EARTHQUAKE PROTECTION FOR WATER-BASED FIRE PROTECTION SYSTEMS

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1.0 SCOPE

This data sheet provides recommendations for earthquake protection of water-based fire protection systems. Apply these recommendations to locations in FM 50-year through 500-year earthquake zones, as described in Data Sheet 1-2, *Earthquakes.*

Loads and capacities in this data sheet are based on the Allowable Stress Design (ASD) analysis method.

For non-earthquake-related automatic sprinkler system installation recommendations, see Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers.*

1.1 Hazards

Improperly protected sprinkler piping, water supply systems, and other equipment can move violently during an earthquake. Even when structures are minimally damaged, impairment of the fire protection system after an earthquake can result from breaks in sprinkler piping, or from damage to water tanks/reservoirs or water supply equipment such as controllers. Additionally, depending on its location, the water released from a pipe break can damage building non-structural systems, such as ceilings or cleanrooms, and equipment.

After an earthquake, the threat of fire is greater due to obvious hazards such as flammable gas or ignitable liquids releases, but also due to the increased presence of ignition sources, many of which are difficult or impossible to identify and mitigate before an earthquake occurs. With an impaired fire protection system, any fire following an earthquake has the potential to become an uncontrolled fire and cause an extremely large loss. Earthquakes also may create unexpected heavy demands on public fire service and emergency response team resources, delaying or preventing successful manual fire control.

1.2 Changes

October 2017. This data sheet has been revised with editorial corrections and clarifications throughout, as well as several technical changes. The most significant editorial and technical changes are enumerated below.

A. Editorial corrections and clarifications

1. Revised Section 1.0, Scope.

2. Added Section 1.1, Hazards.

3. Relocated and updated substantial amounts of text, along with supporting tables and figures, from Section 2.0, Loss Prevention Recommendations into Section 3.1 as commentary. Commentary is provided for:

a) Section 2.1, Introduction

b) Section 2.2.1.1, Sway Bracing Locations for Steel Piping (Recommendations 2.2.1.1.1, 2.2.1.1.2, 2.2.1.1.4)

c) Section 2.2.1.2, Horizontal Seismic Loads for Sway Bracing Design (Recommendations 2.2.1.2.1, 2.2.1.2.2, 2.2.1.2.3)

d) Section 2.2.1.3, Configuration and Design of Sway Bracing (Recommendations 2.2.1.3.5, 2.2.1.3.6)

e) Recommendation 2.2.1.4.8 (flexibility across seismic separations and between independent structures)

f) Recommendation 2.2.1.6.2 (restraint of suspended ceilings)

g) Recommendation 2.2.1.7.2 (plain end fittings)

h) Section 2.2.1.9, Pipe Material Other Than Steel (Recommendations 2.2.1.9.1, 2.2.1.9.2)

4. Updated Section 2.1, Introduction; Section 4.0, References; Appendix A, Glossary of Terms; and Appendix C, Supplemental Information.

5. Renumbered all tables and relocated most tables that were in Section 2.0 to Section 3.1. Clarifications were added to Table 3.1.5 (old Table 1), and to Table 3.1.9-G and Table 3.1.9-H (old Table 15 and Table 16).

B. Technical Revisions

1. Revised the clearance requirements that allow a structural floor to be considered as a four-way brace for a riser or vertical pipe (Recommendation 2.2.1.1.2.2).

2. Added a requirement for lateral restraint at ends of branch lines that do not require bracing (Recommendation 2.2.1.1.6).

3. Revised the minimum “G” factors used to determine horizontal design loads for sway braces (Recommendation 2.2.1.2.2 and its commentary in Section 3.1).

4. Provided guidance on sizing steel U-bolts used as braces (Recommendation 2.2.1.3.2).

5. Added requirements for positioning sway braces on horizontal and vertical piping (Section 2.2.1.3.5 and its commentary in Section 3.1).

6. Added references for calculating capacities of attachments to structures and clarified types of structural members to which attachments should not be made (Recommendation 2.2.1.3.6). Revised Table 3.1.9-E and Table 3.1.9-F (old Table 13 and Table 14), reducing the maximum allowed horizontal loads for structure attachments using post-installed concrete anchors (to account for updated concrete expansion anchor capacities and the required overstrength factor [Ω_0] now included in ASCE 7).

7. Provided additional guidance regarding flexibility needed on pipe drops to racks and independent mezzanines (Recommendations 2.2.1.4.5.4 and 2.2.1.4.6.5 and the commentary in Section 3.1.10).

8. Added the option of using an FM Approved flexible pipe loop or other engineered method to accommodate differential movement across a building seismic separation or between buildings (Recommendation 2.2.1.4.8 and its commentary in Section 3.1).

9. Added statement allowing the use of FM Approved flexible sprinkler hose in suspended ceilings (Recommendation 2.2.1.5.3.1) and modified requirements for restraint of acoustical tile suspended ceilings having sprinklers (Recommendation 2.2.1.6.2 and its commentary in Section 3.1).

10. Noted that the use of FM Approved plain-end fittings may be disallowed by other data sheets and provided guidance where their use is unavoidable (Recommendation 2.2.1.7.2 and its commentary in Section 3.1).

11. Added a requirement that concrete anchors used for hangers be qualified for use in seismic applications (Recommendation 2.2.1.8.1.2).

12. Added guidance for earthquake protection of copper pipe (Recommendation 2.2.1.9.1 and its commentary in Section 3.1) and explanatory information on earthquake performance of CPVC pipe (commentary in Section 3.1 for Recommendation 2.2.1.9.2).

13. Added references to other data sheets having additional seismic design requirements for water storage tanks and reservoirs (Section 2.2.6).

14. Revised the changes needed to a NFPA 13-designed fire protection system (NFPA 13, 2016) in order for the installation to be considered essentially equivalent to the Data Sheet 2-8 provisions (Section 2.3.1.1).

15. Summarized data sheet recommendations in Table D.1, Outline of Data Sheet 2-8 Recommendations (job aid located in Appendix D).

16. Renumbered all figures and relocated many of the figures previously in Section 2.0 to Section 3.1. Extensively revised Fig. 2.2.1.3.5-A (combines old Fig. 3 and Fig. 5), Fig. 2.2.1.3.5-B (combines old Fig. 4 and Fig. 6), Fig. 2.2.1.3.6-A (combines old Fig. 14 and Fig. 15), Fig. 3.1.1-A (old Fig. 17), Fig. 3.1.9-B (old Fig. 9), Fig. 3.1.9-C (old Fig. 11), Fig. 3.1.9-D (old Fig. 13) and Fig. 3.1.9-G (previously unnumbered figure). Deleted old Fig. 8, Fig. 10 and Fig. 12. Added Fig. 2.2.1.3.5-C, Fig. 3.1.1-B, Fig. 3.1.1-D, Fig. 3.1.9-A, Fig. 3.1.9-E, Fig. 3.1.9-F, Fig. 3.1.10-B, Fig. 3.1.10-C, Fig. 3.1.11, and Fig. 3.1.12.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The recommendations in this data sheet are intended to (1) greatly improve the likelihood that the fire protection system(s) will remain in working condition after the earthquake, and (2) minimize potential water damage from fire protection system leakage. For each type of fire protection system described in the following sections, completion of all recommendations will maximize the probability of the system performing as intended during an earthquake.

Section 2.3 gives guidance on using other codes and standards to provide earthquake protection of fire protection systems similar to that recommended in this data sheet.

In general, recommendations are related to the following seven goals:

1. Bracing piping and equipment to minimize uncontrolled differential movement between these items and the structure(s) to which they are attached.

2. Providing flexibility on piping systems and on other equipment where differential movement between portions of those piping systems or equipment is expected. Except where large differential movement occurs over a short distance, flexible couplings provide sufficient flexibility between portions of sprinkler piping systems where needed.

3. Providing adequate clearance around piping or sprinklers that are near or that penetrate structural members, walls, floors, equipment, or other objects so that potential damage from impact is minimized.

4. Using appropriate types of pipe hangers and sway bracing, properly located and attached to the structure to minimize the potential for pullout.

5. Using appropriate types of piping and pipe-joining methods to minimize potential pipe breaks.

6. Providing anchorage of equipment and tanks to minimize potential sliding and/or overturning

7. Providing fire protection system plans and calculations with proper verification of design, and proper verification that the completed installation is in accordance with the design as well as good installation practices.

Also see further commentary in Section 3.1.1.

Note: Provide FM Approved equipment, materials, and services whenever they are applicable and available. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals (www.approvalguide.com)

2.2 Protection

2.2.1 Sprinkler Systems, Including In-Rack Sprinkler Systems and Small-Hose Piping Systems

2.2.1.1 Sway Bracing Locations for Steel Piping

Guidance in this section applies to steel pipe. See 2.2.1.9 for other pipe materials.

2.2.1.1.1 At a minimum, locate and space sway bracing for sprinkler system (ceiling and in-rack) and hose system steel piping per this section. Braces and their attachments must also be sized to resist design forces per 2.2.1.2 and configured per 2.2.1.3. Provide additional sway braces when necessary to reduce the tributary load so the brace capacity is not exceeded or so sway bracing locations will coincide with adequate structural members to which the sway braces will be attached. Also see further commentary in Section 3.1.2.

2.2.1.1.2 Provide adequately sized and configured bracing on sprinkler system risers, whether they are single or manifolded type and regardless of size, in accordance with the following guidelines. Also see further commentary in Section 3.1.3.

2.2.1.1.2.1 Provide a four-way sway brace within 2 ft (0.6 m) of the top of each riser. When possible, avoid the use of a single manifolded sway bracing assembly at the top of multiple adjacent risers. If used, limit the manifolded arrangement to two risers.

2.2.1.1.2.2 In multistory buildings, provide a four-way brace on the riser within 2 ft (0.6 m) of each building floor level. A four-way brace can be considered to exist when the riser passes through a structural floor and clearances do not allow more than ½ in. (13 mm) movement in any horizontal direction (note: this arrangement will require additional flexible couplings on the riser; see 2.2.1.4.3.3).

2.2.1.1.2.3 Provide additional intermediate four-way sway bracing on risers at an interval not to exceed 40 ft (12.2 m). Where flexible couplings are used, arrange this intermediate four-way sway bracing so a brace is provided within 2 ft (0.6 m) of **every other** flexible coupling (adding four-way braces if necessary). For risers in multistory buildings or towers that have attached feed or cross mains not located at floor levels, add four-way braces if necessary such that a brace is provided within 2 ft (0.6 m) of these mains.

2.2.1.1.2.4 For risers fed from horizontal manifold piping, provide a two-way lateral sway brace within 2 ft (0.6 m) of the end of any horizontal manifold piping longer than 6 ft (1.8 m), or when any flexible couplings are used on either the horizontal manifold piping or on the riser stub between the floor and the connection to the horizontal manifold piping. See Fig. 2.2.1.1.2.

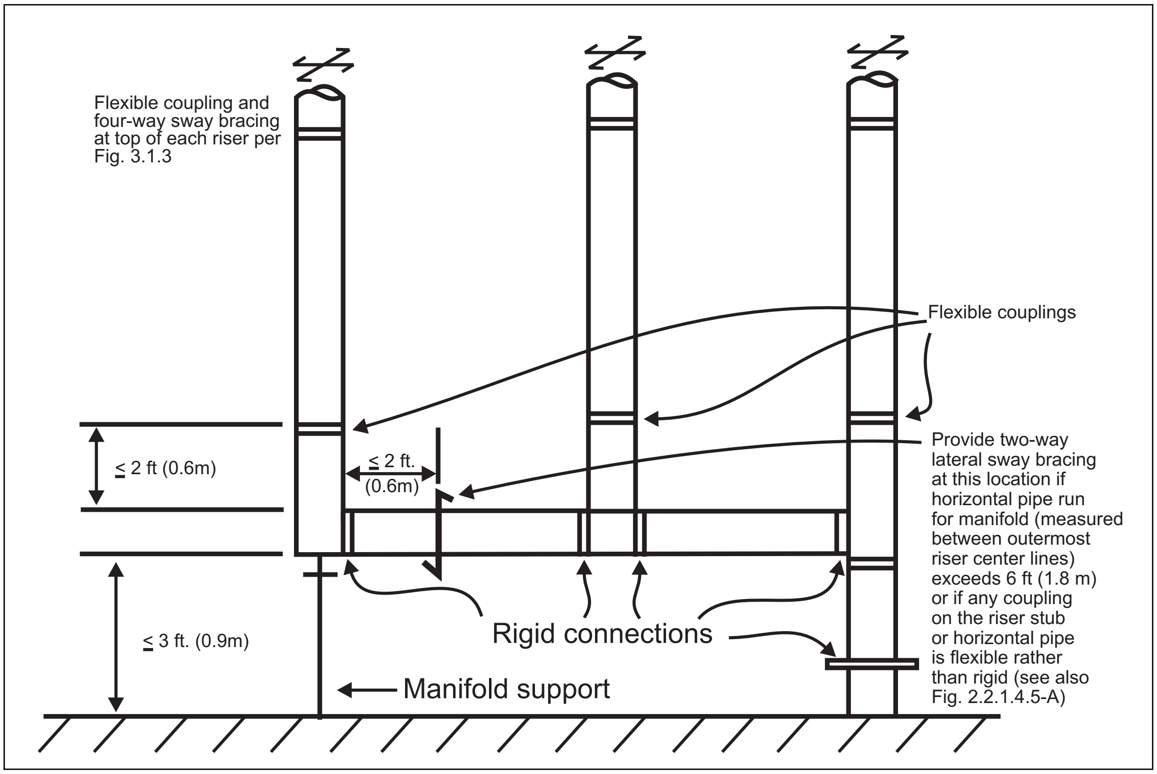


Fig. 2.2.1.1.2. Arrangement of manifolded risers

2.2.1.1.3 Provide adequately sized and configured bracing on vertical cross main or feed main piping, regardless of size, in accordance with the following guidelines.

2.2.1.1.3.1 For vertical cross main or feed main piping of 6 ft (1.8 m) or more, provide four-way sway bracing at both the top and bottom, and intermediate four-way sway bracing similar to risers as recommended in 2.2.1.1.2.3. Locate the top and bottom braces on the largest diameter pipe within 2 ft (0.6 m) of the respective piping turn.

2.2.1.1.3.2 For vertical cross main or feed main piping of less than 6 ft (1.8 m), provide four-way bracing located on the largest diameter pipe within 3 ft (0.9 m) of any turn equipped with flexible coupling(s).

2.2.1.1.4 Provide adequately sized and configured bracing on horizontal feed main or cross main piping, regardless of size, in accordance with the following guidelines. Also see further commentary in Section 3.1.4.

2.2.1.1.4.1 At horizontal changes of direction, provide horizontal feed main or cross main piping that has pipe runs of 6 ft (1.8 m) or more adjacent to the change in direction with both lateral and longitudinal sway bracing within 2 ft (0.6 m) of the change of direction. If the diameter of the main reduces at the change of direction, locate braces on the larger diameter pipe.

2.2.1.1.4.2 At ends of horizontal feed mains and cross mains, provide lateral bracing within 6 ft (1.8 m) of the end, and provide longitudinal bracing within 40 ft (12.2 m) of the end. Consider seismic separation assemblies and flexible pipe loops in feed mains and cross mains per 2.2.1.4.8 as the end of the piping on both sides of the assembly or loop.

2.2.1.1.4.3 When unnecessary flexible couplings (i.e., more flexible couplings than recommended in 2.2.1.4) are installed on horizontal feed mains or cross mains, provide additional lateral sway bracing as follows:

A. Within 2 ft (0.6 m) of every other flexible coupling on straight pipe runs, and

B. Within 2 ft (0.6 m) of any horizontal change of pipe direction having flexible couplings but not braced per 2.2.1.1.4.1.

2.2.1.1.4.4 For straight pipe runs, after giving credit to any sway bracing installed per Sections 2.2.1.1.2 to 2.2.1.1.4.3, provide sway bracing on horizontal feed mains and cross mains at a maximum spacing of 40 ft (12.2 m) for lateral sway bracing and 80 ft (24.4 m) for longitudinal sway bracing using the following guidelines.

A. A four-way brace on a vertical pipe (e.g., at the top of the riser) may be counted as the initial lateral and longitudinal brace for the attached horizontal pipe (i.e., feed main or cross main) of the same or smaller diameter when the brace is located within 2 ft (0.6 m) of the horizontal pipe.

B. A lateral brace within 2 ft (0.6 m) of the end of a feed main or cross main piping connection to another main that is perpendicular and of the same or lesser diameter may be used to also act as a longitudinal brace for the perpendicular main.

C. A longitudinal brace within 2 ft (0.6 m) of the end of a feed main or cross main piping connection to another main that is perpendicular and of the same or lesser diameter may be used to also act as a lateral brace for the perpendicular main.

2.2.1.1.4.5 The following items or configurations may not be used to provide, or allow the omission of, lateral or longitudinal sway bracing on any horizontal feed main or cross main.

A. U-hangers, including wraparound types (however, U-bolts configured per 2.2.1.3.2 may be used as lateral bracing).

B. Feed mains and cross mains supported by hangers having short rods.

C. Sway bracing on branch lines.

2.2.1.1.5 Provide adequately sized and configured bracing on sprinkler system branch lines as described below. See also 2.2.1.1.6 for additional lateral restraint requirements at ends of branch lines.

2.2.1.1.5.1 Provide lateral sway bracing on 2½ in. (65 mm) diameter and larger branch lines and portions of branch lines that are greater than 20 ft (6.1 m) in length in accordance with the following guidelines.

A. For branch lines less than 4 in. (100 mm) in diameter, lateral sway bracing is not needed on pipes individually supported by rods that meet the following criteria:

1. All rods have a length less than 6 in. (150 mm) from the supporting member attachment to the top of the branch line, and

2. there is no more than 1/2 in. (13 mm) of space between the top of the branch line piping and the bottom of the support rod.

B. A four-way brace on a vertical pipe (e.g., at the bottom of a drop) may be counted as the initial lateral brace for the attached horizontal branch line of the same or smaller diameter when the brace is located within 2 ft (0.6 m) of the horizontal pipe.

C. A longitudinal brace within 2 ft (0.6 m) of the end of a branch line connection to another branch line that is perpendicular and of the same or lesser diameter may be used to also act as a lateral brace for the perpendicular branch line.

D. U-bolts configured per 2.2.1.3.2 and wraparound U-hangers (but not other types of U-hangers) meeting the criteria per 2.2.1.3.4 may be used as lateral sway bracing for branch lines.

E. When more flexible couplings than recommended in 2.2.1.4 are installed on branch lines, provide additional lateral sway bracing:

1. within 2 ft (0.6 m) of every other flexible coupling on straight pipe runs, and

2. within 2 ft (0.6 m) of any horizontal change of pipe direction having flexible couplings.

F. Locate the first lateral sway brace on a branch line no closer than 10 ft (3.1 m) nor greater than 40 ft (12.2 m), including all vertical and horizontal branch line section lengths, from the branch line connection to the cross main.

G. For dead-end branch lines locate the last lateral brace not more than 6 ft (1.8 m) from the end. Consider seismic separation assemblies and flexible pipe loops per 2.2.1.4.8 as the end of the piping on both sides of the assembly or loop.

H. Locate a lateral brace on branch lines not more than 6 ft (1.8 m) from horizontal changes in direction.

I. After giving credit to any branch line lateral sway bracing installed or allowed to be omitted per Items A to H above, provide lateral sway bracing on straight runs of branch line spaced at a maximum of 40 ft (12.2 m).

2.2.1.1.5.2 Provide longitudinal sway bracing on 2½ in. (65 mm) diameter and larger branch lines and portions of branch lines that are greater than 40 ft (12.2 m) in length in accordance with the following guidelines.

A. A four-way brace on a vertical pipe (e.g., at the bottom of a drop) may be counted as the initial longitudinal brace for the attached horizontal branch line of the same or smaller diameter when the brace is located within 2 ft (0.6 m) of the horizontal pipe.

B. A lateral brace within 2 ft (0.6 m) of the end of a branch line connection to another branch line that is perpendicular and of the same or lesser diameter may be used to also act as a longitudinal brace for the perpendicular branch line.

C. Locate the first branch line longitudinal sway brace closest to the cross main between 20 ft and 80 ft (6.1 m and 24.4 m), including all vertical and horizontal branch line section lengths, from the branch line connection to the cross main.

D. For dead-end branch lines, locate the last longitudinal brace not more than 40 ft (12.2 m) from the end. Consider seismic separation assemblies and flexible pipe loops per 2.2.1.4.8 as the end of the piping on both sides of the assembly or loop.

E. Locate a longitudinal brace on branch lines not more than 40 ft (12.2 m) from horizontal changes in direction.

F. After giving credit to any branch line longitudinal sway bracing installed per Items A to E above, provide longitudinal sway bracing on straight runs of branch line spaced at a maximum of 80 ft (24.4 m).

2.2.1.1.6 For sprinkler system branch lines that do not require lateral bracing per 2.2.1.1.5.1 (i.e., those with diameters less than 2½ in. [65 mm]), provide a short hanger (as defined in 2.2.1.1.5.1.A) or a lateral restraint (as defined below) not more than 6 ft (1.8 m) from the end of dead-end branch lines to control lateral deflections at that location.

