed in a manner that would subject the rod to bending moments."

Adopted changes to 1996 Edition of NFPA 13:

Proposals for deletion of the exception for longitudinal bracing were based primarily on the observation that hangers used in the industry do not offer resistance to longitudinal motion, but permit sliding within the pipe hanger.

Proposed additional changes to NFPA 13:

FM and others proposed deletion of the 6-inch hanger exception based on loss experience in the Loma Prieta and Northridge earthquakes, but the Committee rejected the proposal on the basis that there was no substantiation of poor performance to justify the change.

It is interesting that while some call for the elimination of the 6-inch exemption, others call for extending the exemption to 12 inches to match common code criteria for other types of piping systems. However, the NFPA Sprinkler Committee has in the past been made aware of adverse earthquake experience with a 300-mm (12 inch) exemption under the provisions of another sprinkler installation standard (Voss, 1978).

It should be suggested that the UL and FM standards for hangers should consider a minimum lateral strength and fatigue resistance of hangers if they are intended to carry the intended loads under this exemption.

The intent of the exemption should also be clarified, particularly with regard to measurement of the six inches. A continuing subject of controversy is whether the 6 inches is measured as the length of the rod itself, the length of the exposed rod between points of support, or the distance between the structural member and the top of the piping.

15. Bracing/Restraint of Branch Lines

1987 - Sway bracing not required for branch lines.

Exception requires restraint of end sprinkler on line against excessive movement by wrap-around U-hook or other approved means.

1989 - Second exception added to require lateral bracing for branch lines 2½ in. or larger.

1991 - Third exception added to require wrap-around U-hook, lateral brace or 440-lb. brace wire restraint at maximum 30 ft. intervals within 2 ft. of hanger where upward or lateral movement of sprinklers would result in impact against building structure, equipment or finish materials.

1994 - Sprigs exceeding 8 ft. in length must be restrained against lateral movement.

1996 - Statements regarding need to brace branch lines with diameter 2-1/2 inches and larger moved to requirements for lateral and longitudinal braces.

End of branch lines to be restrained against excessive "vertical and lateral movement"

Sprig-ups 4 ft. or longer to be restrained against lateral movement.

Also in 1996, consideration was given to a requirement for sprinkler drops 4 ft. and longer and sprinkler drops on armovers greater than 12 in. to be restrained or otherwise protected to prevent damage from a suspended ceiling.

Observations from Northridge Earthquake:

Broken branch line piping and fittings was a commonly-reported failure mode in the Northridge earthquake, although many of the incidents were attributed to failure of hangers or lack of sufficient clearances to accommodate movement. In some cases, failures were attributed to broken threads on thinwall steel pipe, such as at the Sears store in Burbank, the Media Mall in Burbank, and the Hollywood Center parking structure in Hollywood.

Slippage or rolling of sprig-ups was observed in several locations, such as at the Carpenter's Union Hall in Sylmar and at the Encino Financial office building and parking garage in Encino, where approximately 300 sprig-ups had to be reset to a vertical position following the earthquake.

Adopted changes to 1996 Edition of NFPA 13:

The change in the restraint requirement for sprig-ups from the former 8 ft to those over 4 ft in height was substantiated by observed shearing of threads in the Northridge earthquake.

In addressing the restraint provided to the end of the branch line, the Committee clarified that vertical movement as well as horizontal movement is a concern, but rejected a proposal to delete the word "excessive". The Committee stated: "Some degree of judgment does have to be made in order to determine if damage would result due to movement of the pipe."

Proposed additional changes to NFPA 13:

As part of its report on nonstructural damage in hospitals in the Northridge earthquake, Ayers & Ezer Associates stated "In our opinion the bracing at 30 ft. intervals does not solve the interaction problem between the piping and other building components. For example, at 1 g, a 3/4-inch steel pipe braced at 30 ft intervals will swing as much as 24 inches. Also NFPA does not provide for longitudinal bracing of branch lines or vertical forces in any bracing." One of the recommendations of the report was for NFPA to extend the bracing requirement to 3/4-inch lines. (Note: NFPA 13 has prohibited the use of steel pipe with diameter less than 1-inch since the 1950s, although 3/4-inch copper and listed nonmetallic tube is permitted).

FM proposed requiring restraint of all branch lines with flexible couplings. The NFPA Committee rejected this based on lack of reported problems, noting that excessive movement which could result in impact of sprinklers was already addressed.

The Committee also rejected a proposal to require bracing of all branch lines, which would have permitted exceptions for branch lines supported by wrap-around U-hooks and small branch lines restrained by the splayed wire option. In rejecting this proposal, the Committee stated: "In general, branch line piping does not require bracing."

The Committee further rejected an FM proposal to require bracing for branch lines on gridded systems, stating there was no reason to treat a gridded system differently than other systems.

16. Ceiling / Sprinkler Interaction

1983 - Minimize or prevent pipe breakage

1991 - Prevent pipe breakage

Observations from Northridge Earthquake:

Both the Ayers & Ezer and the FSABSC reports cited a number of incidents in which the sprinkler / ceiling interaction resulted in damage to the sprinklers or to the piping. A common mode of failure was the breaking of threads at the tops of drops to sprinklers penetrating a substantial ceiling. This was observed at the Holy Cross Medical Center, the Olive View Hospital, the Rocketdyne facility in Canoga Park, and elsewhere.

Adopted changes to 1996 Edition of NFPA 13:

A tentative change was adopted by the Committee which was challenged during the floor adoption. The floor recommended against the change, and the Committee supported the floor action. The change was originally proposed by Industrial Risk Insurers (IRI), requiring that hung or dropped ceilings and sprinkler drops be braced as a unit. FM had made a similar proposal. The insurance companies cited substantial damage in the Northridge earthquake from sprinklers and ceilings moving at different frequencies, shearing sprinklers and fitting threads. The Committee originally rejected the wording of the original submittals, stating that bracing was not needed in all cases, and that integral bracing might result in new problems. During the public comment period, IRI proposed new wording whereby, when hung or dropped ceilings were braced against movement from earthquakes, the sprinkler drops be restrained as an integral part of that system. In accepting the comment in principal, the Committee developed text as follows:

> "Where ceilings are seismically braced to prevent horizontal and vertical movement, branch lines and armovers in excess of 24 in horizontally, if provided, shall be restrained against upward movement and sprinklers shall be provided with a one piece escutcheon.
> Exception: Recessed, flush, and concealed sprinklers shall not be required to be provided with the escutcheon."

The floor action supported concerns that the Committee action addressed upward movement only, whereas the intent of the original submittal was to address differential lateral movement as well, which was responsible for breaking some drops at their top connections. It was agreed that existing provisions called for branch line restraint where movement could result in damage to sprinklers.

Proposed additional changes to NFPA 13:

IRI had also proposed, based on Northridge experience, a ban on the use of armovers above hung ceilings in areas subject to earthquakes. The Committee rejected this proposal based on lack of justification.

One of the recommendations of the Ayes & Ezer Report was to provide clearance space for differential movement between sprinklers and hard ceilings and walls, using larger than normal escutcheon plates.

The Ayres & Ezer Report includes an Appendix E which illustrates what is described as "a fire sprinkler contractor solution to head damage at hard ceilings by the use of enlarged escutcheons," excerpted from a study completed for the Holy Cross Hospital in Santa Monica by the U.S. West mechanical corporation. The survey and inspection report following the earthquake noted that one-piece sprinkler flanges which fixed the sprinkler rigidly to the ceiling had resulted in damage to the ceilings when the vertical earthquake motion caused the sprinkler flange to tear up through the ceiling, and subsequent damage to the sprinklers when the motion pushed the sprinkler back through the ceiling. The report recommended the "two-piece semi-recess flange" as a means of permitting the sprinkler drop to slide up and down without damaging the sprinkler or the ceiling.

Under the proposed 1997 *NEHRP Provisions*, sprinkler/ceiling interaction would be regulated by minimum clearance requirements unless the ceiling is rigidly braced. In Seismic Design Categories D, E, and F, sprinklers and other penetrations would be required to have a 2-inch (50 mm) oversize ring, sleeve, or adapter through the ceiling tile to allow for free movement of at least 1 inch (25 mm) in all horizontal directions. Alternatively, a swing joint that can accommodate 1 inch (25 mm) of ceiling movement in all horizontal directions may be provided at the top of the sprinkler drop. In Seismic Design Categories B and C, sprinklers would be required to have a minimum of 1/4 inch (6 mm) clearance on all sides.