Where lateral restraints are used, size them to resist a 150 lb (0.67 kN) horizontal load (ASD) and place them within 2 ft (0.6 m) of the last branch line hanger (i.e., the hanger resisting upward movement as required by 2.2.1.8.1.5.B). Examples of acceptable methods of restraint include, but are not limited to, the following:

A. A wraparound U-hanger per 2.2.1.3.4 except with $l/r \leq 400$

B. A sway brace with $l/r \leq 400$

C. A pair (one each side of the pipe) of 12-gauge (0.106 in. [2.7 mm] diameter) steel splay wires, each oriented at least 45 degrees from vertical. Two separate splay wires with the ends of each fastened to connectors at the pipe and structure, or a single wire wrapped one full turn around the pipe with both ends fastened to the structure, may be used. Secure by wrapping the ends of the wire(s) around the splay wire with at least four tight turns within 1½ in. (40 mm) similar to suspended ceiling splay wire bracing (see commentary in Section 3.1.11)

D. A hanger oriented at least 45 degrees from vertical having $l/r \leq 400$ with the rod extended to within 1/2 in. (13 mm) of the pipe that is capable of transferring axial loads in both directions, or two hangers that resist only downward loads(one each side of the pipe) oriented at least 45 degrees from vertical.

2.2.1.2 Horizontal Seismic Loads for Sway Bracing Design

2.2.1.2.1 Determine the horizontal seismic design load (H) at a sway bracing location per the following equation:

$$H = G \cdot W_p$$

Where:

G = the horizontal acceleration (“G” factor) expected from an earthquake per 2.2.1.2.2.

W_p = the weight of the water-filled piping located within the zone of influence for that sway bracing location per 2.2.1.2.3.

Also see further commentary in Section 3.1.5.

2.2.1.2.2 Use a minimum “G” factor, based on the Allowable Stress Design (ASD) analysis method per the following equation:

$$G = (0.7) \cdot S_{DS}$$

The following “G” factors, determined based on the generic values of S_{DS} from Data Sheet 1-2, *Earthquakes*, may be used for any site, and must be used when the value of S_{DS} for the location is not available from the American Society of Civil Engineers standard, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7) or a reliable source that uses the ASCE 7 methodology:

- FM 50-year earthquake zones: G = 0.9 (based on S_{DS} = 1.3g)
- FM 100-year earthquake zones: G = 0.65 (based on S_{DS} = 0.9g)
- FM 250-year earthquake zones: G = 0.4 (based on S_{DS} = 0.55g)
- FM 500-year earthquake zones: G = 0.4 (based on S_{DS} = 0.55g)

Use a higher “G” factor if required by local authorities per the building code for the location involved.

See Section 3.1.6 for the definition of S_{DS} as well as additional commentary.

2.2.1.2.3 Determine the weight (W_p) to be used for each sway brace design (or each controlling sway brace design) by including the water-filled weight of all piping tributary to that brace (i.e., within the zone of influence). Where a sway brace is used to brace more than one pipe (i.e., as allowed per 2.2.1.1.2, 2.2.1.1.4 and 2.2.1.1.5) base the design load in each horizontal direction on the tributary weight from all pipes being braced.

Zones of influence for various pipes are defined in the Section 3.1.7 commentary.

2.2.1.3 Configuration and Design of Sway Bracing

2.2.1.3.1 Provide sway bracing to resist horizontal seismic loads. Sway brace(s) at each location should be capable of resisting the horizontal seismic design load (H) as determined per 2.2.1.2. Provide additional members to resist any net vertical force component that occurs as a result of sway brace placement on horizontal pipe (see 2.2.1.3.5.6).

2.2.1.3.2 A properly sized and attached U-bolt that fastens the pipe directly to, and holds the pipe tightly against, a structural supporting member may be used as a lateral (but not a longitudinal) sway brace when located on horizontal piping, or as a four-way sway brace when located on vertical piping. Consideration of a vertical resultant force for horizontal pipe is unnecessary for this configuration.

Determine the maximum ASD horizontal seismic design load capacity (H_{ASD}) of the U-bolt based on the assumption that H is resisted in shear by one leg of the U-bolt. Use the gross area (A_g) of the rod leg (even if the rod is threaded), the tensile strength of the steel (F_u), and the formula:

$$H_{ASD} = 0.17 F_u \cdot A_g$$

For typical steel (F_u = 58,000 psi [400 MPa]) the “H_{ASD}” that can be resisted by a U-bolt can be taken as: 750 lb for 5/16 in. rod, 1090 lb for 3/8 in. rod and 1940 lb for ½ in. rod (3.42 kN for 8 mm rod, 5.34 kN for 10 mm rod and 7.69 kN for 12 mm rod).

2.2.1.3.3 Do not use U-hangers, including wraparound types, as lateral or longitudinal sway bracing for feed mains and cross mains.

2.2.1.3.4 Wraparound U-hangers may be used as lateral (but not longitudinal) sway bracing for branch lines that need sway bracing if they meet all of the following criteria:

A. They have both legs bent out at least 30 degrees from the vertical,

B. They are the proper diameter and length per 2.2.1.3.5.3 and are sized per 2.2.1.3.5.5 for the seismic loads specified in 2.2.1.2,

C. They are properly attached to the building structure per 2.2.1.3.6, and

D. There is no more than 1/2 in. (13 mm) of space between the top of the branch line piping and the wraparound portion of the U-hanger.

2.2.1.3.5 For sway bracing that consists of individual diagonal element(s) or diagonal plus vertical elements, configure and size these elements per the following guidelines. Also see further commentary in Section 3.1.8.

2.2.1.3.5.1 Determine allowable loads for the pipe-attached component and the structure-attached component per the *Approval Guide*. Size the brace member (e.g., steel pipe, steel angle, steel rods, or steel flats) connecting the two components per this data sheet and to meet *Approval Guide* requirements, if any. For horizontal piping, Fig. 2.2.1.3.5-A and Fig. 2.2.1.3.5-B show bracing options for lateral and longitudinal sway bracing. Fig. 2.2.1.3.5-C shows four-way bracing on vertical piping.

2.2.1.3.5.2 Position the diagonal brace elements as follows.

A. On horizontal piping, position diagonal element(s) at an angle (Θ) from the vertical of at least 30 degrees (and preferably at least 45 degrees).

B. On risers and other vertical piping, orient the diagonal elements of the four-way brace at 90 degrees from each other and with an angle (Θ) of 45 degrees from each principal axis. Where this is not possible, position each diagonal element at least 30 degrees but not more than 60 degrees from each principal axis (i.e., oriented 60 to 120 degrees from each other).

C. Where two diagonal tension-compression braces are used (as shown in Fig. 2.2.1.3.5-B and Fig. 2.2.1.3.5-C) they should be placed such that the brace angles (Θ_L and Θ_R) are as close to equal as possible. In no case should Θ_L and Θ_R differ by more than 15 degrees.

2.2.1.3.5.3 For braces used to resist both tension and compression, choose the shape, size, and length of the braces so the slenderness ratio, l/r (length/least radius of gyration), does not exceed 200, in order to provide adequate resistance to buckling. Base the slenderness ratio on the actual length of the brace between attachment points to the structure and the pipe being braced.

2.2.1.3.5.4 For braces used in tension only, choose the shape, size, and length of the braces to result in a slenderness ratio, l/r (length/least radius of gyration), that does not exceed 300 (i.e., cable bracing would not qualify). Base the slenderness ratio on the actual length of the brace between attachment points to the structure and the pipe being braced.

2.2.1.3.5.5 Select each brace so the maximum length between attachment points to the structure and the pipe being braced does not exceed the length calculated based on the slenderness ratio, l/r, limitations in Sections 2.2.1.3.5.3 and 2.2.1.3.5.4; and so the brace can resist the percentage of the total horizontal design load, H, that is assigned to it, but not less than H/2 (see commentary in Section 3.1.8 for determining the distribution of “H” between braces).

In lieu of calculations, the length limitations and maximum horizontal design loads can be taken from Table 3.1.8-A through Table 3.1.8-F in the Section 3.1.8 commentary. Alternatively, these values may be calculated using the brace properties (e.g., radius of gyration and cross sectional area) and resulting ASD capacities determined from the American Institute of Steel Construction (AISC) Standard 360, *Specification for Structural Steel Buildings*, or a similar local building code or standard (except that any increase in ASD capacity allowed for seismic loading - traditionally a one-third increase - shall not be applied).

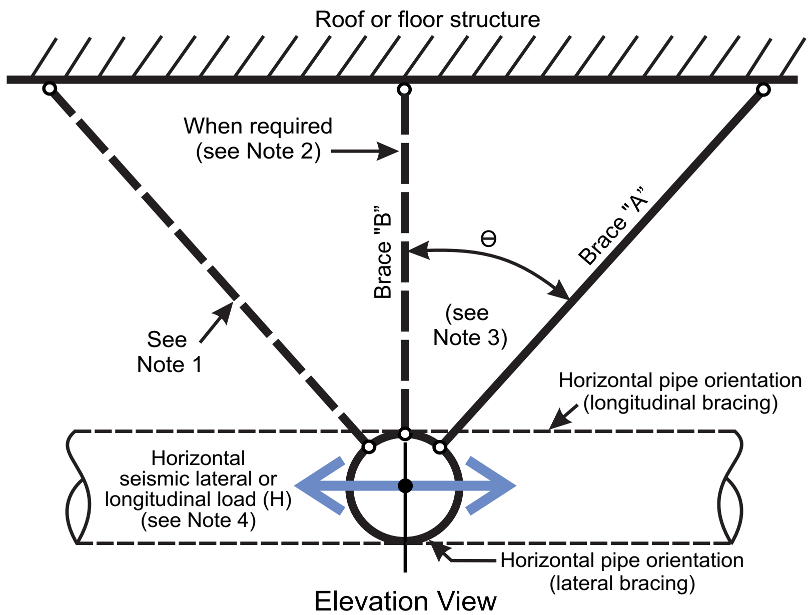
2.2.1.3.5.6 Where a single diagonal tension-compression ($l/r \leq 200$) sway brace is used, or where two diagonal tension-only ($l/r \leq 300$) sway braces are used (see Brace[s] “A” in Fig. 2.2.1.3.5-A), calculate the net vertical uplift force (V_F) derived from the horizontal seismic design load (H), as:

$$V_F = (H/\tan \Theta) - (1/2) \cdot W_P$$

Where:

V_F = Net vertical uplift force
H = Horizontal design load from 2.2.1.2
Θ = Angle of Brace(s) A from vertical
W_P = Weight of the water-filled pipe within the zone of influence

If V_F is greater than 0 (zero), either increase the angle (Θ) of Brace(s) A from vertical to reduce the vertical upward force or provide Brace "B" in Fig. 2.2.1.3.5-A, attached to the pipe no more than 6 in. (150 mm) from the point of attachment on the pipe for Brace(s) A. Brace "B" will preferably be an actual brace member but could be a substantial hanger (e.g., clevis or pipe clamp hanger) that has been adequately modified to resist the net vertical uplift force - see additional guidance in the Section 3.1.8 commentary.



Note 1: Where Brace "A" is designed for tension only (200 < ℓ/r ≤ 300), a Brace "A" is needed both to the left and right of the vertical.

Note 2: When Brace "B" is required to resist net vertical uplift force it may be an adjacent hanger that meets guidelines in the text in relation to strength, fasteners, and attachment methods.

Note 3: The angle from vertical (Θ) must be at least 30° and preferably at least 45°.

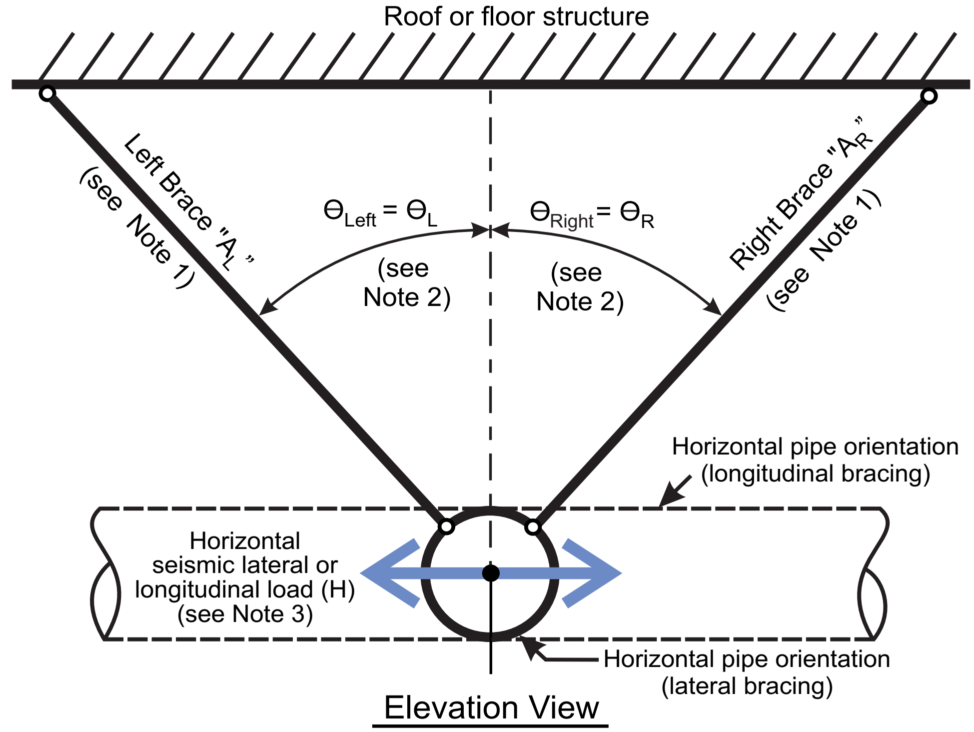
Note 4: The horizontal seismic load may differ in the lateral and longitudinal directions.

Fig. 2.2.1.3.5-A. Lateral or longitudinal sway bracing on horizontal pipe using one vertical and one diagonal brace

2.2.1.3.6 Select the proper method to attach the sway bracing to the structure and to the piping per the following guidelines. Also see further commentary in Section 3.1.9.

2.2.1.3.6.1 Arrange all parts and fittings in a straight line such that eccentric loading on any of the sway bracing components is minimized.

2.2.1.3.6.2 Make connections to the structure and the piping with components that are FM Approved or that provide a positive mechanical attachment (e.g., a U-bolt per 2.2.1.3.2). These connections should also be able to be visually verified as to correct installation.



Note 1: Braces "A_L" and "A_R" should be capable of resisting both tension and compression. When Braces "A_L" and "A_R" are designed for tension only ($200 < \ell/r \le 300$) treat as a special condition of Figure 2.2.1.3.5-A.

Note 2: The angles from vertical for the left and right braces (Θ_L and Θ_R) must each be at least 30° and preferably at least 45°. Θ_L and Θ_R should be as nearly equal as possible, but in no case should they differ by more than 15°.

Note 3: The horizontal seismic load may differ in the lateral and longitudinal directions.

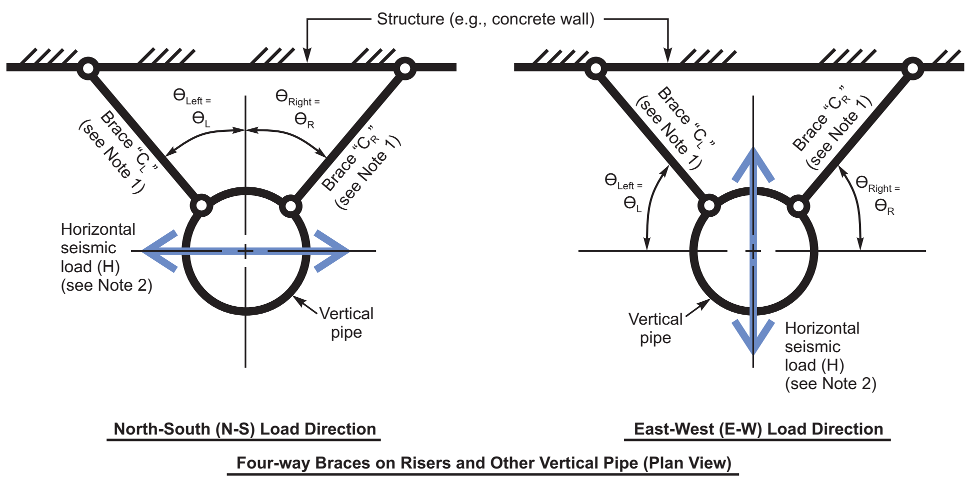
Fig. 2.2.1.3.5-B. Lateral or longitudinal sway bracing on horizontal pipe using two diagonal braces

2.2.1.3.6.3 Make attachments to the building, rack or other structure in accordance with the following guidelines:

A. Determine the shear and tension loads on the fasteners based on the sway bracing configuration (e.g., those illustrated in Fig. 2.2.1.3.5-A, Fig. 2.2.1.3.5-B and Fig. 2.2.1.3.5-C for sway bracing that includes individual diagonal elements) and how the fasteners attach to the structure (e.g., into the underside, the side or the face of the structural member).

B. For sway bracing configurations using two opposing tension and compression diagonal braces, distribute the larger of one-half the horizontal seismic load (H/2) or the load determined by proportional distribution of design load, H, to each fastener (as described in the Section 3.1.8 and Section 3.1.9 commentaries).

C. For sway bracing configurations using two opposing tension-only diagonal braces, distribute the full horizontal seismic design load (H) to each fastener because neither brace is being considered as capable of resisting compression.



Note 1: Braces "C_L" and "C_R" should be capable of resisting both tension and compression, and should preferably be oriented at 90º from each other with $\Theta_L = \Theta_R = 45º$. Where this is not possible, meet the following requirements:

- $30º \leq \Theta_L \leq 60º$
- $30º \leq \Theta_R \leq 60º$
- Θ_L and Θ_R as nearly equal as possible, but in no case do they differ by more than 15º.

Note 2: The horizontal seismic load (H) may differ in each orthogonal direction.

Fig. 2.2.1.3.5-C. Four-way bracing on risers and other vertical piping using two diagonal braces

D. When structural members do not meet minimum requirements defined elsewhere (such as when wood members are dimensionally inadequate) or whenever any doubt exists regarding their load-carrying capabilities, provide verification with the system design information that the structural member and the attachment point for the sway bracing are able to carry the anticipated load. Where it is necessary to reinforce the structural members, include a structural engineering analysis or verification with the system design information.

2.2.1.3.6.4 Make attachments to wood members per the following:

A. Connect sway braces to wood components with through-bolts whenever practicable. When roof configuration or other factors make the use of through-bolts impractical, lag screws may be used.

B. Use neither through-bolts nor lag screws in wood members less than 3½ in. (90 mm) in least dimension.

C. Dimensionally locate through-bolts and lag screws with respect to structural members per Fig. 2.2.1.3.6-A.

D. Pre-drill holes for through-bolts 1/32 or 1/16 in. (0.8 or 1.6 mm) larger in diameter than the bolt diameter.

E. Pre-drill lead (pilot) holes for lag screws in accordance with Table 2.2.1.3.6 and Fig. 2.2.1.3.6-B.

F. Install lag screws properly, by turning them with a wrench, not driving them with a hammer.

G. In lieu of calculations, select the appropriate fastener size from Table 3.1.9-A through Table 3.1.9-D in the Section 3.1.9 commentary for through-bolts and lag screws in wood. Alternatively, calculate the appropriate fastener size based on Allowable Stress Design (ASD) capacities determined from the American Wood Council (AWC) Standard ANSI/AWC NDS, *National Design Specification (NDS) for Wood Construction* (including the allowed load duration factor) or a similar local building code or standard.

2.2.1.3.6.5 Make attachments to concrete components per the following:

A. Do not use powder-driven fasteners to attach sway bracing to concrete components of the structural system.

B. Meet the following requirements for post-installed concrete anchors (e.g., expansion anchors or wedge anchors installed in hardened concrete):

1. Use expansion or wedge anchors that are listed for use in seismic applications by the local governing jurisdiction based on testing that establishes parameters for anchor design (see the commentary in Section 3.1.9).

2. Provide a minimum edge distance of 12 times the bolt diameter ($12D_b$) and a minimum nominal (i.e., before the anchor is set) embedment depth of $6D_b$ ($7D_b$ for ½ in. [12 mm] anchors), unless otherwise allowed by the manufacturer and calculations are provided to verify adequacy.

3. All details of the installation must conform with the manufacturer's instructions and any guidelines established by the local governing jurisdiction as part of their load ratings, including any inspection requirements or certification of concrete strength.

4. Include verification of the capability of the structural member and the point of attachment to withstand the anticipated load with the system design information.

C. In lieu of calculations, select the appropriate fastener size (meeting the conditions in Item B above) from Table 3.1.9-E or Table 3.1.9-F in the Section 3.1.9 commentary for expansion or wedge anchors. Alternatively, calculate the appropriate fastener size based on ASD capacities for post-installed concrete anchors selected from a manufacturer's product line meeting the four conditions in Item B above as well as the following conditions:

1. Establish the shear and tension capacities of an anchor or group of anchors using ACI 318, American Concrete Institute *Building Code Requirements for Structural Concrete and Commentary* or a similar local building code or standard. Reduce the ACI 318 shear and tension capacities to account for ASCE 7 overstrength (Ω_0) and load factors by multiplying ACI 318 LRFD values by 0.42 or by multiplying ACI 318 ASD values by 0.6.