As an alternate to providing large clearances around sprinkler system penetrations through ceiling systems, the proposed 1997 *NEHRP Provisions* would permit the sprinkler system and ceiling grid to be designed and tied together as an integral unit. Such a design would be required to consider the mass and flexibility of all elements involved, including: ceiling system, sprinkler system, light fixtures, and mechanical (HVAC appurtenances. The design would be required to be performed by a registered design professional.

If the NEHRP provisions are adopted into building codes as proposed, however, it is considered likely that sprinkler manufacturers will develop special "earthquake escutcheons" for high-risk earthquake areas, incorporating the required clearance features.

17. Sway Bracing - Brace Components

1983 - Sway bracing to be designed to withstand a force in tension or compression.

1985 - For individual braces, the slenderness ratio *l/r,* limited to 200.

1987 - Maximum length load tables added to appendix based on three ranges of angle

1989 - Maximum length and load tables moved from appendix to body of standard.

1994 - Allowable slenderness ratio increased to 300.

1996 - Sway brace assemblies to be listed for a maximum allowable load. Loads to be reduced as shown in table for angles less than 90° from vertical:

Angle from Vertical	60-89°	45-59°	30-44°	
Reduction in Load (Multiplier)	0.866	0.707	0.5	

Where pipe, angles, flats or rods are used as braces, an exception requires listing only of brace fittings and connections.

Another exception to permit tension-only bracing systems when listed for this service and installed in accordance with listing limitation.

Threaded pipe used as part of a sway brace assembly to be not less than Schedule 30.

(Appendix) - Sway brace members should be continuous. Where splices are necessary they should be designed and constructed to ensure that brace integrity is maintained.

Observations from Northridge Earthquake:

Reported sway brace failures were generally related to fastening or anchoring methods, not the brace itself.

Adopted changes to 1996 Edition of NFPA 13:

A number of changes were made to the standard to accommodate a "tension-only" bracing system. This system is based on the use of prestretched aircraft cable. The basic change was a new exception to Section 4-14.4.3.5.2, the section which requires that braces be designed to withstand forces in tension and compression. A new exception to that section allows use of a tension-only bracing system if listed for such service and installed in accordance with listing limitations, including installation instructions. In this manner the NFPA Committee on Automatic Sprinklers chose to follow the special listing precedent used a decade earlier with nonmetallic sprinkler system piping. The details of acceptable levels of performance are left to the listing organization to determine. However, the Committee did provide appendix guidance in A-4.14.4.3.5.2, consisting of a list of considerations that the investigation should involve. This includes "a means to prevent vertical motion due to seismic forces." New material added to Section 4-14.4.3.5.5 requires two tension-only braces to be used in opposing directions at each brace location.

For all braces, whether or not listed, Section 4-14.4.3.5.5 of the standard was revised to require maximum allowable horizontal loads based on the maximum allowable loads from Table 4-14.3.5.5 (which is based in turn on Euler's formula) or on the manufacturer's certified maximum allowable horizontal loads. The maximum loads are to be certified for the three ranges of angles from vertical used within the table, with loads reduced according to the brace angle. The section goes on to state that the maximum allowable horizontal loads must include a minimum safety factor of 1.5 against the ultimate break strength of the brace components.

New Section 4-14.4.3.5.7 requires sway brace assemblies to be listed for a maximum allowable load, with the aforementioned reduction in loads based on angle range contained in Table 4-14.4.3.5.7. An exception permits pipe, angles, flats and rod used as part of a sway to be used without a listing, although the bracing fittings and connections used with them must be listed.

Underwriters Laboratories revised its listing criteria to accommodate the new changes, with new tests for brace component manufacturers. The UL product test requirements were effective November 27, 1996.

Proposed additional changes to NFPA 13:

Factory Mutual proposed limiting the maximum slenderness ratio l/r to 200, stating that the Committee substantiation defending the reduced loads for l/r up to 300 is flawed. According to FM, braces with l/r exceeding 200 will not resist buckling. The Committee feels the reduced loads ensure integrity against buckling, and stated "there are some situations where longer braces are necessary to accommodate piping installed above drop ceilings but below a structural system with deep members." FM also proposed reducing the loads in Table 4-14.4.3.5.5 by a safety factor of 12/23 for Euler's equation, but this was rejected by the Committee based on the fact that this safety factor is typically used to prevent failure of a building structural system. The Committee stated NFPA 13 criteria is intended to maintain piping integrity and is supported by past experience. In developing its subsequent revised Data Sheet, FM continued the use of the NFPA 13 tabular values for allowable brace loads, but only for l/r up to 200.

18. U-Hooks as Sway Braces

1983 - U-type hangers satisfy bracing requirements except longitudinal brace needed for 2½-in and larger piping. U-type hangers used as lateral braces to have legs bent at 10 degrees from vertical.

1987 - U-type hangers satisfy requirements for lateral sway bracing...

1991 - Wrap-around U-type hangers permitted as lateral sway bracing provided legs are bent out 30 degrees from vertical and slenderness ratio criteria satisfied.

1996 - Allowance extended to U-type hooks arranged to keep the pipe tight to the underside of the structural element.

Observations from Northridge Earthquake:

None.

Adopted changes to 1996 Edition of NFPA 13:

Allowance extended to U-type hooks arranged to keep the pipe tight to the underside of the structural element.

Proposed additional changes to NFPA 13:

None.

19. Sway Bracing - Fasteners to Structure

1983 - Pipe not to be fastened to building sections which will move differently.

1987 - C-type clamps (with or without retaining straps) prohibited from brace attachment.

Fastener load tables added to appendix based on six orientation/angle conditions.

1989 - Fastener load tables moved from appendix to body of standard and expanded to nine orientation/angle conditions.

1994 - Powder-driven fasteners not permitted to attach braces unless specifically listed for this service.

1996 - Types of fasteners limited to those in Table 4-6.4.3.5.4.

Connections to wood to be made using through bolts with washers on each end. Holes to be 1/16 in. greater than diameter of bolt. Exception to permit lag screws/lag bolts where through bolts not practical due to thickness or inaccessibility. Holes to be predrilled 1/8 in. smaller than maximum root diameter.

The structural components must be capable of carrying the added applied loads.

Appendix cautions added re. expansion anchors in concrete.

Observations from Northridge Earthquake:

Of the 19 FSABSC survey forms which indicated the presence of powder-driven fasteners, 11 forms indicated failure of these fasteners:

Van Nuys - brewery/warehouse - Failure of powder-driven fasteners anchoring braces to steel beams
Conoga Park - retail store - Failure of powder-driven fasteners anchoring braces to steel beams
Century City - parking structure - Pull-out failure of approximately 100 powder-driven hanger fasteners from concrete
Chatsworth - warehouse - Failure of powder-driven fasteners anchoring braces
Van Nuys - department store - Failure of powder-driven fasteners anchoring hangers
Canoga Park - manufacturing/warehouse/office facility - Failure of powder-driven fasteners
Northridge - hospital - Failure of powder-driven fasteners anchoring braces
Santa Monica - parking structure - Failure of powder-driven fasteners anchoring braces and hangers
Encino - office bldg w/ parking structure - Failure of powder-driven fasteners
Santa Monica - hospital - Failure of powder-driven fasteners
Los Angeles - manufacturing/warehouse - Failure of powder-driven fasteners

Several of these failures resulted from the use of powder-driven fasteners to support braces, which was prohibited beginning with the 1994 edition of NFPA 13. However, most resulted from the use of the fasteners to support hangers.

Other fastener failures noted frequently were C-clamps (prohibited from use in attaching braces since 1987) and lag bolts.

Adopted changes to 1996 Edition of NFPA 13:

The new limitations on the use of lags to situations where through bolts are not practical, and the additional new criteria involving the use of lag screws and lag bolts, were justified on the basis of observed pull-out failures of lags, some of which was attributed by the Committee to poor installation practices.

The appendix material added on expansion anchors in concrete clarify that the criteria in Table 4-14.4.3.5.6 are based on the use of shield-type expansion anchors. The new appendix material explains that most current fasteners are expansion anchors, either deformation-controlled or torque-controlled.

Proposed additional changes to NFPA 13:

FM proposed that fasteners which relied upon friction be listed for seismic service based on dynamic testing. The Committee rejected this based on lack of clear application, and lack of guidance to the listing laboratories on appropriate dynamic load testing criteria.