2. The relationship between actual calculated shear and tension loads, and allowable shear and tension loads, must conform to the following equations:

$$(S_{ACT}/S_{ALL}) + (T_{ACT}/T_{ALL}) \le 1.2$$
$$(S_{ACT}/S_{ALL}) \le 1.0$$
$$(T_{ACT}/T_{ALL}) \le 1.0$$

where
S_{ACT} = calculated actual shear load (see the commentary in Section 3.1.9)
S_{ALL} = local governing jurisdiction-approved ASD allowable shear load (including overstrength [Ω_0] and load factor reductions)
T_{ACT} = calculated actual tension load (see the commentary in Section 3.1.9)
T_{ALL} = local governing jurisdiction-approved ASD allowable tension load (including overstrength [Ω_0] and load factor reductions)

D. Cast-in-place concrete inserts may be used in place of expansion anchors if the insert has been qualified for use in seismic applications and the governing jurisdiction-approved ASD loads for the inserts (including overstrength [Ω_0] and load factor reductions) are greater than or equal to the values for the specified expansion anchor upon which Table 3.1.9-E and Table 3.1.9-F are based (see table notes). Alternatively, determine the ASD capacity for a seismically qualified cast-in-place concrete insert by calculations similar to those described above in Item B and Item C for post-installed concrete anchors.

2.2.1.3.6.6 Make attachments to steel structural members per the following:

A. Make attachments to steel structural members (e.g., hot-rolled I-beams and channels or cold-formed tubes) at locations where the steel is not less than 0.1046 in. (2.65 mm) thick (i.e., 12 gauge or thicker) using through-bolts in drilled holes, welded studs, or connection hardware that is FM Approved for use in resisting seismic loads. Do not use powder-driven fasteners or C-clamps (even those with retaining straps) to attach sway bracing to steel structural members.

B. In lieu of calculations, select the appropriate fastener size from Table 3.1.9-G or Table 3.1.9-H for through-bolts. Alternatively, calculate the appropriate fastener size based on ASD capacities determined from the American Institute of Steel Construction (AISC) Standard 360, *Specification for Structural Steel Buildings*, or a similar local building code or standard (except that any increase in ASD capacity allowed for seismic loading - traditionally a one-third increase - shall not be applied).

C. Install welded studs, with load-carrying capabilities adequate for the anticipated horizontal seismic design load (H), in accordance with American Welding Society Standard D1.1, *Structural Welding Code* or equivalent international standard.

D. For attachment to other types of steel structural members, such as a light-gauge (i.e., 13 to 30 gauge, corresponding to a thickness less than 0.1046 in. [2.65 mm]) “C” or “Z” purlin, a truss, or an open-web joist, determine the adequacy of the structural member and the point of attachment to carry the anticipated load as part of the system design and include it with the system design information. It is preferred that braces attach near the tops of these members. Do not attach braces in any of the following manners:

1. To the bottom flange or to the web near the bottom flange of a “C” or “Z” purlin (unless the flange is braced to adequately transfer the force to the tops of adjacent purlins)

2. To the bottom chord of open-web joists or light trusses (unless the bottom chord is braced to adequately transfer the force to the tops of adjacent members)

3. To web members of open-web joists or trusses

4. By bolting in the slot between two structural members forming a truss or joist chord

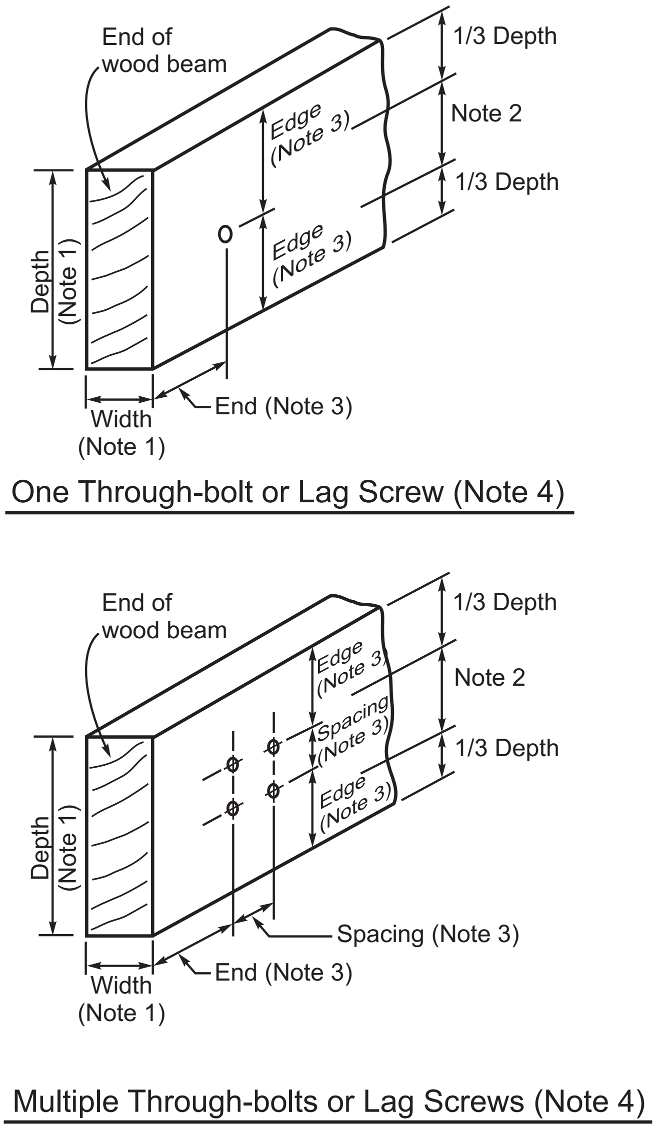
5. To steel deck without structural concrete fill (which is not considered to be a steel structural member)

2.2.1.3.6.7 Make attachments to the sprinkler piping in accordance with the following guidelines. See Fig. 3.1.1-A and 3.1.1-B in the Section 3.1.1 commentary for examples of bracing attachment to piping.

A. Make connections, capable of carrying the anticipated seismic load, directly to the sprinkler piping with FM Approved connectors or with a pipe clamp, a U-bolt that is mechanically fastened to the brace using nuts and washers, or other positive mechanical means of attachment.

B. Avoid loosely fitting methods of attachment that allow excessive movement, such as pipe rings.

C. Provide verification of the load-carrying capacity for the attachment to the pipe with the system design information.



Notes:

1. Attach to wood members having minimum 3½ in. (90 mm) width and depth. Attach to deeper beams if necessary to meet minimum edge and spacing distances.

2. Place through-bolts or lag screws within the middle third of the beam depth while also meeting the minimum end, edge and spacing distances.

3. Minimum distances, expressed as multiples of the through-bolt or lag screw diameter (D) and measured from the centerline of the through-bolt or lag screw hole, are:

- 7D to ends of beams
- 4D to edges of beams
- 4D spacing between bolts

4. Provide standard washers, or other metal, between the wood and the heads/nuts of through-bolts and lag screws.

Fig. 2.2.1.3.6-A. Dimensional locations for lag screws and through-bolts in wood

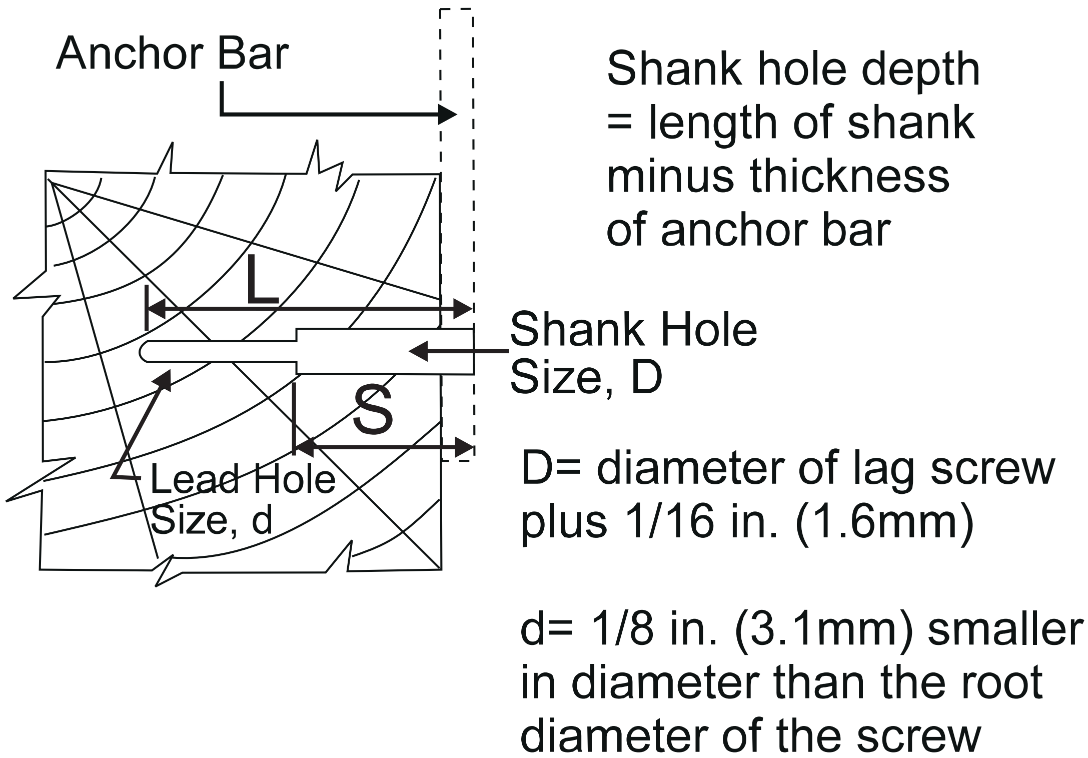


Fig. 2.2.1.3.6-B.Pilot hole sizing for lag screws−use with Table 2.2.1.3.6

Table 2.2.1.3.6 Hole Dimensions for Lag Screws

Length of lag screw under head, L, in. (mm)	*Length of shank,* S, in. (mm)*	*Depth of lead hole,* in. (mm)*
2 (50)	½ (13)	1-¾ (45)
3 (75)	1 (25)	2-¾ (70)
4 (100)	1-½ (40)	3-¾ (95)
5 (125)	2 (50)	4-¾ (120)
6 (150)	2-½ (65)	5-¾ (145)
7 (180)	3 (75)	6-¾ (175)
8 (200)	3-½ (90)	7-¾ (195)

*Depth of hole for shank is the length of the shank minus the attachment thickness. For remainder of hole depth use lead hole boring only.

2.2.1.4 Flexibility Needed to Allow Differential Movement

2.2.1.4.1 Provide adequate flexibility between portions of properly braced, welded and non-welded sprinkler systems, regardless of pipe size, that are expected to move differentially with respect to each other using the following guidelines and techniques.

Guidance in this section applies to steel pipe. See 2.2.1.9 for other pipe materials.

2.2.1.4.2 If more flexible couplings are installed than recommended in this section, provide additional lateral sway bracing to prevent excessive movement of piping per 2.2.1.1.2.3, 2.2.1.1.4.3 and 2.2.1.1.5.1.E.

2.2.1.4.3 Provide flexibility for sprinkler risers per the following recommendations.

2.2.1.4.3.1 Provide a flexible coupling within 2 ft (0.6 m) of the top and bottom of each individual riser that is connected directly to underground piping (see Fig. 3.1.3 in the Section 3.1.3 commentary for details). This applies to risers located outside and inside buildings. Where welded piping systems exist from the riser through the cross mains, the flexible coupling at the top of the riser may be omitted.

2.2.1.4.3.2 When multiple risers are supplied by a single manifold connection to an underground main, provide each riser with a flexible coupling within 2 ft (0.6 m) of the top, and a flexible coupling within 2 ft (0.6 m) of the bottom where connected to the manifold. Locate the horizontal manifold piping 3 ft (0.9 m) or less above floor level and brace manifold piping when needed (see 2.2.1.1.2.4). Connect the horizontal manifold to the main riser and the main riser to the riser stub at floor level with flanged or other rigid connections (see Fig. 2.2.1.1.2). Where welded piping systems exist from the riser through the cross mains, the flexible coupling at the top of the riser may be omitted.

2.2.1.4.3.3 For multistory building risers, additional flexible coupling(s) are needed at each floor level. When the pipe doesn't penetrate a floor slab, steel plate, etc. (e.g., is in an open tower), or when it does penetrate one of these elements and clearances meet the recommendations of 2.2.1.5.1, locate the flexible coupling within 1 ft (0.3 m) of the floor (either above or below the floor; see Fig. 2.2.1.4.3). Where clearances per 2.2.1.5.1 are not provided, install flexible couplings within 1 ft (0.3 m) both above and below the floor. (Exception: the flexible coupling below the floor should be located below any main supplying that floor.)

2.2.1.4.3.4 Flexible couplings are not needed on riser piping beneath floors that rest directly on the ground; however, a flexible coupling is needed above the ground floor as recommended in 2.2.1.4.3.1 and 2.2.1.4.3.2.

2.2.1.4.3.5 Provide a flexible coupling within 2 ft (0.6 m) above or below any intermediate points of bracing for risers. Where welded piping systems exist from the riser through the cross mains, these flexible couplings may be omitted.

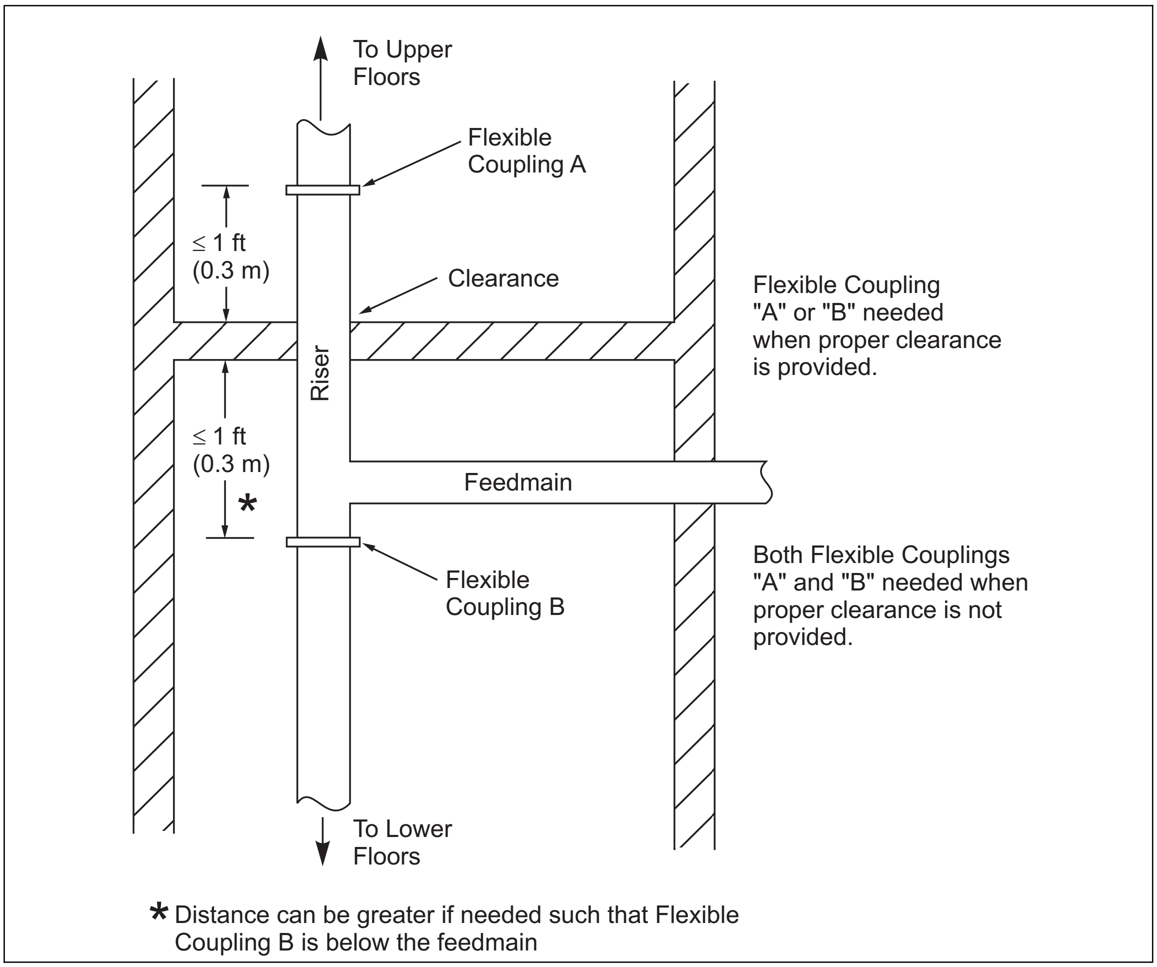


Fig. 2.2.1.4.3. Arrangement of flexible couplings for risers passing through floors of multistory buildings

2.2.1.4.4 Provide flexibility on feed mains and cross mains per the following recommendations.

2.2.1.4.4.1 Provide a flexible coupling within 2 ft (0.6 m) above or below intermediate points of bracing for vertical mains. Where welded piping systems exist from the riser through the cross mains, these flexible couplings may be omitted.

2.2.1.4.4.2 Provide flexible couplings within 2 ft (0.6 m) of the top and bottom of vertical mains that are 6 ft (1.8 m) or greater in length (in conjunction with the sway bracing recommended in 2.2.1.1.3.1). Where welded piping systems exist from the riser through the cross mains, these flexible couplings may be omitted.

2.2.1.4.4.3 Provide a seismic separation assembly, FM Approved flexible pipe loop or other comparable arrangement per 2.2.1.4.8 where mains cross a building seismic expansion joint or span between independent buildings or structures.

2.2.1.4.4.4 Where a main penetrates a wall and requirements (e.g., clearances) per 2.2.1.5.1 are not met, install flexible couplings within 1 ft (0.3 m) of each side of a wall. Where welded piping systems exist from the riser through the cross mains, these flexible couplings may be omitted.

2.2.1.4.5 Provide flexibility for in-rack sprinkler systems per the following guidelines.

2.2.1.4.5.1 Provide flexible couplings at the top and bottom, and at intermediate points of lateral support, of each in-rack sprinkler system riser as required for other risers, both in cases where the in-rack sprinkler system riser is attached directly to the underground piping and where the riser is attached directly to the ceiling sprinkler system riser (see 2.2.1.4.3.1, 2.2.1.4.3.2, 2.2.1.4.3.5 and Fig. 2.2.1.4.5-A).

2.2.1.4.5.2 Provide a flexible coupling within 2 ft (0.6 m) above or below intermediate points of bracing of the in-rack sprinkler system riser, or other vertical pipe. Except for pipe drops supplying in-rack sprinklers, where welded piping systems exist from the riser through the cross mains, these flexible couplings may be omitted.

2.2.1.4.5.3 Provide a seismic separation assembly, FM Approved flexible pipe loop or other comparable arrangement per 2.2.1.4.8 where any in-rack sprinkler system piping crosses a building seismic expansion joint or spans between independent buildings or structures. See 2.2.1.4.5.4 for drops to racks.

2.2.1.4.5.4 For pipe drops feeding in-rack sprinklers from overhead piping, provide a flexible coupling within 2 ft (0.6 m) of the pipe drop connection to the overhead piping or armover, and a flexible coupling within 2 ft (0.6 m) above the initial in-rack sprinkler pipe drop attachment to the rack (see Fig. 2.2.1.4.5-B). Use flexible couplings that allow angular deflection from center line not less than that needed to accommodate, within the distance between the two flexible couplings, the expected lateral deflection of the building (at the location of the overhead piping) plus the expected lateral deflection of the rack (at the location of the initial attachment to the rack). Unless calculated otherwise, assume the lateral deflection of each structure is 1.5% of the height from the base to the point where the pipe is attached.

Where the two flexible couplings cannot accommodate the lateral deflection, instead provide FM Approved flexible pipe at the top and bottom of the drop, a FM Approved pipe loop per 2.2.1.4.8 at the top and/or the bottom of the drop or other engineered solution. See additional commentary for 2.2.1.4.8 in Section 3.1.10.

2.2.1.4.5.5 Provide flexible coupling(s) on the horizontal portion of in-rack sprinkler piping within 2 ft (0.6 m) of the connections to vertical pipe drops (see Fig. 2.2.1.4.5-B).

2.2.1.4.5.6 When pipe drops supplying in-rack sprinklers are connected to overhead horizontal piping via an armover, do not provide flexible couplings on the armover. However, provide a hanger of the type that will resist vertical upward movement per 2.2.1.8.1.3 and Fig. 2.2.1.4.5-B.

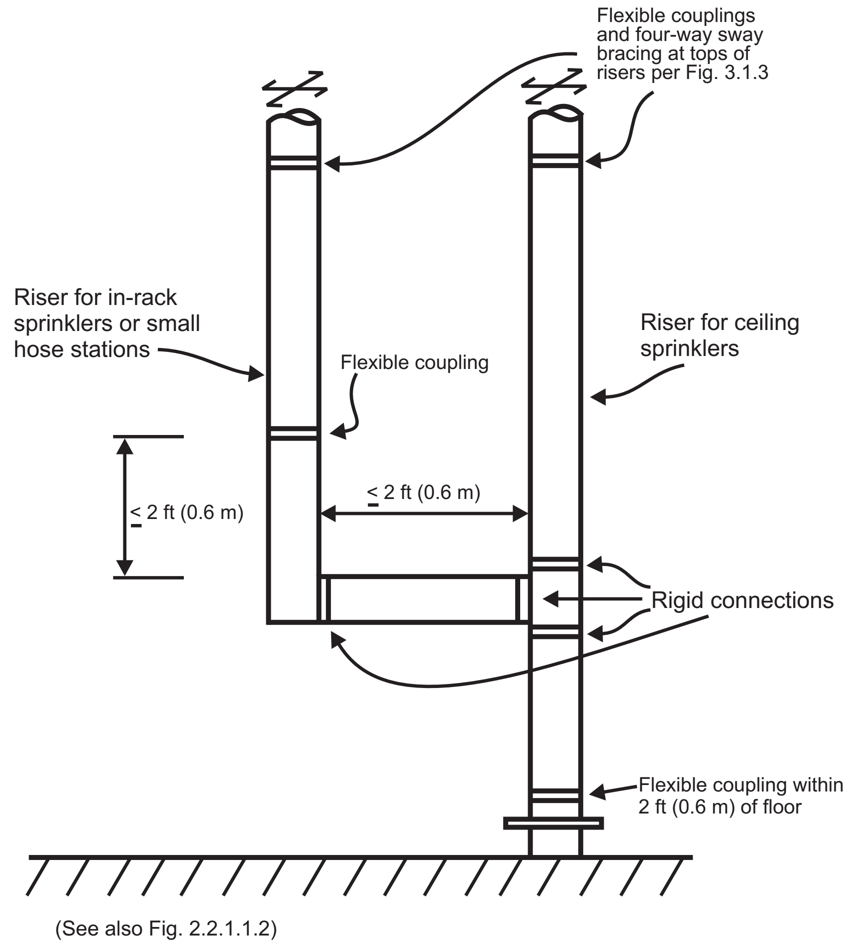


Fig. 2.2.1.4.5-A. Arrangement of combination risers for ceiling sprinklers and in-rack sprinklers/hose stations

2.2.1.4.6 For drops to below suspended ceilings, mezzanines, walkways, etc. that supply more than one sprinkler (see Fig. 2.2.1.4.6), provide flexibility per the following guidelines.