The proposed 1997 *NEHRP Provisions* prohibit powder driven fasteners from tension load applications in Seismic Design Categories D, E, and F unless approved for seismic service.

20. Hanger and Piping Restrictions in Earthquake Areas

1987 - C-type clamps used to attach hangers must be equipped with retaining strap or other approved means to prevent movement.

1996 - Retainer straps used on C-clamps to be listed for use under seismic conditions or to be a steel strap not less than 16 gauge thickness and 1 in. wide, wrapped around beam flange not less than 1 inch. Lock nuts and lips (on "C" or "Z" purlin) not permitted.

- Where horizontal force factor exceeds 0.5 W_p, powder-driven fasteners must be specifically listed for such forces.

- Pipe nipples less than 1-in not permitted in revamping systems in earthquake areas.

Observations from Northridge Earthquake:

The lack of retainer straps on C-type clamps was cited in the FSABSC report as a problem in the Anheuser-Busch plant in Van Nuys, in which 2,000 feet of 8-inch main fell to the floor. In that case, locknuts were reported as being present. Sliding of C-type clamps off flanges was also reported in the Rocketdyne facility in Canoga Park (locknuts provided), the General Motors plant in Van Nuys (locknuts provided), the I Magnum store in Woodland Hills (locknuts provided), the Sears store in Burbank (locknuts provided), the American National Can Co. in Chatsworth (locknuts and retaining straps provided), the Fedco Department Store in Van Nuys (locknuts provided), Redken Labs in Canoga Park (locknuts provided), the HEXCEL warehouse in Chatsworth (locknuts provided), and St. Johns Hospital in Santa Monica.

The Ayers & Ezer report also made special mention of the fact that one-sided C-clamps used for gravity hangers contributed to pipe movement and failures at screwed joints.

As mentioned in the previous item, of the 19 FSABSC survey forms which indicated the presence of powder-driven fasteners, 11 forms indicated failure of these fasteners. Several of these dealt with the use of powder-driven fasteners supporting hangers, not earthquake braces. An observation with regard to piping issues was the difficulty in shutting off flow from damaged sprinklers. At the Sepulveda Veteran's Administration Hospital, for example, broken sprinkler piping on the 3rd floor was still flowing water the day after the earthquake because the building was evacuated.

Adopted changes to 1996 Edition of NFPA 13:

The changes requiring retainer straps on C-type clamps were adopted to be compatible with state requirements adopted in California following the Northridge earthquake.

The ban on pipe nipples smaller than 1-inch in revamping systems, as opposed to nipples as small as 1/2-inch normally permitted, was based on observations of failures in the Northridge earthquake where such fittings served drops to suspended ceilings.

The information on failures of powder-driven fasteners used to support hangers led to the requirement that, where horizontal force factors exceed 0.5 W_p, powder-driven fasteners must be specifically listed for such forces.

Proposed additional changes to NFPA 13:

FM proposed a rule stating that a branch line hangers be located a minimum of 6 ft from cross mains, citing field observations that hangers close to cross mains acted as restraints, overloading the connections and leading to failures. The Committee rejected this proposal based on the lack of supporting information, recognition that some structural systems may not permit the hanger to be positioned greater than 6 ft from the cross main, and stated "Systems with longitudinal bracing in accordance with NFPA 13 should not be subject to damage."

With regard to concrete fasteners, many groups are simultaneously working with manufacturers in the development of a new test requirements, including UL discussed previously. Some general agreements are reportedly being pursued within both the ACI 318 and 355 committees. Chapter 6 in the 1997 *NEHRP Provisions* includes anchorage provisions which are based on the UBC as modified by ACI. These apply only to cast-in-place headed bolts, however, not "post-installed" drilled or shot. It may be years before issues are settled such as the use of concrete strength vs. bolt strength, failure cones, and other matters. ACI 355 has agreed to go a concrete capacity method, but will take two years to publish this information, which may be an appropriate approach for NFPA 13. At a given embedment and concrete strength, a strength limit is achieved.

The problems associated with the need to shut down part or all of the system in a building that is being evacuated due to structural damage should be considered by the NFPA Sprinkler Committee. The EERI suggestions for smaller zones, or alternatives such as exterior-accessible control stations, could be considered for high risk earthquake areas.