2.2.1.4.6.1 Provide a flexible coupling within 2 ft (0.6 m) of the connection to overhead piping or armovers for pipe drops that exceed 2 ft (0.6 m) in length.

2.2.1.4.6.2 Provide flexible coupling(s) on the horizontal portion within 2 ft (0.6 m) of any tee or elbow connecting pipe drops to sprinkler piping beneath ceilings, mezzanines, walkways, etc.

2.2.1.4.6.3 Provide a flexible coupling within 2 ft (0.6 m) above and/or below any points of bracing on the drop when needed to accommodate differential movement.

2.2.1.4.6.4 When pipe drops are connected to overhead horizontal piping via an armover, do not provide flexible couplings on the armover itself. See 2.2.1.8.1.3 for guidance on hangers supporting armovers.

2.2.1.4.6.5 When the drop is between two independent structures (e.g., overhead piping at the roof of a building that supplies an independent interior mezzanine structure), provide additional flexibility (e.g., FM Approved flexible piping at both the top and bottom of the drop, or a flexible pipe loop per 2.2.1.4.8 at either the top or bottom of the drop) if the expected deflections exceed those that can be accommodated by flexible couplings alone. Unless calculated otherwise, assume the lateral deflection of each structure is 1.5% of the height from its base to the point where the pipe is attached and that the structures can move in opposite directions. See commentary for 2.2.1.4.8 in Section 3.1.10 for additional guidance.

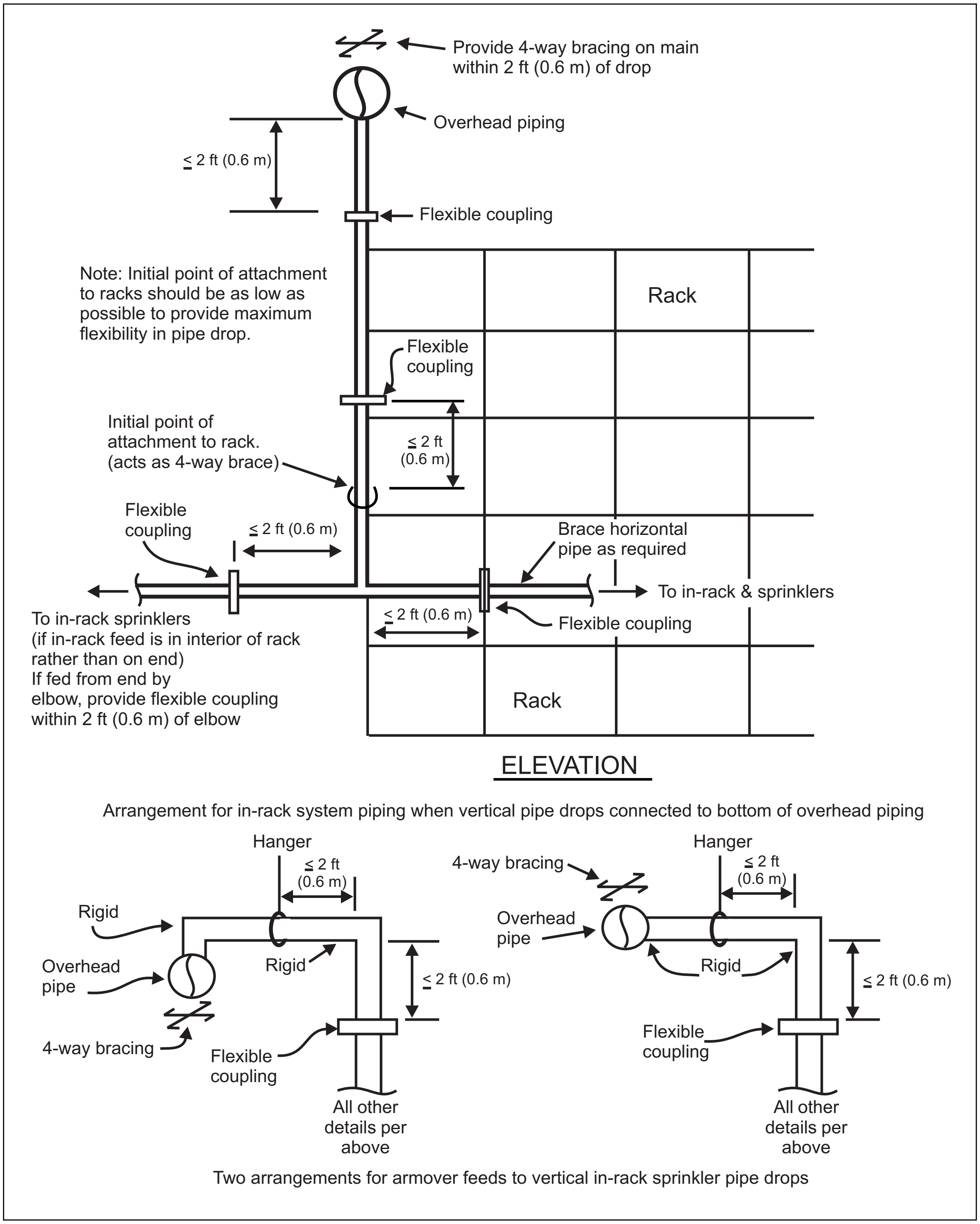


Fig. 2.2.1.4.5-B.. Arrangements for piping feeding in-rack sprinklers

2.2.1.4.7 Provide flexibility for hose rack/header piping per the following guidelines.

2.2.1.4.7.1 Provide flexible couplings on each dedicated hose system riser as required for other risers. For flexible couplings at the top and bottom of the riser see 2.2.1.4.3.1, or 2.2.1.4.3.2 and Fig. 2.2.1.4.5-A. For flexible couplings at intermediate points of bracing on the riser see 2.2.1.4.3.5.

2.2.1.4.7.2 Provide a seismic separation assembly, FM Approved flexible pipe loop or other comparable arrangement per 2.2.1.4.8 where any hose system piping crosses a building seismic expansion joint or spans between independant buildings or structures.

2.2.1.4.7.3 Provide flexible couplings within 2 ft (0.6 m) of the connection to overhead piping or armover for hose system pipe drops greater than 2 ft (0.6 m) in length.

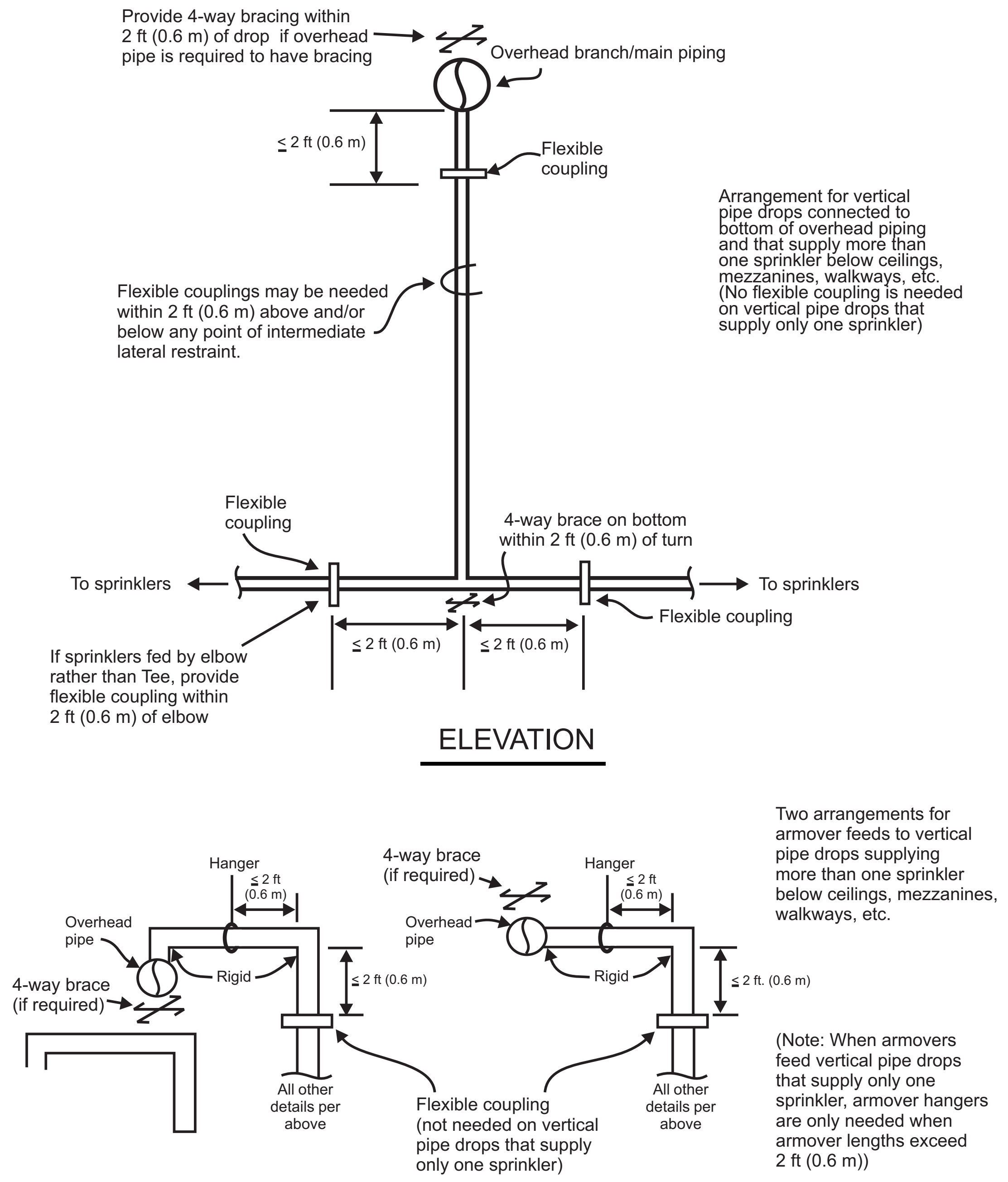


Fig. 2.2.1.4.6. Arrangements for pipe drops supplying sprinklers below ceilings, mezzanines, walkways, etc.

2.2.1.4.8 Install seismic separation assemblies; or FM Approved flexible pipe loops, or flexible pipe or fittings; that allow adequate earthquake movement in two orthogonal horizontal directions as well as vertically on all fire protection system piping that crosses a building seismic expansion joint, or other separation between or creating two independent buildings or structures, above ground level. Other engineered methods that provide a comparable degree of flexibility in all three directions may be acceptable. Also see further commentary in Section 3.1.10.

2.2.1.5 Clearance

2.2.1.5.1 Provide clearance around piping through walls or floors per the following guidelines.

2.2.1.5.1.1 Except as allowed in 2.2.1.5.1.2, where piping passes through walls, platforms, mezzanines, roofs, or floors, provide a hole or sleeve with a nominal diameter 2 in. (50 mm) larger than the pipe for pipes 1 in. (25 mm) diameter through 3½ in. (90 mm), and 4 in. (100 mm) larger than the pipe for pipe sizes 4 in. (100 mm) and larger. Openings may be sealed with mastic or a weak, frangible mortar. If the pipe passes through a fire separation, the space can be filled with mineral wool held in place with a pipe collar.

2.2.1.5.1.2 Clearance is not needed when wall material is frangible, such as gypsum board, and the wall is not required to have a fire rating, or when flexible couplings are provided on both sides of the penetration per 2.2.1.4.3.3 or 2.2.1.4.4.4.

2.2.1.5.2 Provide at least 2 in. (50 mm) clearance between piping and walls/structural members in the following locations:

A. Between ends of piping and walls/structural members

B. When piping passes through walls/structural members, then turns 90 degrees to run parallel to the wall, between the parallel pipe run and the wall/member

C. When piping passes through walls/structural members, between any flanges, fittings, or other devices on the piping and the wall

2.2.1.5.3 Provide clearance to sprinklers per the following guidelines.

2.2.1.5.3.1 For sprinklers installed in suspended ceilings, provide an oversize adapter through the ceiling tile to allow for free movement, in all horizontal directions, of not less than 1/2 in. (13 mm), and preferably not less than 1 in. (25 mm) (i.e., a hole diameter that is 1 in. [25 mm] to 2 in. [50 mm] larger than the diameter of the sprinkler or pipe through the ceiling). Alternatively, accommodate differential movement by connecting to overhead pipe using FM Approved flexible sprinkler hose (for this alternative, the suspended ceiling must meet the requirements of the FM Approval and must be seismically designed per 2.2.1.6.2).

2.2.1.5.3.2 For other sprinklers, provide vertical and horizontal clearance of at least 2 in. (50 mm) to structural or nonstructural elements. A smaller clearance is acceptable where the system is arranged so that less relative movement between the sprinkler and the object is expected (e.g., by providing hangers that limit upward vertical movement per 2.2.1.8.1 or by accommodating the movement with FM Approved flexible sprinkler hose) or where the sprinkler is protected from impact. Provide greater horizontal clearance (4-6 in. [100-150 mm]) to sprinklers when possible.

2.2.1.6 Restraint of Items That Can Impact Sprinklers

2.2.1.6.1 For storage racks with in-rack sprinklers, obtain documentation to verify that rack anchorage and rack design meet the design standards for new construction in Data Sheet 1-2 or equivalent seismic design code requirements for the seismic zone involved. In the absence of such verification, have a seismic analysis conducted by qualified personnel, and make any resulting recommended improvements. Bolt the racks to the floor, cross brace between racks, or employ other techniques as necessary.

2.2.1.6.2 Anchor/brace suspended ceilings that have sprinklers within or below. For acoustical tile ceilings, vertical compression strut/diagonal steel splay wire bracing assemblies and other details as described in American Society of Civil Engineers (ASCE) Standard 7, *Minimum Design Loads and Other Criteria for Buildings and Other Structures* and the ASTM International standards referenced therein may be used. Other methods that provide equivalent restraint may be used. Also see further commentary in Section 3.1.11.

2.2.1.6.3 Anchor/brace all other equipment that may impact the sprinkler system. Such equipment includes, but is not limited to, HVAC equipment (ductwork, diffusers, heaters, etc.), conveyors, and cable trays.

2.2.1.7 Pipe Joining Methods

2.2.1.7.1 Use welded or rigid pipe connections, except when flexible couplings are specifically recommended per 2.2.1.4. This includes all branch line and branch line riser nipple connections to cross mains, branch line connections to riser nipples, and the two connections for any take-out piping installed on gridded branch lines to facilitate flushing investigations. Unless specifically recommended in 2.2.1.4, use of extra flexible couplings will necessitate additional lateral sway bracing per 2.2.1.1.2.3, 2.2.1.1.4.3 and 2.2.1.1.5.1.E.

2.2.1.7.2 Do not use plain-end couplings (two semicircular halves that fit together to connect pipe ends and having no torque indication devices to ensure proper installation) for sprinkler installations. FM Approved plain-end fittings (one-piece devices into which pipe ends are inserted and held in place by set screws that have a torque-indicating means to ensure proper torque has been applied) are acceptable for use in areas where earthquake protection is needed except where their use is disallowed in other data sheets (e.g., in semiconductor fabrication buildings per Data Sheet 7-7, *Semiconductor Fabrication Facilities* and above cleanrooms per Data Sheet 1-56, *Cleanrooms*). Also see further commentary in Section 3.1.12.

2.2.1.8 Type, Attachment, and Locations of Hangers

2.2.1.8.1 Follow the hanger guidelines in Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers,* with the following exceptions.

2.2.1.8.1.1 Do not use powder-driven fasteners to attach hangers to the building structure.

2.2.1.8.1.2 When used, post-installed concrete anchors and cast-in-place concrete inserts shall be of a type qualified for use in seismic applications (see 2.2.1.3.6.5.B for post-installed concrete anchors).

2.2.1.8.1.3 Provide hangers of the type that resist upward vertical movement at the following locations (note that for very long armovers, hangers in addition to those recommended below will be needed when normal hanger spacing rules apply):

A. On all armovers to vertical pipe drops that supply more than one sprinkler, regardless of the length of the armover, located within 2 ft (0.6 m) of the drop.

B. On all armovers greater than 2 ft (0.6 m) long that supply one sprinkler, located within 2 ft (0.6 m) of the drop (see Fig. 2.2.1.4.6).

2.2.1.8.1.4 Provide all C-clamp hangers with retaining straps to minimize the potential that the C-clamp will slip off the structural member.

2.2.1.8.1.5 Provide hangers on branch lines arranged to prevent the pipe from bouncing upward at the following locations.

A. At every other hanger on gridded branch lines.

B. At the last hanger on dead-end branch lines, including outrigger lines on gridded systems.

2.2.1.8.1.6 Provide a hanger of the type that resists upward vertical movement at the hanger closest to any upright sprinkler that is located within 2 in. (50 mm) both horizontally and vertically of a structural or nonstructural element.

2.2.1.8.1.7 Provide hangers for in-rack sprinkler piping of a type that resists upward vertical pipe movement with no more than 1/2 in. (13 mm) of space between the top of the pipe and the hanger’s point of vertical resistance. Provide positive mechanical attachment to the rack structure that resists vertical movement and does not allow the hanger to slip sideways off the point of attachment. Provide retaining straps on all C-clamps.

2.2.1.9 Pipe Material Other than Steel

2.2.1.9.1 When copper sprinkler pipe material is needed, use rigid pipe (i.e., hard temper) Type K, L or M with soldered or brazed joints (except where flexibility is required per 2.2.1.4). In general, treat sprinkler systems with copper piping the same as those using steel pipe with regard to sway bracing, flexibility, clearance and hangers. However, space lateral braces on horizontal pipe and four-way braces on vertical pipe at intervals not to exceed 25 ft (7.6 m). Also see further commentary in Section 3.1.13.

2.2.1.9.2 Do not use nonmetallic pipe in above-ground installations. Also see further commentary in Section 3.1.14.

2.2.2 Standpipes

2.2.2.1 Seismic Considerations for Standpipes

2.2.2.1.1 Treat standpipes the same as sprinkler system risers with regard to sway bracing, flexibility, and clearance.

2.2.2.1.2 When hose outlets are fed from pipe that penetrates walls or floors, provide flexibility, clearance around the piping, and clearance between the piping and walls the same as for sprinkler pipe.

2.2.3 Water-Spray Systems

2.2.3.1 Seismic Considerations for Water-Spray Systems

2.2.3.1.1 In general, treat water-spray systems the same as sprinkler systems with regard to sway bracing, flexibility, and clearance.

2.2.3.1.2 Use special approaches for sway bracing design and attachment to the equipment or structure when necessary based on the nature of the particular system and the equipment being protected by the water-spray system.

2.2.4 Foam-Water Sprinkler Systems

2.2.4.1 Seismic Considerations for Foam-Water Sprinkler Systems

2.2.4.1.1 Treat foam-water sprinkler system piping the same as ordinary sprinkler system piping with regard to sway bracing, flexibility, and clearance.

2.2.4.1.2 Provide foam-making equipment, such as tanks, pumps, etc. with appropriate flexibility, clearance, and anchorage/restraint to protect against damage that may result from differential movement between different portions of the system and/or structural and nonstructural elements.

2.2.5 Fire Pump Installations

2.2.5.1 Sway Bracing

2.2.5.1.1 Provide four-way sway bracing the same as for sprinkler system risers for any vertical riser piping that extends from the pump to discharge through the ceiling to floors above.

2.2.5.1.2 Provide horizontal overhead piping and piping on pipe stands with two-way lateral and longitudinal sway bracing. Design sway bracing on the same basis as for sprinkler system piping. Make attachments for the sway bracing at structural elements capable of carrying the seismic loads.

2.2.5.2 Flexibility Needed to Allow Differential Movement

2.2.5.2.1 For suction and discharge piping, apply the following guidelines.

A. When the pump house rests directly on the ground and suction or discharge piping enters or exits through the floor, and no clearance around the piping is provided, flexible couplings are unnecessary because the pump house floor is not expected to move differentially from the ground.

B. When the fire pump and driver, including suction and discharge piping, are located above grade in a building, provide flexibility on the suction and discharge piping the same as for sprinkler system piping.

C. Flexible couplings are not needed for pipe penetrations that feed hose headers or relief valve discharge outlets on an outside wall.

2.2.5.2.2 Provide flexibility on fuel line connections to both the fire pump drivers and the fuel tanks that supply fire pump drivers.

2.2.5.3 Clearance

2.2.5.3.1 Provide clearance per 2.2.1.5.1 around piping penetrations through walls, platforms, mezzanines, roofs, and floors.

2.2.5.4 Anchorage

2.2.5.4.1 Anchor the base plates for the fire pump and driver to the pump house floor.

2.2.5.4.2 Anchor the controller to the floor and or/wall to prevent damage to the controller itself, and to prevent breakage of piping (such as to a pressure switch) or electrical connections between the controller and other equipment due to differential movement.

2.2.5.4.3 Anchor fuel tanks for internal combustion engines to support frames, if any, or directly to the supporting floor and/or wall. Brace support frames to prevent buckling of the legs and also anchor the frames.

2.2.5.4.4 For internal combustion engines, restrain starter battery sets, brace battery racks to prevent buckling of the legs, and anchor the battery racks to prevent sliding and/or overturning that could damage connections between batteries or from the battery set to the engine.

2.2.5.4.5 Anchor any other unrestrained equipment in the pump house if it exposes any of the fire pump equipment to damage from impact due to uncontrolled differential movement such as sliding, overturning, or swinging.

2.2.5.5 Emergency Electric Power Supply Connection

2.2.5.5.1 When emergency electric power supplies are available on site, connect jockey pumps.

2.2.5.5.2 If the emergency power supply is arranged to supply emergency electric power to the electric motor driving the fire pump, then provide the emergency power supply with full seismic protection. When the emergency power supply is a diesel-engine powered generator, provide seismic protection for all equipment in the same manner as described in 2.2.5.4 for internal combustion engines that drive fire pumps.

2.2.6 Water Storage Tanks and Reservoirs

2.2.6.1 Ground-Supported, Flat-Bottom Steel Tanks

2.2.6.1.1 For all ground-level tanks, use tanks that are FM Approved for installation in a seismic zone that is at least as severe as the seismic zone in which the facility is located, as determined from Data Sheet 1-2. Anchor the tank in accordance with the Approval report. Refer to Data Sheet 3-2, *Water Tanks for Fire Protection,* for more detailed information.

2.2.6.1.2 Coordinate the foundation design (which is not typically part of the Approval report) with the tank design so that a foundation of sufficient size and mass to prevent rocking of the tank is provided. Refer to Data Sheet 3-2 for design details.

2.2.6.1.3 For anchored tanks, provide flexible couplings as follows:

A. When the tank discharge pipe runs horizontally to a pump, provide two flexible couplings on the pipe between the tank and the pump. Locate one as close to the tank wall as possible and the other within 2 ft (0.6 m) of the pump.

B. When the tank discharge pipe feeds into an underground main, provide two flexible couplings between the tank and the ground entrance. Locate one as close to the tank wall as possible. Locate the other within 2 ft (0.6 m) of the ground entrance.

2.2.6.1.4 For tanks that are unanchored because analysis shows the tank is adequate without anchorage, provide flexibility in piping connections to accommodate 2 in. (50 mm) of horizontal displacement in any direction and 4 in. (100 mm) of upward vertical movement at the base of the tank unless different values are calculated by a Registered Professional or Chartered Engineer competent in this area of practice.

2.2.6.1.5 Provide clearance per 2.2.1.5.1 around piping penetrations through walls, platforms, mezzanines, roofs, and floors.

2.2.6.2 Elevated Tanks

2.2.6.2.1 For elevated tanks, having the tank body mounted on legs or a pedestal, refer to Data Sheet 3-2 for more detailed information.

2.2.6.3 Embankment-Supported Fabric Tanks and Lined Earth Reservoirs

2.2.6.3.1 Refer to Data Sheet 3-4, *Embankment-Supported Fabric Tanks* and Data Sheet 3-6, *Lined Earth Reservoirs for Fire Protection* for more detailed information regarding these tank types.

2.2.6.4 Other Suction Tank Types

2.2.6.4.1 Refer to Data Sheet 3-2 for additional details regarding other types of suction tanks.

2.2.7 Fire Protection System Plans and Calculations

2.2.7.1 Items to be Submitted to FM for Review

2.2.7.1.1 In addition to the plans and/or calculations normally submitted for fire protection systems, provide plans, calculations, and equipment information for all earthquake protection features of the fire protection systems, including the following items:

A. Sway bracing details, including:

1. Sway bracing locations, indicating the type of sway bracing being provided,

2. Sway bracing calculations showing horizontal seismic design loads, with indication of the controlling zone of influence for each bracing type,

3. Schedule of sway bracing type, size, and design criteria (length, angle from vertical, and load capacities), and

4. Details of attachment to the structure and to the piping, including verification of structural capacity to withstand seismic load, details of sizing and load capacities of fasteners, and verification of load capabilities of anchors not covered in this data sheet.

B. Location of flexible couplings and seismic separation assemblies or flexible pipe loops.

C. Location of clearances around piping for seismic purposes.

D. Anchorage or seismic design details for storage racks that have in-rack sprinklers.

E. Anchorage or seismic design details for suspended ceilings beneath which sprinklers are installed.

F. For fire pump installations, all seismic design details as outlined in 2.2.5.

G. For water storage tanks or reservoirs, all seismic design details as outlined in 2.2.6.

2.3 Use of Other Codes and Standards

Other codes and standards listed below, when used with the noted limitations, exceptions, and additions, provide earthquake protection of fire protection systems similar to that recommended in this data sheet.

2.3.1 National Fire Protection Association (NFPA) Standards

2.3.1.1 NFPA 13, 2016 Edition

National Fire Protection Association (NFPA) Standard NFPA 13, *Standard for the Installation of Sprinkler Systems,* 2016 Edition, Section 9.3, Protection of Piping Against Damage Where Subject to Earthquakes (and its associated appendix), is similar in most respects to this data sheet's recommendations for the sprinkler system itself. However, NFPA 13 does not address some items (such as earthquake protection of water supplies and pumps, or anchorage of equipment) that can impact sprinkler systems.

NFPA 13 (2016), Section 9.3, can be used with the changes noted below to provide earthquake protection similar to that recommended in this data sheet.

<u>2.3.1.1.1 Bracing of Piping</u>: In addition to the NFPA 13 (2016) requirements, adhere to the recommendations from Section 2.2 of this data sheet for the following items related to bracing of piping.

A. In multistory buildings, lay out intermediate 4-way bracing on risers so that bracing is provided at each floor having a supply main.

B. Brace horizontal manifolds at the base of risers per 2.2.1.1.2.4 of this data sheet.

C. Provide 4-way bracing at both the top and bottom of vertical feed mains and cross mains 6 ft (1.8 m) or longer per 2.2.1.1.3.1 of this data sheet.

D. Do not omit lateral bracing on feed mains and cross mains (regardless of size) nor on branch lines 4 in. (100 mm) and larger where the pipe is supported by short rod hangers (i.e., do not apply NFPA 13 Section 9.3.5.5.10 to these pipes).

E. Do not use wraparound U-hangers and U-hangers that hold the pipe tight against the underside of a structural member as lateral braces on feed mains and cross mains, regardless of size (i.e., do not apply NFPA 13 Item 9.3.5.5.11 to feed mains and cross mains). U-bolts, however, may be used as lateral braces per 2.2.1.3.2 of this data sheet.

F. Provide lateral and longitudinal braces at changes of direction for horizontal feed mains and cross mains per 2.2.1.1.4.1 of this data sheet.

G. Provide longitudinal bracing on branch lines 2½ in. (65 mm) and larger per 2.2.1.1.5.2 of this data sheet. Branch line longitudinal bracing should not be used to brace the cross main.

H. Limit the l/r ratio for braces used in compression to 200 or less (modification of NFPA 13 Item 9.3.5.11.3). Limit the l/r ratio for braces used in tension to 300 or less. Do not use cable or wire bracing (i.e., do not apply NFPA 13 Item 9.3.5.4.2).

I. Do not use powder-driven fasteners to attach braces to the building structure (i.e., do not apply NFPA 13 Item 9.3.5.11.11).

J. Do not attach braces to wood members less than 3½ in. (90 mm) unless the member adequacy is confirmed by a Registered Professional or Chartered Engineer competent in this area of practice.

K. Determine the net vertical uplift force resulting from the horizontal load at brace locations and the method of resisting the net vertical uplift force using the recommendations in 2.2.1.3.5 of this data sheet (i.e., do not apply NFPA 13 Item 9.3.5.10).

L. When NFPA 13 does not provide data for determining C_p (the seismic coefficient used in NFPA 13), use a minimum value of C_p of 0.9 in FM 50-year earthquake zones, 0.65 in FM 100-year earthquake zones, and 0.4 in FM 250- and 500-year earthquake zones (i.e., don't use C_p = 0.5 as specified in NFPA 13 Item 9.3.5.9.5, at least in FM 50-year and 100-year earthquake zones).

2.3.1.1.2 Other Earthquake Protection Guidance: In addition to the NFPA 13 (2016) requirements, adhere to the recommendations in Section 2.2 of this data sheet for the following items.

A. Apply the flexible coupling recommendations in 2.2.1.4.3 and 2.2.1.4.4 of this data sheet for risers and vertical mains regardless of the pipe size (i.e., do not apply the 2½ in. [65 mm] restriction in NFPA 13 Item 9.3.2.1).

B. Confirm adequacy of flexibility at drops to in-rack sprinklers and independent mezzanines per 2.2.1.4.5.4 and 2.2.1.4.6.5, respectively, of this data sheet.

C. Do not use powder-driven fasteners to attach hangers to the building structure (i.e., do not apply NFPA 13 Item 9.3.7.7).

D. Do not use plain end couplings.

E. Do not use nonmetallic pipe above ground.

F. Provide clearance to sprinkler heads in accordance with 2.2.1.5.3 of this data sheet.

G. For hangers, adhere to the recommendations in 2.2.1.8 of this data sheet.

H. Provide anchorage for storage racks with in-rack sprinklers, for suspended ceilings with sprinklers beneath, and for other equipment that can impact sprinklers in accordance with the recommendations in 2.2.1.6 of this data sheet.

I. Provide seismic protection of foam-water sprinkler systems in accordance with the recommendations in 2.2.4 of this data sheet.

J. Provide seismic protection of fire pump installations in accordance with the recommendations in 2.2.5 of this data sheet.

K. Provide seismic protection of water storage tanks and reservoirs in accordance with 2.2.6 of this data sheet.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Commentary for Section 2.0 Loss Prevention Recommendations

This section contains additional explanatory material related to some Section 2.0 loss prevention recommendations. The specific section or recommendation number to which the commentary applies is identified (e.g., "Commentary for 2.2.1.1.2") before the commentary itself.

3.1.1 Commentary for 2.1

Earthquake-related stresses and strains are imparted to a fire protection system through the building or the ground to which it is attached, due to inertial movement within the system itself or from impact with structural or nonstructural items. Uncontrolled differential movement can cause damage when fire protection systems are not provided in a systematic manner with the necessary features that incorporate sway bracing, flexibility, clearance, and anchorage where needed. Because an uncontrolled fire after an earthquake can result in a devastating loss, the primary concern related to deficiencies in earthquake protection is that the fire protection systems will be impaired as a result of strong ground shaking. In terms of frequency, however, the most common type of damage, based on past experience, is due to water leakage from broken overhead sprinkler piping or sprinklers, primarily due to lack of sway bracing where needed.

Common sources of water damage are broken or separated overhead sprinkler piping, broken sprinklers due to impact with nearby structural members or other equipment, broken sprinklers or pipe drops due to excessive differential movement between unbraced suspended ceilings and the pipe drops, and broken in-rack sprinkler system piping or sprinklers due to excessive rack movement. In addition to damage from water leakage, fire protection systems are often impaired due to direct damage to the systems, or due to damage to public water supplies or utilities needed for fire protection. Significant impairments to fire protection systems may expose a facility to a severe fire loss following an earthquake.

In evaluating the many incidents of damage, two conclusions are very apparent:

A. Only by providing, in a systematic manner, the necessary features (which incorporate sway bracing, flexibility, clearance, and anchorage where needed) can a fire protection system be adequately protected from earthquake damage.

B. The omission of even a few of the critical components necessary for adequate earthquake protection may result in impairment of the system or substantial water damage. The necessary shutdown of the system to stop further water damage also creates a long-term fire protection system impairment.

Some examples of sway bracing are shown in Fig. 3.1.1-A. Two of the most common sway bracing methods that may be used on any pipe are:

A. An FM Approved pipe-attached component (Fig. 3.1.1-B) and an FM Approved structure-attached component having a proper anchor to the structure (Fig. 3.1.1-C), with a diagonal brace member capable of resisting tension and compression (i.e., a tension-compression brace) between, which can be used to brace horizontal piping in either the lateral or longitudinal direction or can be configured in pairs to act as a four-way brace on vertical piping, and

B. An adequately designed and connected standard steel U-bolt that directly attaches the pipe tightly to a structure, which can brace horizontal pipe in the lateral, but not longitudinal, direction or can act as a four-way brace on a vertical pipe (see riser in Fig. 3.1.1-A).

Certain methods of sway bracing may not be acceptable on some pipe (e.g., sprinkler system mains) even though they might be acceptable on other pipe (e.g., small branch lines) if they are properly configured and attached to the structure. An example is that wrap-around U-hangers may not brace feed mains or cross mains but can be used to laterally brace branch lines.

In addition to bracing, other important features necessary for adequate earthquake protection of fire protection systems are specified in the recommendations. Two examples, shown in Fig. 3.1.1-D, include providing retaining straps on C-clamps that connect hangers to steel members (which prevents them from "walking" off the steel support during strong ground shaking) and hangers that restrain upward movement of branch lines where needed to prevent sprinklers from impacting structural or nonstructural elements.

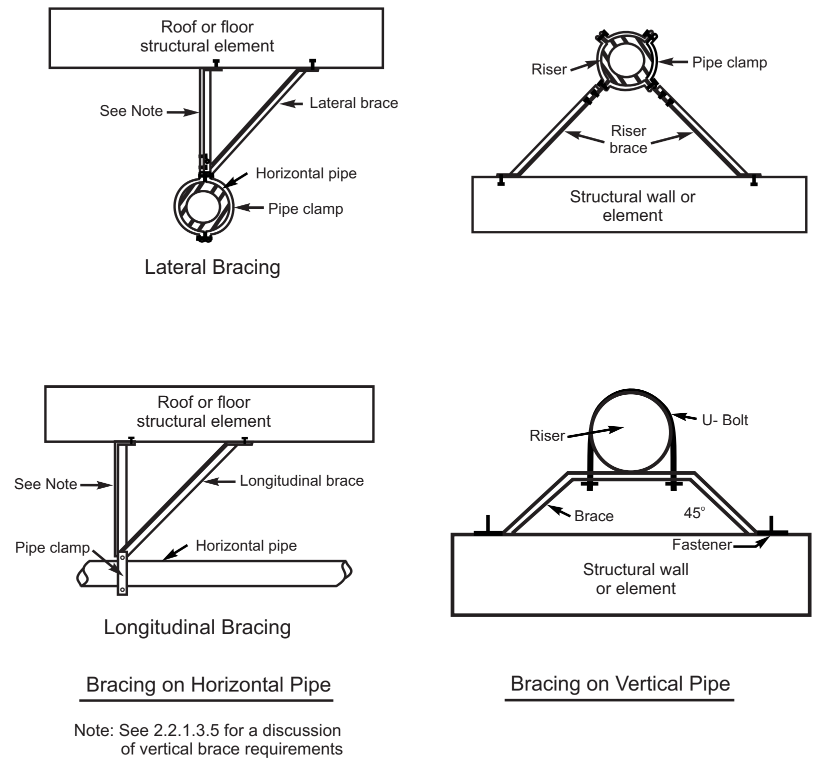


Fig. 3.1.1-A. Examples of sway bracing for horizontal and vertical piping

Fig. 3.1.1-B. Examples of pipe-attached components (must be FM Approved)

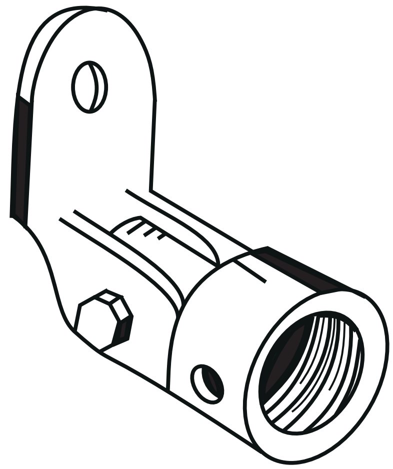
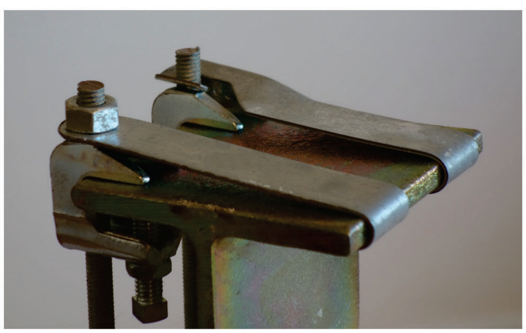


Fig. 3.1.1-C. Example of structure-attached component (must be FM Approved) with hole for anchor to the structure



C-clamp hanger connections with retaining straps

U-hanger with U-bolt retainer preventing upward movement

Fig. 3.1.1-D. Examples of other necessary earthquake protection features

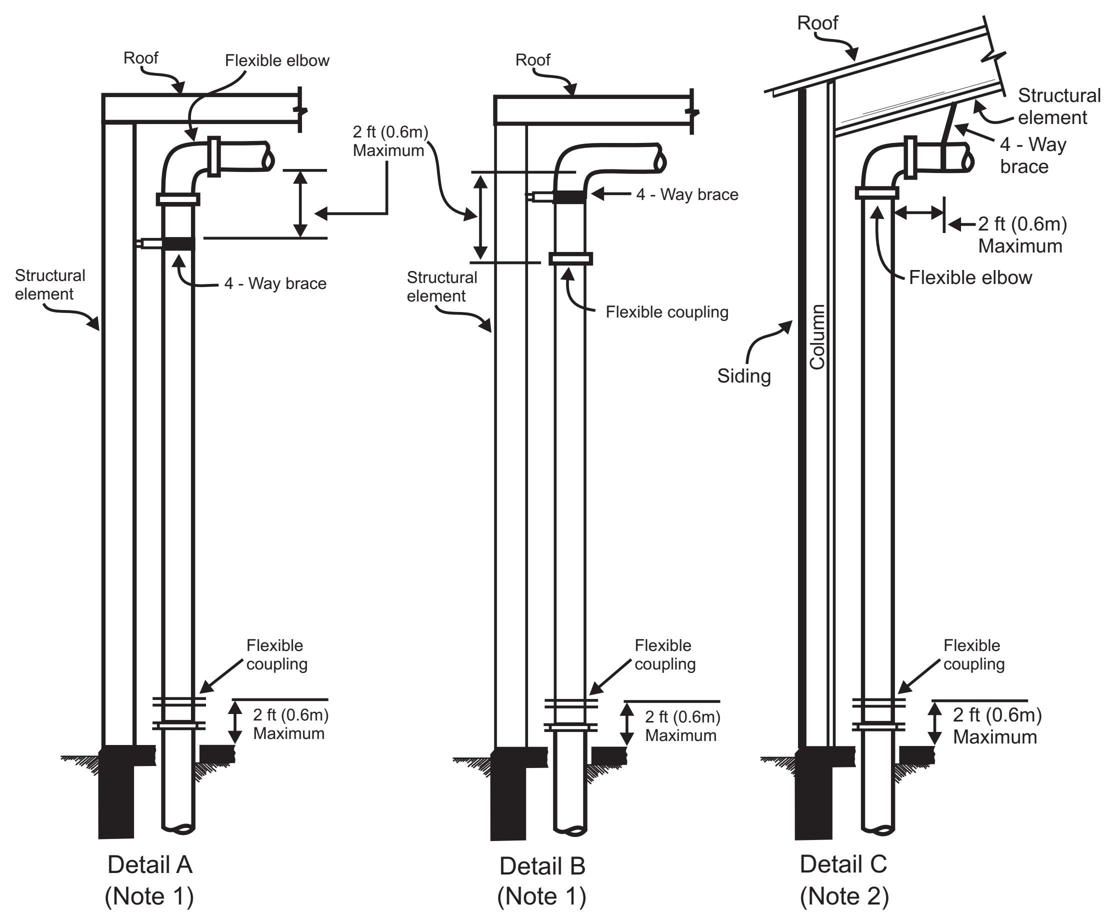
3.1.2 Commentary for 2.2.1.1.1

The maximum spacing of sway braces may result in design forces at brace locations that are too large with respect to the capacity of the brace member, or the capacity of brace connections to the pipe or the structure, or the capacity of the structural member itself. In these cases, smaller spacing between braces may be needed.

Sway braces on ceiling systems are typically arranged to coincide with substantial structural members (e.g., wood members that are nominally 4 in. [100 mm] thick rather than 2 in. [50 mm] thick); this may necessitate that brace spacing be less than the maximum allowed. Likewise, braces on large piping within storage racks (e.g., branch lines 2-1/2 in. [65 mm] in diameter or larger) may need to be spaced closer than the maximum allowed in order to coincide with storage rack frames or to limit forces at connections to the storage rack frames.