Summary and Conclusions

Based on the above, a compilation of recommendations for additional changes to NFPA 13 to improve the performance of sprinkler systems in earthquakes, or to improve the proper application of the protection criteria, is as follows and addresses fifteen of the twenty subject areas:

1. Applicability of Earthquake Protection Provisions

Proposals:

Revise the exception to the general rules on earthquake protection of sprinkler systems (Section 4-14.4.3.1) to clarify that the alternative method does not need to be based on a dynamic analysis, nor does the sprinkler system performance need to match that of the building structure.

2. General Intent of Earthquake Protection Provisions

Proposals:

The stated intent of the provisions in Section 4-14.4.3.1, "to prevent pipe breakage" should be retained but clarified in an appendix section. The statement should be made that inadvertent operation of sprinklers is considered as equivalent to pipe breakage. It should also be stated that, if the building remains occupiable and the water supply source is intact, the fire sprinkler system should be fully operational following the earthquake.

3. Flexible Couplings - General Applicability

Proposals:

Review 1996 DOE study of mechanical coupling performance under simulated earthquake loads to ensure product listing standards are appropriate for anticipated earthquake loads under current hanger and brace spacing rules.

Clarify flexibility and clearance requirements for piping passing through walls to eliminate apparent conflict between Section 4-14.4.3.2(c) and Section 4-14.4.3.4.

4. Flexible Couplings for Risers

Proposals:

None

5. Drops to Hose Lines and Sprinklers in Racks

Proposals:

Clarify the intent of Section 4-14.4.3.2(f) of the standard where a drop from a cross main to a branch line exceeds 15 ft, as to whether one flexible coupling provides appropriate flexibility, whether some bracing or restraint is needed for the bottom of the drop in such a case, and how branch line loads are transferred to lateral braces.

Consider a change to Section 4-14.4.3.2 (e) for additional flexibility in drops to free-standing racks to accommodate a relative displacement equal to at least 5 percent of rack height.

6. Flexible Couplings for Expansion Joints

Proposals:

None.

7. Seismic Separation Assemblies

Proposals:

Provide additional text to Section 4-14.4.3.3 or its appendix section to clarify sizing the seismic separation assemblies for various combinations of pipe diameter and separation distance, support of the assemblies, and bracing of piping immediately upstream and downstream.

8. Clearances

Proposals:

Rewrite Section 4-14.4.3.4.1 to prevent the possibility of clearance through successive structural members on alternating sides of the pipe.

Give additional analysis to the new clearance requirement of 2 inches from structural members not used, collectively or individually, to support the piping to determine its suitability for avoiding damage to piping when considering expected building deflections and typical system flexibility.

9. Sway Bracing - General

Proposals:

Review the appendix figures to accurately reflect location and spacing of braces.

Consider requirements for vertical accelerations if required by other applicable code or authority having jurisdiction.

Provide guidance on the arrangement of braces or reinforcement of hangers to resist upward loads.

10. Sway Bracing - Loads

Proposals:

Consider dropping the long-standing assumed load of half the weight of the water-filled piping (horizontal acceleration of 0.5 g), based on the recognition that building codes are now more commonly addressing the question of loads, and that such loads may be site-specific and based on accelerations in excess of 1.0 g. Reorganize the NFPA 13 criteria to simply provide guidance on how to apply those loads in the determination of bracing details.

11. Sway Bracing - Longitudinal Bracing

Proposals:

Review the need for a maximum distance of a longitudinal brace to the end of a main.

12. Sway Bracing - Lateral Bracing

Proposals:

None.

13. Sway Bracing for Excessive Flexibility

Proposals:

None.

14. Short Hanger Exception to Bracing

Proposals:

Review applicable product standards for hangers to determine if sufficient lateral strength and fatigue resistance of hangers is ensured for the intended loads under this exemption.

Clarify the intent of the exemption, particularly with regard to measurement of the six inches.

15. Bracing/Restraint of Branch Lines

Proposals:

The Committee should reexamine its position with respect to restraint or bracing of branch lines, to determine if the interaction problems between the piping and other building components can be resolved in the absence of such restraint or bracing, and to determine if current system components and technologies (such as threading of thinwall pipe) provide the inherent strength to withstand expected forces and displacements.