3.1.3 Commentary for 2.2.1.1.2

Examples of four-way braces at the tops of risers are shown in Fig. 3.1.3. For risers located on the outside of the building, either Detail A or B of Fig. 3.1.3 may be used, with the brace attached to a structural element. Details B and C are preferred because they allow unrestricted angular deflection of the flexible coupling at the top of the riser, thus better accommodating the horizontal drift of the roof.



Note 1: For risers located outside of buildings, Detail A or B may be used with the bracing attached to a structural element.

Note 2: May be preferred for metal buildings.

Fig. 3.1.3. Flexible coupling and four-way sway bracing details for risers

3.1.4 Commentary for 2.2.1.1.4

When structural member locations are such that a lateral brace cannot be attached within 6 ft (1.8 m) of the feed main or cross main end, additional structural members or an extension of the feed main or cross main to allow proper location of the lateral sway bracing will be needed.

3.1.5 Commentary for 2.2.1.2.1

It is not required that each brace be designed for the exact force determined using the weight of the water-filled piping in its zone of influence (W_p) multiplied by the "G" factor. For simplicity of calculations, the same W_p may be used for the design of several braces as long as it is based on the weight of water-filled pipe in the controlling zone of influence. Table 3.1.5 shows weights for water-filled steel pipe to be used with the appropriate "G" factor to calculate design loads.

Table 3.1.5 Weight of Water-Filled Steel Pipe

Pipe Nominal Diameter in. (mm)	*Weight, lb/ft (N/m)*
Schedule 40	
1 (25)	2.1 (31)
1-¼ (32)	2.9 (43)
1-½ (40)	3.6 (53)
2 (50)	5.1 (75)
2-½ (65)	7.9 (116)
3 (80)	10.8 (159)
3-½ (90)	13.5 (198)
4 (100)	16.4 (241)
5 (125)	23.5 (345)
6 (150)	31.7 (465)
8* (200)	47.7 (700)
Schedule 10 and Lightwall	
1 (25)	1.8 (26)
1-¼ (32)	2.5 (37)
1-½ (40)	3.0 (44)
2 (50)	4.2 (62)
2-½ (65)	5.9 (87)
3 (80)	7.9 (116)
3-½ (90)	9.8 (144)
4 (100)	11.8 (173)
5 (125)	17.3 (254)
6 (150)	23.0 (338)
8 (200)	40.1 (589)

[a] The Schedule 40/Schedule 30 weights can also be used for DIN EN 10255 piping. For DIN EN 10255-M (which replaced DIN 2440) pipe, table weights are conservative (about 5% high for pipe up to 2 in. [50 mm] and 15-25% high for larger pipe). For DIN EN 10255-H pipe, table weights are not conservative (5-10% low) for pipe up to 2 in. (50 mm), but are conservative for larger pipe (about 5-15% high).
[b] The Schedule 10/Lightwall weights can also be used for DIN EN 10220 pipe (DIN EN 10220 seamless replaced DIN 2448; DIN EN 10220 welded replaced DIN 2458). Table weights are generally within 5% (higher or lower) of the DIN EN 10220 weights.

3.1.6 Commentary for 2.2.1.2.2

An in-depth discussion of the method to determine design forces for equipment (including sprinkler piping) used in the American Society of Civil Engineers standard, *Minimum Design Loads and Other Criteria for Buildings and Other Structures* (ASCE 7) can be found in Appendix C of Data Sheet 1-2, *Earthquakes.* Because code design forces vary based on the item's location in the building as well as the design acceleration (S_{DS}) specific to the site, the "G" factor based on building code requirements will actually vary both within a building and from site to site in the same FM earthquake zone. Using the design forces from a more detailed analysis is acceptable, assuming all values (e.g., S_{DS}) are accurate and can be justified.

The Load and Resistance Factor Design (LRFD) horizontal seismic design force, which is applied independently in two orthogonal directions (i.e., the lateral and longitudinal direction for piping), is determined using the general equation:

$$F_p = \frac{0.4 \cdot a_p}{R_p}\left(1 + 2 \cdot z/h\right) S_{DS} \cdot I_p \cdot W_p \qquad \text{(for LRFD)}$$

With

$$0.3 \le \frac{0.4 \cdot a_p}{R_p}\left(1 + 2 \cdot z/h\right) \le 1.6$$

Where:

F_p = horizontal seismic design force (LRFD)

a_p = component amplification factor that varies from 1.00 to 2.50 (from ASCE 7 tables)

R_p = component response modification factor that varies from 1.00 to 12 (from ASCE 7 tables)

z = height in the structure with respect to the base at the point of component attachment. For items at or below the base, z is taken as zero. The value of z/h need not exceed 1.0 (e.g., even in roof penthouses that are higher than the average roof height [h]).

h = average roof height of the structure with respect to the base

S_{DS} = the design spectral response acceleration parameter at a short (0.2-second) period (at 5% damping and adjusted for Site Class [soil] effects), expressed as a portion of the gravitational acceleration (g) - see Data Sheet 1-2 for more information and for generic values of S_{DS} vs. FM earthquake zone

I_p (or I_E) = component seismic importance factor - the code-required value varies from 1.0 (“normal” equipment) to 1.5 (essential, life-safety, or hazardous material-containing equipment)

W_p = component operating weight

Note that this data sheet uses Allowable Stress Design (ASD) forces, which are determined by multiplying the LRFD forces by 0.7. That is (from 2.2.1.2.1):

$$H = G \cdot W_p = 0.7 \cdot F_p$$

The “G” factor specified in 2.2.1.2.2, was calculated using ASCE 7-10 for the most common case: piping supported at the roof of a building or by flexible structures at grade (e.g., tall pipe stands). For this condition “z” is 1.0 and the resulting amplification factor is 3.0, which is also the maximum amplification value and can therefore conservatively be used throughout a building. The other ASCE 7-10 factors used to calculate the “G” factor include: the component amplification factor (a_p), taken as 2.5; the component response modification factor (R_p), taken as 4.5; and the component importance factor (I_p), taken as 1.5. Substituting these values into the equation above for F_p gives:

$$F_p = \frac{0.4 \cdot 2.5}{4.5}\left(3\right) S_{DS} \cdot 1.5 \cdot W_p = 1.0 \cdot S_{DS} \cdot W_p$$

Thus:

$$H = G \cdot W_p = 0.7 \cdot F_p = 0.7 \cdot S_{DS} \cdot W_p$$

And, therefore:

$$G = 0.7 \cdot S_{DS}$$

The use of a single “G” factor throughout the building in each earthquake zone (based on the generic values of S_{DS} shown in 2.2.1.2.2) may result in horizontal seismic design forces for sprinkler pipe bracing that can be slightly more or less conservative than the “G” factor that would be calculated based on a strict application of ASCE 7 criteria. However, just as each brace is not typically designed for the exact weight of the pipe tributary to it, the use of a single “G” factor is a reasonable simplification that allows standardized braces to be used throughout the system.

3.1.7 Commentary for 2.2.1.2.3

The weight (W_p) to be used for each sway brace design (or each controlling sway brace design) is determined by including the water-filled weight of all piping within the zone of influence. The zone of influence is defined below. Where a sway brace is used to brace more than one pipe (i.e., as allowed per 2.2.1.1.2, 2.2.1.1.4 and 2.2.1.1.5) base W_p in each horizontal direction on the tributary weight from all pipes being braced.

A. Four-way sway bracing at risers, vertical feed mains and cross mains, and drops:

1. Where the four-way sway brace restrains only the vertical pipe (e.g., an intermediate riser brace where there is no attached feed main or cross main) the zone of influence includes the length of the vertical pipe above and below the sway brace that is tributary to that sway brace (i.e., half the length of pipe to the next four-way sway brace above plus half the length of pipe to the next four-way sway brace below). Use the resulting weight of pipe to determine the load to be applied in each orthogonal horizontal direction.

2. Where the four-way sway brace for the vertical pipe also serves as a lateral and longitudinal sway brace for an attached horizontal pipe (e.g., feed main or cross main), the four-way sway brace zone of influence is determined as follows.

a. In the lateral direction of the horizontal pipe, add the tributary length of vertical pipe above and below the sway brace, plus the tributary lengths of feed main, cross main, and branch line piping, as described below in Item B for lateral two-way sway bracing, located between the four-way sway brace and the first lateral sway brace on the horizontal pipe.

b. In the longitudinal direction of the horizontal pipe, add the tributary length of vertical pipe above and below the sway brace, plus the tributary lengths of feed main, cross main, and branch line piping, as described below in Item C for longitudinal two-way sway bracing, located between the four-way sway brace and the first longitudinal sway brace on the horizontal pipe.

3. The weight of the water-filled pipe for manifolded bracing design includes the total load for the two risers being braced.

B. Lateral two-way sway bracing:

1. For feed mains, the zone of influence includes the length of the feed main to the left and right of the sway brace that is tributary to that brace (i.e., half the length of pipe to the next sway brace to the left plus half the length of pipe to the next sway brace to the right).

2. For cross mains, the zone of influence includes the tributary length of cross main being braced plus the length of all branch lines attached to that section of cross main that are not distributed to branch line longitudinal sway bracing.

3. For branch lines that require sway bracing, the zone of influence typically includes the length of the branch line to the left and right of the sway brace that is tributary to that sway brace. The tributary length of pipe between the first lateral sway bracing location and the cross main connection may either be based on an equal distribution to the cross main longitudinal bracing and the first lateral sway bracing location (see Item C.2 for longitudinal two-way sway bracing below), or may be totally distributed to the first lateral sway bracing location.

C. Longitudinal two-way sway bracing:

1. For feed mains, the zone of influence includes the length of the feed main to the left and right of the sway brace that is tributary to that brace (i.e., half the length of pipe to the next sway brace to the left plus half the length of pipe to the next sway brace to the right).

2. For cross mains, the zone of influence includes the tributary length of cross main being braced; do not include loads from branch lines, except when a portion of branch line lateral sway bracing is being included as described above in Item B.3 for lateral two-way sway bracing.

3. For branch lines that require sway bracing, the zone of influence typically includes the length of the branch line to the left and right of the sway brace that is tributary to that sway brace. The tributary length for the piping between the cross main and the first sway bracing location should be based on an equal distribution between that bracing location and the cross main lateral sway bracing as described above in Item B.2 for lateral two-way sway bracing.

D. For sway bracing at horizontal changes in direction that is located within 2 ft (0.6 m) of the end of a feed main or cross main connection to a perpendicular main of the same or smaller diameter, and which will be used as a lateral sway brace for one pipe and a longitudinal sway brace for the perpendicular pipe, the zone of influence includes the total tributary lateral and longitudinal weights of mains and branch lines as described above.

3.1.8 Commentary for 2.2.1.3.5

Because braces are less effective as they become steeper relative to the direction of the applied load, when restraining a horizontal pipe the closer a diagonal brace element is to the direction of the applied horizontal seismic design load (H), the better. Four-way riser braces are most advantageously oriented at 90 degrees from each other and at 45 degrees from the principal pipe axes because they must resist forces in all horizontal directions.

The axial force in a diagonal brace increases as the brace becomes steeper relative to the direction of H, possibly requiring a larger member and stronger connections. For example, for a horizontal pipe having one diagonal brace oriented at an angle (Θ) from the vertical, the axial force in the brace is (H/sin Θ), which equals about 2H if Θ is 30 degrees, 1.4H if Θ is 45 degrees, 1.16H if Θ is 60 degrees, and 1.0H if Θ is 90 degrees.

The axial force in the diagonal brace also generates a vertical component equal to (H/tan Θ), which increases as Θ decreases. For the same single diagonal brace restraining a horizontal pipe as noted above, the vertical component would be 1.73H if Θ is 30 degrees, 1.0H if Θ is 45 degrees, and 0.58H if Θ is 60 degrees; there would be no vertical component if the brace is oriented at Θ=90 degrees. For a horizontal pipe, the upward component is more likely to exceed the effective pipe dead weight when the brace is steep (i.e., Θ is small), thus requiring a vertical element to resist the net uplift. Note that the net uplift is the vertical component of the axial force in the diagonal brace that results from resisting H, it is not a result of vertical earthquake accelerations.

The effective pipe dead weight is assumed to be half of the weight of the water-filled pipe in the zone of influence (W_p) since the pipe that contributes to the horizontal seismic design load (H) doesn't necessarily help resist uplift. For example, branch lines can contribute to H for lateral cross main braces since the branch lines are axially stiff, however the branch lines are flexible in bending and so would not contribute much dead weight to counteract uplift of the cross main.

A final disadvantage of using steeper braces is that horizontal deflections at brace locations may increase as the brace angle (Θ) decreases.

When two diagonal tension-compression braces are used, it is advantageous to place them as symmetrically as possible such that forces in the braces are nearly equal. When not symmetrically placed, the brace that is closest to the direction of H will resist more than half of the force. The proportion of the load that goes to the steeper brace based on geometry will be less than half of H, but the brace should, at a minimum, be sized as if it resists H/2 (in practice, the same member and connections, determined based on the controlling load, are usually used for both braces to avoid installation errors). In the extreme (e.g., a horizontal pipe with one brace at Θ = 30 degrees and the other at Θ = 90 degrees) the brace at the larger angle may resist all or almost all of the force.

Table 3.1.8-A through Table 3.1.8-F indicate maximum allowable lengths (measured along the diagonal) for different brace shapes and sizes and maximum horizontal design load (either H or a fraction of H not less than H/2, depending on sway bracing configuration) for each brace for three different ranges of angles (Θ) for the brace. For horizontal pipe, Θ is measured from the vertical (see Fig. 2.2.1.3.5-A and Fig. 2.2.1.3.5-B). For four-way braces on vertical pipe, see Fig. 2.2.1.3.5-C for the orientation of Θ relative to the load direction.

Maximum allowable horizontal design loads in the tables are determined by multiplying the Allowable Stress Design (ASD) axial compression capacity along the brace by (sin Θ) for the smallest angle (Θ) within the range given. The ASD axial compression capacity is found by multiplying the controlling ASD allowable compressive stress (F_a) from AISC 360 by the cross-sectional area (A) of the member.

In the United States, commonly used steel has a modulus of elasticity (E) of 29,000,000 psi and a yield stress (F_y) of 36,000 psi; in Europe, common values are E = 200,000 MPa and F_y = 235 MPa. The value of F_a for braces depends on these values, but mainly depends on the l/r ratio. For example, F_a from AISC 360 using the E and F_y values above would be approximately 12,730 psi (85.5 MPa) for l/r = 100; 3760 psi (25.9 MPa) for l/r = 200; and 1670 psi (11.5 MPa) for l/r = 300.

For example, from Table 3.1.8-A for a 1 in. diameter Schedule 40 pipe (A = 0.494 in.^{2}) and l/r = 100, the ASD axial compression capacity is about 0.494·12730 = 6300 lb and the table values are therefore: 6300·sin30 = 3150 lb for Θ between 30 and 44 degrees, 6300·sin45 = 4455 lb for Θ between 45 and 59 degrees, and 6300·sin60 = 5456 lb for Θ between 60 and 90 degrees. Tables are included for l/r = 100, for l/r = 200, and for l/r = 300 (although H values are based on controlling compressive stresses, braces with l/r greater than 200 may be used in tension only). The following guidelines apply:

A. For Fig. 2.2.1.3.5-A using one vertical and one diagonal brace:

1. The angle from the vertical for Brace A must be at least 30 degrees (and preferably at least 45 degrees).

2. Size and arrange Brace A to carry in both tension and compression (l/r = 200 or less) the full horizontal seismic design load (H), determined in Section 2.2.1.2.

3. Calculate the net vertical uplift force (V_F) derived from the horizontal seismic design load (H) per the equation in 2.2.1.3.5.6. If V_F is less than or equal to 0 (zero), Brace B is not needed.

4. Brace B, when needed, should be connected to the pipe within 6 in. (150 mm) of Brace A, and can either be of the same shape and size as Brace A, without any further calculation, or can be selected on the basis of the actual calculated net vertical uplift force. Although less desirable, Brace B may be a hanger that is located no more than 6 in. (150 mm) from the point of attachment on the pipe for Brace A and meets the following criteria:

a. The hanger is of substantial design, such as a clevis or a pipe clamp hanger, or a hanger that has been tested and found to be adequate to resist upward forces (i.e., light duty hangers such as swivel rings are not acceptable), and

b. The hanger attachment to the fire protection system piping is capable of transferring the net vertical upward force V_F from the pipe to the hanger rod and is snug and concentric, with no more than ¼ in. (6 mm) between the top of the piping and the hanger so that excessive movement cannot occur (extending the hanger rod to the top of the pipe to transfer the upward load is not an acceptable method), and

c. The hanger rod l/r does not exceed 200 and the rod is adequate to resist the net vertical upward force V_F as a brace (this may necessitate the use of a rod stiffener or other means, such that l/r does not exceed 200 and adequate capacity is provided), and

d. The hanger connection to the structure is capable of transferring the net vertical upward force V_F and is fastened to the structure by a positive means of mechanical attachment, such as through-bolts, lag screws, or concrete anchors that are properly sized for the load and meet all requirements specified for brace connections.

B. For tension-only sway bracing (l/r = 300 or less), which may be used when it is necessary to have longer brace members due to physical or dimensional constraints, treat as a special condition of Fig. 2.2.1.3.5-A by providing opposing diagonal braces (i.e., two Braces A) similar to Item 1 above:

1. The angle from vertical for Braces A must be at least 30 degrees (and preferably at least 45 degrees).

2. Size and arrange Braces A in Fig. 2.2.1.3.5-A to carry, in tension, the full horizontal seismic design load (H) determined in 2.2.1.2 since neither brace is being considered as capable of resisting compression.

3. Brace B, when needed, may vary in shape and size from Braces A. Evaluate Brace B based on the net vertical uplift force (V_F) per Item 1 above.

C. For Fig. 2.2.1.3.5-B using two opposing diagonal braces, each capable of resisting tension and compression (l/r = 200 or less):

1. The angle from vertical for Braces A_L and A_R must be at least 30 degrees (and preferably at least 45 degrees).

2. Size and arrange both Braces A_L and A_R in Fig. 2.2.1.3.5-B to carry the larger of one-half of the horizontal seismic design load (H) determined in 2.2.1.2 or the load determined by proportional distribution of design load (H) to the two braces. Where Θ_L equals Θ_R, each brace resists H/2.

Considering Fig. 2.2.1.3.5-B where Θ_L differs from Θ_R, if the distributed portion of the horizontal seismic load reacted by the left brace (Brace A_L) is H_L and the distributed load reacted by the right brace (Brace A_R) is H_R, the load distribution can be expressed as:

$$H_L = (H)((\tan \Theta_L)/(\tan \Theta_L + \tan \Theta_R))$$
$$H_R = (H)((\tan \Theta_R)/(\tan \Theta_L + \tan \Theta_R))$$

Only the force for the brace with the larger angle from vertical (Θ_i) needs to be calculated from the equations above. The proportion of H for the brace with the smaller angle from vertical will be less than half of H and so should be designed, at a minimum, for a force of H/2 (preferably the same brace, sized for the controlling load condition, will be used for both Brace A_L and Brace A_R to avoid installation errors).

3. This sway bracing arrangement will provide adequate resistance to vertical force and no additional procedures are needed in that regard.

D. For the Fig. 2.2.1.3.5-C four-way brace on a vertical pipe using two opposing diagonal braces, each capable of resisting tension and compression (l/r = 200 or less):

1. The angle from the principal axes for Braces C_L and C_R must be at least 30 degrees but not more than 60 degrees (and preferably Braces C_L and C_R will be oriented at 90 degrees from each other and 45 degrees from the principal axes).

2. Braces C_L and C_R in Fig. 2.2.1.3.5-C must be sized such that they adequately resist the horizontal seismic design load (H) in both orthogonal directions (designated in the following discussion as the north-south [N-S] and east-west [E-W] directions). Depending on the relative angles and connection configurations, the larger of the N-S or the E-W horizontal seismic design loads will not necessarily control the design of both braces. Size and arrange both Braces C_L and C_R in each direction (N-S and E-W) to carry the larger of one-half of the horizontal seismic design load (H) determined in 2.2.1.2 or the load determined by proportional distribution of design load (H) to the two braces. Where Θ_L equals Θ_R, each brace resists H/2 in each direction (N-S and E-W).

Considering Fig. 2.2.1.3.5-C where Θ_L differs from Θ_R, if the distributed portion of the horizontal seismic load reacted by the left brace (Brace C_L) is H_L and the distributed load reacted by the right brace (Brace C_R) is H_R, the load distribution can be expressed as:

$$H_L = (H)((\tan \Theta_L)/(\tan \Theta_L + \tan \Theta_R))$$
$$H_R = (H)((\tan \Theta_R)/(\tan \Theta_L + \tan \Theta_R))$$

Note, however, that the angles Θ_L and Θ_R are defined differently in Fig. 2.2.1.3.5-C depending on the direction of the horizontal seismic design load (H). In each direction (N-S and E-W) only the force for the brace with the larger angle (Θ_i) needs to be calculated from the equations above. In a particular direction (N-S or E-W), the proportion of H for the brace with the smaller angle will be less than half of H and so should be designed, at a minimum, for a force of H/2. Preferably the same brace, sized for the controlling load condition, will be used for both Brace C_L and Brace C_R to avoid installation errors.