16. Ceiling/Sprinkler Interaction

Proposals:

For high-risk earthquake areas, the Committee should consider incorporating a rule for a 1-inch annular space around sprinklers penetrating ceilings not braced or restrained as a unit with the branch lines, with the gap to be covered by larger than normal escutcheon plates or "earthquake escutcheons."

For drops to individual sprinklers in rigid ceilings that are not braced or restrained as a unit with the sprinkler branch lines, the Committee should consider a requirement for a flexible coupling at the top of the drop as a means of avoiding damaging stresses.

17. Sway Bracing - Brace Components

Proposals:

The Committee should review the use of new maximum load ratings assigned to braces and brace fittings as part of the UL listing process, and consider whether changes are needed to accommodate the strength design method planned to be incorporated in model code earthquake protection criteria.

18. U-Hooks as Sway Braces

Proposals:

None.

19. Sway Bracing - Fasteners to Structure

Proposals:

The Committee should review ongoing national efforts in the development of anchorage provisions for earthquake protection, and update its fastener load tables in an appropriate manner.

The Committee should seek to develop a consensus-based method for dynamic testing of components and fasteners, which could be used by the listing organizations as part of product evaluation testing.

20. Hanger and Piping Restrictions in Earthquake Areas

Proposals:

The problems associated with the need to shut down part or all of the system in a building that is being evacuated due to structural damage should be considered by the NFPA Sprinkler Committee. Smaller zones, or alternatives such as exterior-accessible control stations, could be considered for high risk earthquake areas.

An appropriate final proposal for the NFPA Committee on Automatic Sprinklers would be to assist in the development of a plan for a comprehensive data collection and analysis effort for post-earthquake damage assessment. Such a plan should be ready to be put into action immediately following the next major earthquake in a large population area expected to have a considerable number of sprinkler systems in place. Data collection on a large and representative sample of systems should be used to replace the past practice of limited observations combined with judgment as the means for substantiating future changes to the fire sprinkler system installation rules.

Appendix A - 1994 Uniform Building Code Provisions

- Volume I references

  UBC Standard 9-1 (1991 NFPA 13)

  No amendments to earthquake protection section.

- Volume II includes structural engineering provisions for earthquake design.

Section 1630.2

Total design lateral seismic force:

$$F_p = Z \ I_p \ C_p \ W_p$$

where:

Z = Zone factor from Table 16 - I

I_p = Occupancy factor from Table 16 - K

C_p = Coefficient for ductile piping from Table 16-0

Table 16-0:

For electrical, mechanical and plumbing equipment and associated...piping and machinery, $C_p = 0.75$

Table 16-K footnote: "For anchorage of machinery and equipment required for life safety systems the value of I_p shall be taken as 1.5."

Table 16 - I:

Seismic Zone	1	2A	2B	3	4
Value of Z	0.075	0.15	0.20	0.30	0.40

Lateral forces by seismic zone:

$$F_p = Z\ I_p\ C_p\ W_p$$

For Zone 1:

$$F_p = (0.075)\ (1.5)\ (0.75)\ W_p = 0.084\ W_p$$

For Zone 2A:

$$F_p = (0.15)\ (1.5)\ (0.75)\ W_p = 0.17\ W_p$$

For Zone 2B:

$$F_p = (0.20)\ (1.5)\ (0.75)\ W_p = 0.23\ W_p$$

For Zone 3:

$$F_p = (0.30)\ (1.5)\ (0.75)\ W_p = 0.38\ W_p$$

For Zone 4:

$$F_p = (0.40)\ (1.5)\ (0.75)\ W_p = 0.45\ W_p$$

Bibliography

Ammann, Walter J., "Seismic Qualification of Sprinkler Systems," Report Submitted to NFPA 13 Earthquake protection Task Group, Hilti Corporate Research, Liechtenstein, September 1992.

Antaki, George A., Guzy, D., and Hoskins, R.S., "Bending Strength of Fire Protection Pipe Joints," PEC-SSA-96-84, U.S. Department of Energy, October 1996.

Ayres & Ezer Associates, "Northridge Earthquake Hospital Water Damage Study", Report to the California Office of Statewide Planning & Development, April 1996.