NOTES FOR TABLE 3.1.8-A THROUGH TABLE 3.1.8-F:

Note 1: The following are tangent values for various angles:

Angle	*Tangent*	*Angle*	*Tangent*
30	0.58	60	1.73
35	0.70	65	2.14
40	0.84	70	2.74
45	1.00	75	3.73
50	1.19	80	5.67
55	1.43	85	11.43

Note 2: The slenderness ratio, Kl/r, is defined as an effective length factor (K) multiplied by the brace length (l) and divided by the least radius of gyration (r). The length and radius of gyration should both be in the same units (e.g., in. or mm). For sway braces, each end is considered to be pinned so the effective length factor (K) can be taken as 1.0 and the slenderness ratio becomes (l/r). The least radius of gyration, r, for

complex brace shapes (such as angles) should be based on tabulated values (e.g., from steel manufacturers), but can be determined for simple brace shapes as follows:

Brace Shape	*Formula for minimum radius of gyration (r_{min}),in. or mm*	*Variables, in. or mm*
Pipe	$0.25 \cdot \sqrt{d_o^2 + d_i^2}$	d_o = outside diameter of pipe d_i = inside diameter of pipe
Rods	0.25d	d = diameter of rod (for fully threaded rods, use the diameter to the root of the threads)
Flats	0.2887t	t = thickness of the flat

Note 3: A steel yield stress (F_y) of 36,000 psi (250 MPa) and a modulus of elasticity (E) of 29,000,000 psi (200,000 MPa) are used to generate the tables and are appropriate for commonly used steel. Gross section properties are used for all shapes except rods threaded over their full length, for which the cross sectional area and radius of gyration are based on the rod diameter at the roots of the threads.

Table 3.1.8-A. Maximum ASD Horizontal Loads (lb) for Steel Sway Brace Members in Compression (US Customary Units) (l/r = 100)

Shape Size, in.	*Least Radius of Gyration, in.*	*Maximum Length, ft, in.*	*Maximum Horizontal Load, lb*		
			Angle of Brace from Vertical		
			30° — 44°	*45° — 59°*	*60° — 90°*
l/r = 100 F_y = 36 ksi					
Pipe (Schedule 40 - Size is Nominal Diameter)					
1	0.421	3 ft 6 in.	3150	4455	5456
1¼	0.54	4 ft 6 in.	4266	6033	7389
1½	0.623	5 ft 2 in.	5095	7206	8825
2	0.787	6 ft 6 in.	6823	9650	11818
Pipe (Schedule 10 - Size is Nominal Diameter)					
1	0.428	3 ft 6 in.	2634	3725	4562
1¼	0.55	4 ft 7 in.	3386	4789	5865
1½	0.634	5 ft 3 in.	3909	5528	6771
2	0.802	6 ft 8 in.	4949	6998	8571
Angles					
1½×1½×¼	0.292	2 ft 5 in.	4387	6205	7599
2×2×¼	0.391	3 ft 3 in.	5982	8459	10360
2½×2×¼	0.424	3 ft 6 in.	6760	9560	11708
2½×2½×¼	0.491	4 ft 1 in.	7589	10732	13144
3×2½×¼	0.528	4 ft 4 in.	8354	11814	14469
3×3×¼	0.592	4 ft 11 in.	9183	12987	15905
Rods (Threaded Full Length)					
⅜	0.075	0 ft 7 in.	446	631	773
½	0.101	0 ft 10 in.	823	1163	1425
⅝	0.128	1 ft 0 in.	1320	1867	2286
¾	0.157	1 ft 3 in.	1970	2787	3413
⅞	0.185	1 ft 6 in.	2736	3869	4738
Rods (Threaded at Ends Only)					
⅜	0.094	0 ft 9 in.	701	992	1215
½	0.125	1 ft 0 in.	1250	1768	2165
⅝	0.156	1 ft 3 in.	1958	2769	3391
¾	0.188	1 ft 6 in.	2819	3986	4882
⅞	0.219	1 ft 9 in.	3833	5420	6638
Flats					
1½×¼	0.0722	0 ft 7 in.	2391	3382	4142
2×¼	0.0722	0 ft 7 in.	3189	4509	5523
2×⅜	0.1082	0 ft 10 in.	4783	6764	8284

Table 3.1.8-B. Maximum ASD Horizontal Loads (N) for Steel Sway Brace Members in Compression (SI Units) (l/r = 100)

Shape Size, mm.	Least Radius of Gyration, mm	Maximum Length, m	Maximum Horizontal Load, N — Angle of Brace from Vertical: 30° — 44°	45° — 59°	60° — 90°
l/r = 100, F_y = 235 MPa					
Pipe (Schedule 40 - Size is Nominal Diameter)					
25	10.69	1.07	13645	19297	23634
32	13.72	1.37	18479	26133	32006
40	15.82	1.58	22069	31211	38225
50	19.99	2.0	29555	41797	51190
Pipe (Schedule 10 - Size is Nominal Diameter)					
25	10.87	1.09	11408	16133	19759
32	13.97	1.40	14667	20742	25404
40	16.10	1.61	16932	23945	29327
50	20.37	2.04	21434	30312	37125
Angles					
30×30×3	5.81	0.58	7449	10535	12903
40×40×4	7.77	0.78	13186	18648	22840
50×50×5	9.73	0.97	20550	29063	35594
60×60×6	11.70	1.17	29584	41838	51241
70×70×7	13.60	1.36	40244	56914	69705
80×80×8	15.60	1.56	52660	74473	91210
Rods (Threaded Full Length)					
10	2.04	0.20	2239	3166	3878
12	2.46	0.25	3264	4617	5654
16	3.39	0.34	6170	8726	10687
20	4.23	0.42	9641	13635	16699
22	4.73	0.47	12053	17046	20877
Rods (Threaded at Ends Only)					
10	2.50	0.25	3363	4755	5824
12	3.00	0.30	4842	6848	8387
16	4.00	0.40	8608	12174	14910
20	5.00	0.50	13450	19021	23296
22	5.50	0.55	16275	23016	28188
Flats					
40×4	1.15	0.12	6850	9688	11865
50×5	1.44	0.14	10703	15137	18539
60×6	1.73	0.17	15413	21797	26696

Table 3.1.8-C. Maximum ASD Horizontal Loads (lb) for Steel Sway Brace Members in Compression (US Customary Units) (l/r = 200)

Shape Size, in.	*Least Radius of Gyration, in.*	*Maximum Length, ft, in.*	*Maximum Horizontal Load, lb*		
			Angle of Brace from Vertical		
			30° — 44°	*45° — 59°*	*60° — 90°*
l/r = 200, F_y = 36 ksi					
Pipe (Schedule 40 - Size is Nominal Diameter)					
1	0.421	7 ft 0 in.	926	1310	1604
1¼	0.54	9 ft 0 in.	1254	1774	2173
1½	0.623	10 ft 4 in.	1498	2119	2595
2	0.787	13 ft 1 in.	2006	2837	3475
Pipe (Schedule 10 - Size is Nominal Diameter)					
1	0.428	7 ft 1 in.	774	1095	1341
1¼	0.55	9 ft 2 in.	996	1408	1724
1½	0.634	10 ft 6 in.	1149	1625	1991
2	0.802	13 ft 4 in.	1455	2058	2520
Angles					
1½×1½×¼	0.292	4 ft 10 in.	1290	1824	2234
2×2×¼	0.391	6 ft 6 in.	1759	2487	3046
2½×2×¼	0.424	7 ft 0 in.	1988	2811	3442
2½×2½×¼	0.491	8 ft 2 in.	2231	3155	3865
3×2½×¼	0.528	8 ft 9 in.	2456	3474	4254
3×3×¼	0.592	9 ft 10 in.	2700	3818	4677
Rods (Threaded Full Length)					
⅜	0.075	1 ft 2 in.	131	186	227
½	0.101	1 ft 8 in.	242	342	419
⅝	0.128	2 ft 1 in.	388	549	672
¾	0.157	2 ft 7 in.	579	819	1004
⅞	0.185	3 ft 0 in.	804	1138	1393
Rods (Threaded at Ends Only)					
⅜	0.094	1 ft 6 in.	206	292	357
½	0.125	2 ft 0 in.	368	520	637
⅝	0.156	2 ft 7 in.	576	814	997
¾	0.188	3 ft 1 in.	829	1172	1435
⅞	0.219	3 ft 7 in.	1127	1594	1952
Flats					
1½×¼	0.0722	1 ft 2 in.	703	994	1218
2×¼	0.0722	1 ft 2 in.	938	1326	1624
2×⅜	0.1082	1 ft 9 in.	1406	1989	2436

Table 3.1.8-D. Maximum ASD Horizontal Loads (N) for Steel Sway Brace Members in Compression (SI Units) (l/r = 200)

Shape Size, mm.	Least Radius of Gyration, mm	Maximum Length, m	Maximum Horizontal Load, N		
			Angle of Brace from Vertical		
			30° — 44°	45° — 59°	60° — 90°
l/r = 200, F_y = 235 MPa					
Pipe (Schedule 40 - Size is Nominal Diameter)					
25	10.69	2.14	4120	5827	7137
32	13.72	2.74	5580	7891	9665
40	15.82	3.16	6664	9425	11543
50	19.99	4.00	8925	12621	15458
Pipe (Schedule 10 - Size is Nominal Diameter)					
25	10.87	2.17	3445	4872	5966
32	13.97	2.79	4429	6263	7671
40	16.10	3.22	5113	7231	8856
50	20.37	4.07	6472	9153	11211
Angles					
30×30×3	5.81	1.16	2250	3181	3896
40×40×4	7.77	1.55	3982	5631	6897
50×50×5	9.73	1.95	6206	8776	10748
60×60×6	11.70	2.34	8933	12634	15473
70×70×7	13.60	2.72	12152	17186	21049
80×80×8	15.60	3.12	15902	22488	27543
Rods (Threaded Full Length)					
10	2.04	0.41	676	956	1171
12	2.46	0.49	986	1394	1707
16	3.39	0.68	1863	2635	3227
20	4.23	0.85	2911	4117	5043
22	4.73	0.95	3640	5147	6304
Rods (Threaded at Ends Only)					
10	2.50	0.50	1015	1436	1759
12	3.00	0.60	1462	2068	2533
16	4.00	0.80	2599	3676	4502
20	5.00	1.00	4062	5744	7035
22	5.50	1.10	4914	6950	8512
Flats					
40×4	1.15	0.23	2069	2925	3583
50×5	1.44	0.29	3232	4571	5598
60×6	1.73	0.35	4654	6582	8061

Table 3.1.8-E. Maximum ASD Horizontal Loads (lb) for Steel Sway Brace Members in Compression (US Customary Units) (l/r = 300)

Shape Size, in.	Least Radius of Gyration, in.	Maximum Length, ft, in.	Maximum Horizontal Load, lb — Angle of Brace from Vertical: 30° — 44°	45° — 59°	60° — 90°
l/r = 300, F_y = 36 ksi					
Pipe (Schedule 40 - Size is Nominal Diameter)					
1	0.421	10 ft 6 in.	412	582	713
1¼	0.54	13 ft 6 in.	558	788	966
1½	0.623	15 ft 6 in.	666	942	1153
2	0.787	19 ft 8 in.	892	1261	1544
Pipe (Schedule 10 - Size is Nominal Diameter)					
1	0.428	10 ft 8 in.	344	487	596
1¼	0.55	13 ft 9 in.	443	626	766
1½	0.634	15 ft 10 in.	511	722	885
2	0.802	20 ft 0 in.	647	915	1120
Angles					
1½×1½×¼	0.292	7 ft 3 in.	573	811	993
2×2×¼	0.391	9 ft 9 in.	782	1105	1354
2½×2×¼	0.424	10 ft 7 in.	883	1249	1530
2½×2½×¼	0.491	12 ft 3 in.	992	1402	1718
3×2½×¼	0.528	13 ft 2 in.	1092	1544	1891
3×3×¼	0.592	14 ft 9 in.	1200	1697	2078
Rods (Threaded Full Length)					
⅜	0.075	1 ft 10 in.	58	82	101
½	0.101	2 ft 6 in.	108	152	186
⅝	0.128	3 ft 2 in.	173	244	299
¾	0.157	3 ft 11 in.	258	364	446
⅞	0.185	4 ft 7 in.	358	506	619
Rods (Threaded at Ends Only)					
⅜	0.094	2 ft 4 in.	92	130	159
½	0.125	3 ft 1 in.	163	231	283
⅝	0.156	3 ft 10 in.	256	362	443
¾	0.188	4 ft 8 in.	368	521	638
⅞	0.219	5 ft 5 in.	501	708	867
Flats					
1½×¼	0.0722	1 ft 9 in.	313	442	541
2×¼	0.0722	1 ft 9 in.	417	589	722
2×⅜	0.1082	2 ft 8 in.	625	884	1083

Table 3.1.8-F. Maximum ASD Horizontal Loads (N) for Steel Sway Brace Members in Compression (SI Units) (l/r = 300)

Shape Size, mm.	Least Radius of Gyration, mm	Maximum Length, m	Maximum Horizontal Load, N Angle of Brace from Vertical 30° — 44°	45° — 59°	60° — 90°
l/r = 300, F_y = 235 MPa					
Pipe (Schedule 40 - Size is Nominal Diameter)					
25	10.69	3.21	1831	2590	3172
32	13.72	4.11	2480	3507	4295
40	15.82	4.75	2962	4189	5130
50	19.99	6.00	3966	5609	6870
Pipe (Schedule 10 - Size is Nominal Diameter)					
25	10.87	3.26	1531	2165	2652
32	13.97	4.19	1968	2784	3409
40	16.10	4.83	2272	3214	3936
50	20.37	6.11	2877	4068	4982
Angles					
30×30×3	5.81	1.74	1000	1414	1732
40×40×4	7.77	2.33	1770	2503	3065
50×50×5	9.73	2.92	2758	3900	4777
60×60×6	11.70	3.51	3970	5615	6877
70×70×7	13.60	4.08	5401	7638	9355
80×80×8	15.60	4.68	7067	9995	12241
Rods (Threaded Full Length)					
10	2.04	0.61	300	425	520
12	2.46	0.74	438	620	759
16	3.39	1.02	828	1171	1434
20	4.23	1.27	1294	1830	2241
22	4.73	1.42	1618	2288	2802
Rods (Threaded at Ends Only)					
10	2.50	0.75	451	638	782
12	3.00	0.90	650	919	1126
16	4.00	1.20	1155	1634	2001
20	5.00	1.50	1805	2553	3127
22	5.50	1.65	2184	3089	3783
Flats					
40×4	1.15	0.35	919	1300	1592
50×5	1.44	0.43	1436	2031	2488
60×6	1.73	0.52	2069	2925	3583

3.1.9 Commentary for 2.2.1.3.6

Fastener allowable stress design (ASD) capacities can be calculated based on an engineering analysis using the standards identified in 2.2.1.3.6 (i.e., ASCE 7 as well as ANSI/AWC NDS for bolts or lag screws in wood, ACI 318 for post-installed concrete anchors, or AISC 360 for bolts in steel). However, for most situations, the maximum ASD horizontal seismic load per brace, based on its structural attachment, can be determined from Table 3.1.9-A through Table 3.1.9-H at the end of this section.

General information related to determining forces in fasteners and additional information regarding concrete anchors is presented below. This is followed by Table 3.1.9-A through Table 3.1.9-H.

Determining forces on fasteners. Determining the shear and tension forces in the fasteners that attach braces to the structure depends on the sway bracing configuration and on how the fasteners attach to the structure. Various example configurations of bracing on horizontal or vertical pipe are illustrated in Fig. 3.1.9-A through Fig. 3.1.9-G. When using these figures, note the following:

A. Fig. 3.1.9-A through Fig. 3.1.9-E for horizontal piping show both possible orientations of the pipe, but a single sway brace is effective only as lateral sway bracing or longitudinal sway bracing, depending on pipe orientation for that particular brace.

B. In Fig. 3.1.9-B through Fig. 3.1.9-D, the horizontal seismic design load (H) is shown occurring in a direction to the left of the page for the purpose of illustrating the derivation of shear and tension loading as a result of seismic load (H) in that direction. In an actual earthquake, the horizontal seismic load can occur in either direction (as shown in Fig. 3.1.9-A). Shear and tension load derivations in Fig. 3.1.9-B through Fig. 3.1.9-D will not change, but will change direction with a change in direction of seismic load (H).

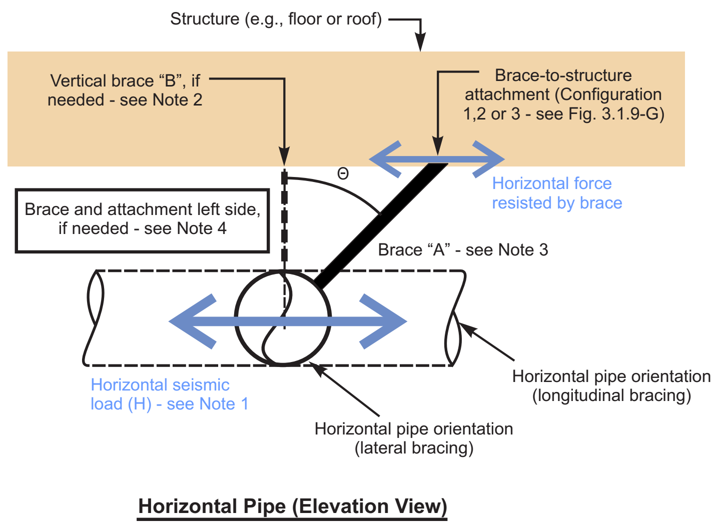
C. Fig. 3.1.9-A shows the arrangement and seismic load distribution to the diagonal brace for a horizontal pipe having one diagonal brace and one vertical brace. For this same arrangement, Fig. 3.1.9-B through Fig. 3.1.9-D show the derivation of shear and tension forces on fasteners to the structure, which depends on the configuration of those fasteners (i.e., into the underside, side or face of the structural member− also see Fig. 3.1.9-G). Where two diagonal tension-compression braces are used, the arrangement and seismic load distribution to the braces are shown in Fig. 3.1.9-E (horizontal pipe) and Fig. 3.1.9-F (vertical pipe). The derivations of shear and tension forces on the diagonal brace fasteners to the structure are not provided for the Fig. 3.1.9-E and Fig. 3.1.9-F arrangements, but will be similar to those shown in Fig. 3.1.9-B through Fig. 3.1.9-D, except that the total horizontal seismic load (H) will be divided between the two braces.

D. Where two tension-compression braces are used (see Fig. 3.1.9-E and Fig. 3.1.9-F) the same fastener configuration would usually be used for both braces (e.g., both attaching to a concrete floor slab for a horizontal pipe or to a concrete wall for a vertical pipe). This will not always be the case. When the two braces have different fastener configurations, determine load capacities for each fastener for the appropriate configuration.

E. In a symmetrical setup (Θ_L is the same as Θ_R in Fig. 3.1.9-E and Fig. 3.1.9-F) where both braces resist tension and compression, the forces in both braces will be of equal magnitude as necessary to resist a horizontal seismic load of H/2 in the applicable direction, and the shear and tension forces in the fasteners to the structure will be the same for both braces (when they are of the same configuration).

F. In an unsymmetrical setup (Θ_L differs from Θ_R in Fig. 3.1.9-E and Fig. 3.1.9-F) where both braces resist tension and compression, the brace with the larger angle (Θ) as defined in those figures always resists more than half of the horizontal seismic design load (H); the brace and fasteners should be designed for this force. The brace with the smaller angle (Θ) (e.g., the steeper brace for horizontal piping) will resist less than half of H using proportional distribution based on geometry but the brace and its connections should always be designed to resist, at a minimum, H/2. As a practical matter, the braces used in a two-brace system should usually be the same to avoid installation errors, and be sized for the worst case condition.

G. For four-way bracing on vertical pipe where both braces resist tension and compression (see Fig. 3.1.9-F), the anchorage configuration to the structure (see Fig. 3.1.9-G) will almost always be different in the two horizontal directions. Since the capacity of attachments to the structure depends on the configuration, four-way brace attachments need to be confirmed in both directions regardless of the relative magnitudes of the horizontal seismic design load (H) in each direction.



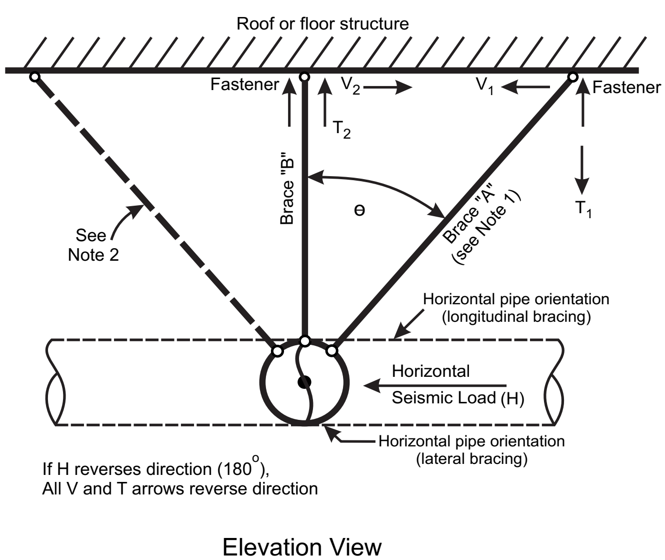
Note 1: The horizontal seismic load (H) is the calculated load at the braced location in the lateral or longitudinal direction (depending on pipe orientation).

Note 2: When the vertical component of the diagonal brace results in net vertical uplift, supplemental vertical restraint (Brace "B") is needed. Increasing the brace angle (Θ) will reduce the vertical component and may allow omission of Brace "B".

Note 3: In the configuration shown (one diagonal brace) Brace "A" must resist both tension and compression. The horizontal force resisted by the brace is equal to the horizontal seismic load (H).

Note 4: When diagonal braces resist tension only, they are needed to both the left and right of the pipe's vertical centerline. For this case, Notes 1 and 2 apply, but the full horizontal seismic load (H) is resisted by the left brace when the load is to the right, and by the right brace when the load is to the left.