Bachman, R. E. and R. M. Drake, "A Study to Empirically Validate the In-Structure Response Accelerations in the 1994 *NEHRP Provisions* Design Force Equations for Architectural, Mechanical, and Electrical Components," Flour Daniel Inc. for NCEER, June 1995

Bachman, R.E. and R.M. Drake, "A Study to Empirically Validate the Component Response Modification Factors in the 1994 *NEHRP Provisions* Design Force Equations for Architectural, Mechanical, and Electrical Components," letter report to the National Center for Earthquake Engineering Research, July 1996.

Council, H., "Proposed Amendments to the 1994 Edition of NFPA 13," State of California - Office of the Fire Marshal, Technical Services Deivision, August 30, 1994.

De Pineres, Oscar G., "A Safer Earthquake Design Code After Northridge", *Civil Engineering*, June 1995.

Drake, R M., and R.E. Bachman, "*NEHRP Provisions* for Nonstructural Components," *ASCE Journal of Architectural Engineering*, March 1996.

Drake, R.M., and R.E. Bachman, "Interpretation of Instrumented Building Seismic Data and Implications for Building Codes," in *Proceedings of the 1995 SEAoC Annual Convention*, 1995.

Drake, R.M., and R.E. Bachman, "1994 *NEHRP Provisions* for Architectural, Mechanical and Electrical Components," *Proceedings,* 5th United States National Conference on Earthquake Engineering, 1994.

"Emergency Response and Damage Assessment of the Northridge, California, Earthquake", *The Building Official and Code Administrator*, March/April, 1994.

EQE Summary Report - The January 17, 1994 Northridge, California Earthquake, EQE International, San Francisco, CA, March 1994.

EQE Summary Report - The January 17, 1995 Kobe Earthquake, EQE International, San Francisco, CA, 1995.

Fleming, R. P., "Retrobracing and Retrobonding," *Sprinkler Quarterly*, National Fire Sprinkler Association, Patterson, NY, Winter 1993

Fleming, R.P., "Sprinkler System Performance in the Northridge Earthquake," *Sprinkler Quearterly*, National Fire Sprinkler Association, Patterson, NY, Spring, 1994.

Foley, S.N., "Picking Up the Pieces," *Fire Journal*, National Fire Protection Association, Quincy, MA, May 1995.

Hart, S., "Northridge Earthquake - January 17, 1994," Report of the Fire Sprinkler Advisory board of Southern California, April 1994.

Installation of Sprinkler Systems, NFPA 13, National Fire Protection Association, Quincy, MA, 1983-1996 editions.

Lama, P. J. and Fey, S., "Seismic Safeguards," *The Construction Specifier*, November 1994.

NEHRP Recommended Provisions for Seismic Regulations for New Buildings, Part 1 - Provisions and Part 2 - Commentary, 1994 Edition, Building Seismic Safety Council for the Federal Emergency Management Agency, 1994.

"Northridge Earthquake Reconnaissance Report, Vol I.", Earthquake Spectra, Earthquake Engineering Research Institute, April 1995

RMS Event Report - Northridge Earthquake, January 17, 1994, Risk Management Software, Inc., 149 Commonwealth Drive, Menlo Park, CA

Seismic Safety of Federal and Federally Assisted, Leased, or Regulated New Building Construction, Volume 2, Federal Emergency Management Agency, December 1992

"The Northridge Earthquake: Report and Analysis," *Fire Engineering*, August 1994.

Voss, D. B., "The Importance of Adequate Seismic Design of Sprinkler Systems: Some Observations Following the 1987 Bay of Plenty Earthquake," 1987 Conference of the Institute of Fire Engineers, Whangarei, New Zealand, September 1987.

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The performance of nonstructural building components in the January, 1994 Northridge earthquake has received a considerable attention, especially building mechanical systems. There has been much anecdotal information indicating less than satisfactory system integrity during and following the Northridge earthquake, which measured 6.8 on the Richter scale. Fire sprinkler systems are of special interest since they are expected to remain functional following earthquakes so as to address post-earthquake fire hazards, and because of the potential for significant water damage that can take place if the system is compromised in a building which otherwise remains structurally intact. The project was recommended to include two parts: 1. An analysis of the performance of fire sprinkler systems in the Northridge earthquake in relation to the specific earthquake protection measures employed in their design and construction, and 2. Development of proposed changes to the national installation standard, NFPA 13, which would improve future system performance by bringing brace fastener details and other aspects of the protection rules up to current levels of technology.

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