Fig. 3.1.9-A. Arrangement and seismic load distribution for one diagonal and one vertical brace restraining a horizontal pipe



V = Shear Loading on Fastener
T = Tension Loading on Fastener

Note 1: A single diagonal brace is appropriate only when Brace "A" is designed for <u>both tension and compression</u>. The full load H is distributed to Brace "A", with V_1, V_2, T_1 and T_2 determined as follows:

$$V_1 = H$$
$$V_2 = O$$
$$T_1 = T_2 = \frac{H}{\tan \Theta}$$

Note 2: Where Brace "A" is designed for tension only, a Brace "A" is needed both to the left and right of the vertical. In this case the full horizontal seismic load (H) is resisted by the right brace for loads to the left (as shown - brace is in tension) and by the left brace for loads to the right. The equations in Note 1 apply, using Θ corresponding to the brace (left or right) being designed.

Fig. 3.1.9-B. Configuration 1 Fasteners with one diagonal and one vertical brace on a horizontal pipe-fasteners into underside of structural member (also see Fig. 3.1.9-A)

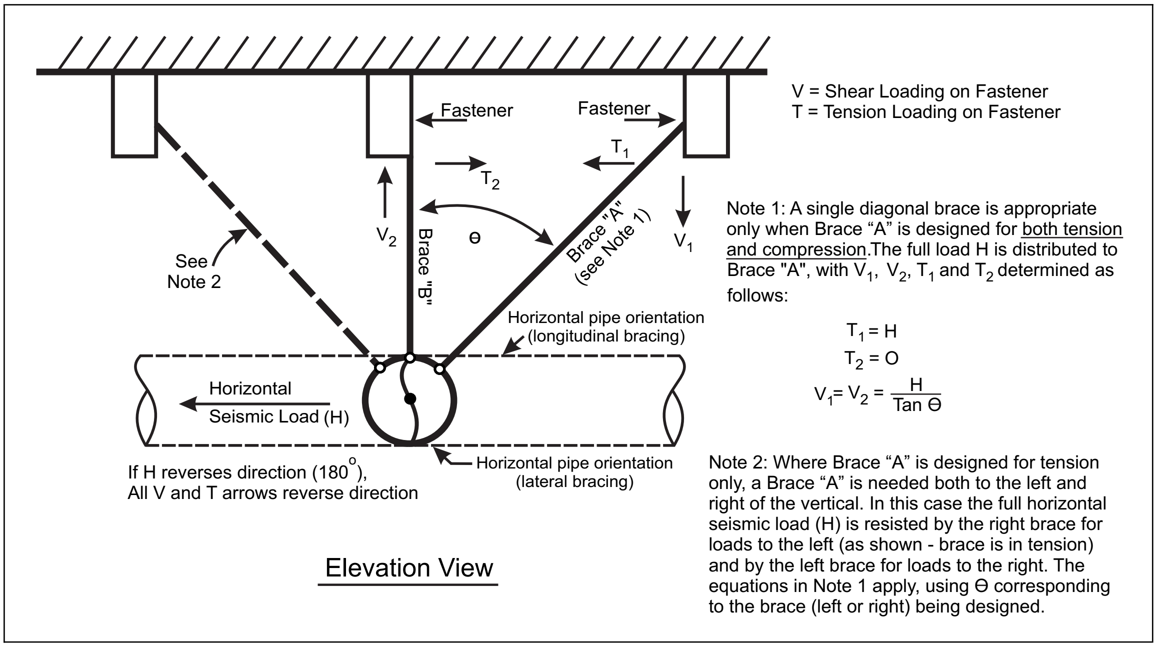


Fig. 3.1.9-C. Configuration 2: Fasteners with one diagonal and one vertical brace on a horizontal pipe-fasteners into side of structural member (also see Fig. 3.1.9-A)

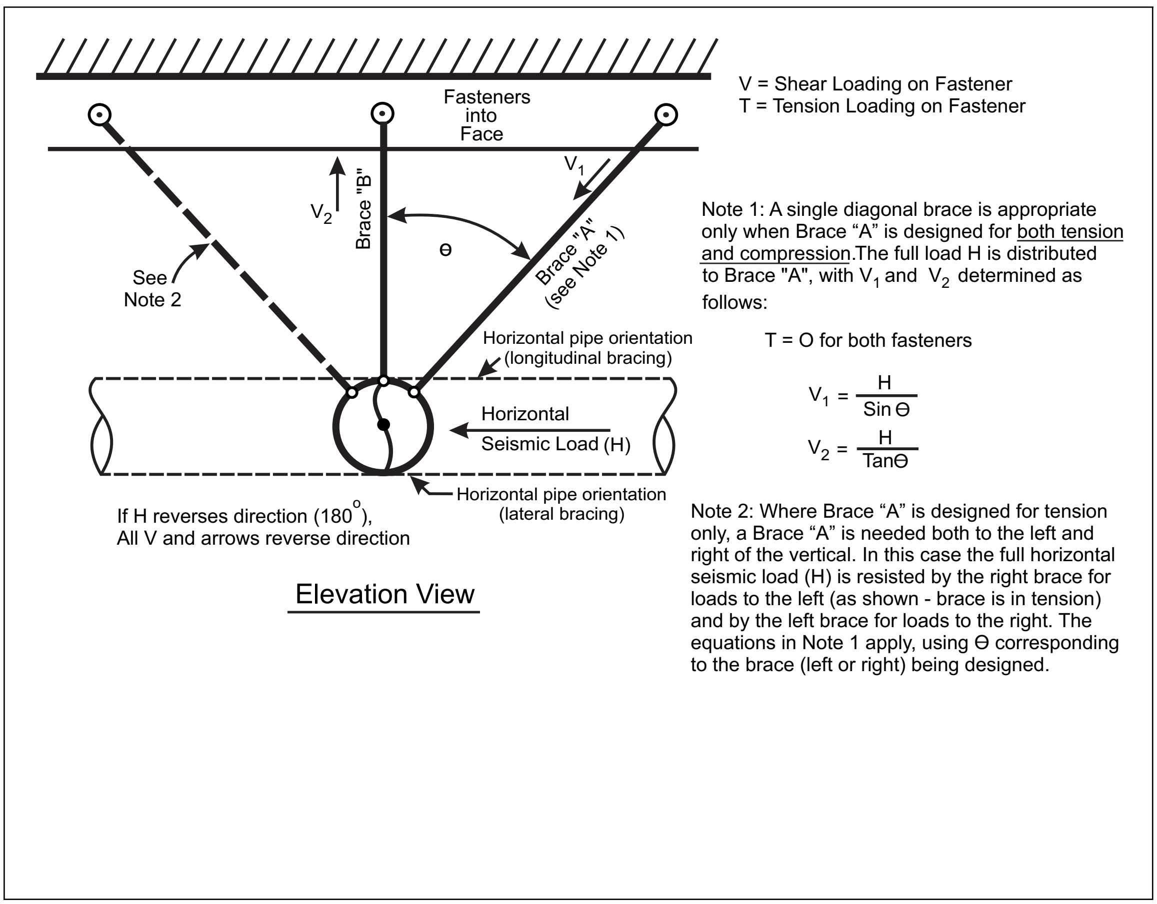
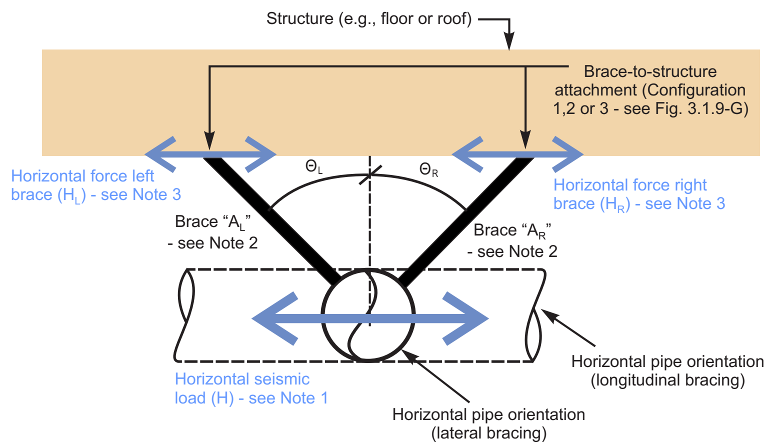


Fig. 3.1.9-D. Configuration 3: Fasteners with one diagonal and one vertical brace on a horizontal pipe−fasteners into face of structural member (also see Fig. 3.1.9-A)



Horizontal Pipe (Elevation View)

Note 1: The horizontal seismic load (H) is the calculated load at the braced location in the lateral or longitudinal direction (depending on pipe orientation).

Note 2: Braces must resist both tension and compression forces.

Note 3: A fraction of the total horizontal seismic load (H) is resisted by each brace in each direction. The relative magnitude of the horizontal force resisted by the left and right braces (H_L and H_R) depends on the brace angles of the left and right braces (Θ_L and Θ_R)

- For the preferred case $\Theta_L = \Theta_R$ resulting in $H_L = H_R$. Therefore, each brace and its attachments would be sized to resist $\frac{1}{2}H$.
- When Θ_L and Θ_R differ:
  - The brace at the larger angle will resist more than half of the total horizontal seismic load; size the brace and its attachments for this force. Taking Θ_1 as the larger angle and Θ_2 as the smaller angle, the horizontal force (H_1) resisted by the brace oriented at the larger angle (Θ_1) as a fraction of the total horizontal seismic force (H) will be:

$$H_1 = \frac{H \cdot tan\theta_1}{(\tan \theta_1 + \tan \theta_2)}$$

  - At a minimum size the brace at the smaller angle and its attachments to resist $\frac{1}{2}$H.
  - To avoid installation errors, where possible use the same brace size and attachment configurations for both braces.

Fig. 3.1.9-E. Arrangement and seismic load distribution for two diagonal tension-compression braces restraining a horizontal pipe

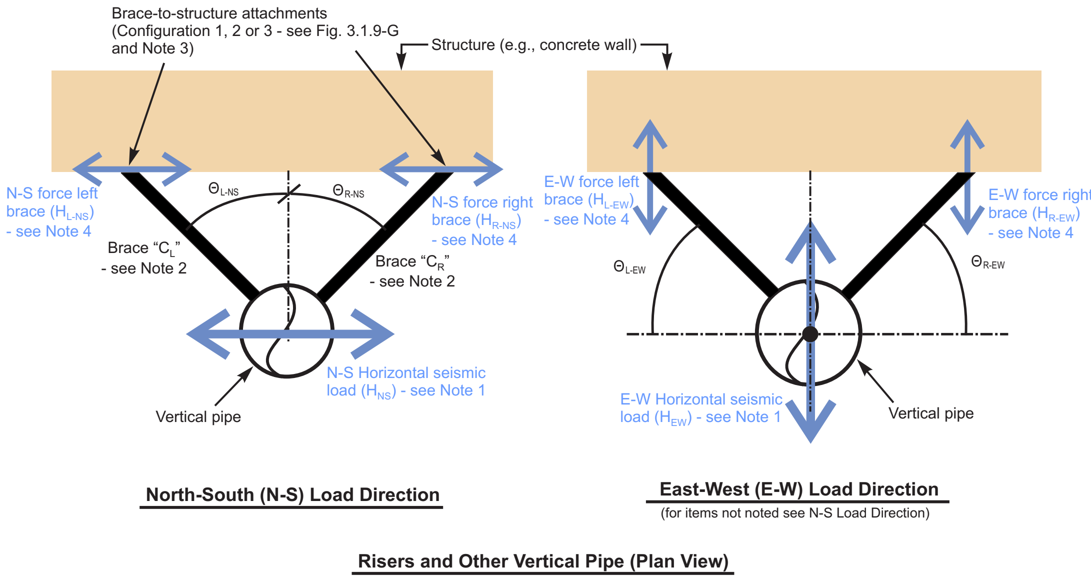
Anchoring to concrete. Concrete anchors can be cast-in-place (installed before the concrete is placed), such as embedded bolts or concrete inserts; or post-installed (installed in hardened concrete), such as expansion anchors and adhesive anchors. The Load and Resistance Factor Design (LRFD) capacities for many concrete anchors can be determined using ACI 318 and manufacturer data. Post-installed concrete anchors must be qualified for use in seismic areas using testing protocols in American Concrete Institute (ACI) standards ACI 355.2, *Qualification of Post-Installed Mechanical Anchors in Concrete* and ACI 355.4, *Qualification of Post-Installed Adhesive Anchors in Concrete* or equivalent international standards. These standards have tests to evaluate, for example, how anchor capacities are affected by concrete cracking, which commonly occurs during earthquakes. ASD capacities can be determined from the LRFD capacities as discussed below.

In LRFD, the following condition must be met:

Design Strength ≥ Required Strength

Which corresponds to:

$\Phi \cdot$(Nominal Strength) ≥ Σ Factored Loads



Note 1: The horizontal seismic load (H) is the calculated load at the braced location and may differ in the two orthogonal directions (shown here as north-south [H_{NS}] and east-west [H_{EW}]). Brace C_L and Brace C_R and their attachments are sized based on the horizontal seismic load in the N-S or E-W directions, whichever results in the more conservative design.

Note 2: Braces must resist both tension and compression forces.

Note 3: The same brace-to-structure attachment will usually have a different configuration, and allowable capacity, in the N-S and E-W directions. The smaller horizontal seismic load (H_{NS} or H_{EW}) could control the attachment size, depending on the configuration.

Note 4: A fraction of the total horizontal seismic load (H_{NS} or H_{EW}) is resisted by each brace in each direction. The relative magnitude of the horizontal force resisted by the left and right braces (H_L or H_R) depends on the brace angles (Θ_L and Θ_R) applicable to that direction.

- For the preferred case $\Theta_L = \Theta_R$ in both the N-S and E-W directions (i.e., all equal to 45°). When $\Theta_L = \Theta_R$ then $H_L = H_R$, therefore each brace and its attachments would be sized to resist $\frac{1}{2}H_{NS}$ or $\frac{1}{2}H_{EW}$, whichever controls.
- When Θ_L and Θ_R differ:
  - The brace at the larger angle will resist more than half of the total horizontal seismic load in that direction. Note that if Brace "C_L" is at the larger angle for N-S loads, then Brace "C_R" will be at the larger angle for E-W loads (and vice versa). Size each brace and its attachments for the appropriate force. Taking Θ_1 as the larger angle and Θ_2 as the smaller angle, the horizontal force (H_1) resisted by the brace oriented at the larger angle (Θ_1) as a fraction of the total horizontal seismic force (H) in each orthogonal direction will be:

$$H_1 = \frac{H \cdot \tan\theta_1}{(\tan\theta_1 + \tan\theta_2)}$$

  - At a minimum size the brace at the smaller angle in each orthogonal direction and its attachments to resist $\frac{1}{2}H_{NS}$ or $\frac{1}{2}H_{EW}$.
  - To avoid installation errors, where possible use the same brace size and attachment configurations for both braces.

Fig. 3.1.9-F. Arrangement and seismic load distribution for two diagonal tension-compression braces restraining a vertical pipe

The LRFD nominal tension and shear strengths of post-installed concrete anchors are determined for several different potential failure conditions including:

A. Tension (N)

- Steel strength of the anchor (N_{sa}), assuming failure of the steel itself
- Concrete breakout strength (N_{cb}), assuming a cone (or flat-topped pyramid) fractures and is pulled from the concrete surface
- Concrete pullout strength (N_{pn}), assuming the anchor is pulled from the hole without fracturing the concrete

- Concrete side-face blowout (N_{sb}), when the anchor is located near a concrete edge and a wedge of concrete fractures from that edge

B. Shear (V)

- Steel strength of the anchor (V_{sa}), assuming failure of the steel itself
- Concrete breakout strength (V_{cb}), when the anchor is located near and loaded toward a concrete edge and a cone or wedge of concrete fractures from that edge
- Concrete pryout strength (V_{cp}), when the anchor is far from a concrete edge and a wedge of concrete is pried from the concrete surface into which the anchor is installed

Each of these nominal capacities is multiplied by its appropriate strength reduction factor (Φ) to arrive at the LRFD design strength. Φ varies from 0.45 to 0.75 based on the ductility of the steel (for steel failure modes); or based on steel reinforcement details, and the reliability and installation sensitivity of the post-installed anchor (for concrete failure modes). The LRFD design strengths in tension and shear are the lowest of these $\Phi \cdot$(Nominal Strength) values.

The controlling LRFD design strengths are then compared against the LRFD required strengths for the controlling load combination(s). A load combination is a summation of the basic code-required loads (e.g., dead, live, earthquake), each multiplied by its LRFD load factor (load factors vary based on type of load, e.g., dead, live or earthquake). When a load combination results in both tension and shear loads on an anchor, the three conditions in 2.2.1.3.6.5.C.2 must be met, showing the anchor is adequate in tension, in shear, and for the combination of tension and shear.

To provide a larger margin against sudden brittle failure, horizontal seismic loads in load combinations are required, per ASCE 7, to be multiplied by an additional LRFD overstrength factor (Ω_o) when anchors to concrete or masonry are likely to be non-ductile (usually because failure will occur in the concrete or masonry, rather than the steel). Most post-installed concrete anchors, and many concrete inserts, are considered non-ductile and $\Omega_o = 2.0$ is applied (i.e., the LRFD required strength for concrete anchors is determined using twice the horizontal earthquake load).

Because braces resist only seismic forces (i.e., not dead or live loads), instead of multiplying the LRFD horizontal seismic load by two, an equivalent method is to compare the usual LRFD required strength to half of the usual LRFD design strength. That is, the nominal tension and shear capacities determined from ACI 318 would be reduced by both the strength reduction factor (Φ) and by a factor of 0.5.

This standard uses ASD loads, not LRFD loads. ASD design strengths for concrete anchors can be determined from LRFD design strengths by applying two factors. First, usual ASD load combinations include a load factor of 0.7 on seismic loads, therefore the LRFD design strengths must be multiplied by 0.7 when loads are given in ASD. Second, the overstrength factor (Ω_o) also applies to ASD loads, but it is reduced to 2.0/1.2 = 1.67. Using the same logic as above for LRFD, instead of multiplying the horizontal seismic loads by 1.67, we can instead reduce the anchor capacity by a factor of 1/1.67 = 0.6. Therefore, for comparison against "H" determined from Section 2.2.1.2 (which is based on ASD), concrete anchor tension and shear capacities can be taken as (0.7)·(0.6) = 0.42 times the LRFD design strength determined from ACI 318. For post-installed concrete anchors, this 0.42 factor has already been incorporated in Table 3.1.9-E and Table 3.1.9-F (i.e., the table values represent 0.42 times the ACI 318 LRFD design strengths so that they can be compared directly against anchor loads resulting from "H" found in Section 2.2.1.2).

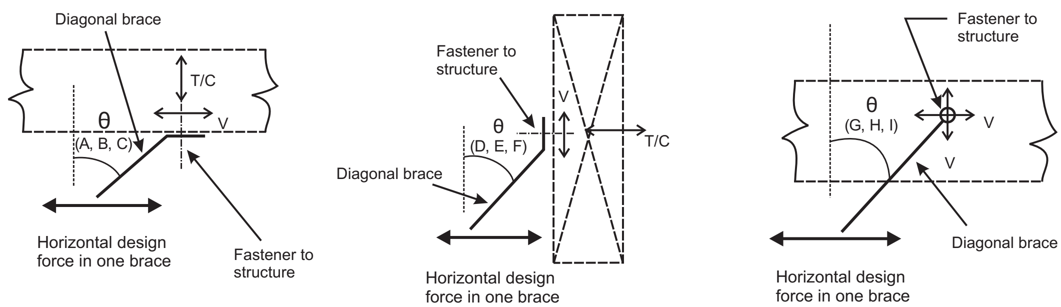
The shear and tension expansion anchor ASD capacities used to develop Table 3.1.9-E and Table 3.1.9-F (see table notes) are reasonable to use for common post-installed concrete anchors, but a particular anchor may have higher ASD capacities. In lieu of using the tables, it is acceptable to calculate ASD shear and tension post-installed concrete anchor capacities as 0.42 times the ACI 318 LRFD design strengths for comparison to the shear and tension loads at the anchor resulting from the ASD seismic load "H" determined from Section 2.2.1.2. Concrete insert ASD shear and tension capacities can be similarly determined.

Maximum horizontal loads using anchor tables. In lieu of calculations, the maximum ASD horizontal seismic load per brace, based on its structural attachment, can be determined from Table 3.1.9-A through Table 3.1.9-H. When using these tables, select the fastener size for the appropriate material (i.e., wood, concrete or steel) into which the fastener is installed, based on the configuration of the fastener with respect to the structural member and the angle of the brace (Θ) as defined in Fig. 3.1.9-G. The angle of the brace (Θ) is from the vertical for horizontal pipe; see Fig. 3.1.9-F for the definition of Θ for braces on vertical pipe. The load values given in the tables correspond to the applied horizontal seismic load (either H or a fraction of H not less than H/2, depending on sway bracing configuration) for the worst-case brace angle (Θ) for the range of angles given. In other words, the horizontal seismic design load on the brace must be less than the table values for the fastener size and configuration selected. Tables include:

A. For through-bolts and lag screws in wood, Table 3.1.9-A and Table 3.1.9-C (US Customary units) or Table 3.1.9-B and Table 3.1.9-D (SI units)

B. For anchorage to normal-weight concrete, Table 3.1.9-E (US Customary units) or Table 3.1.9-F (SI units). For light-weight concrete, use 50% of the table values (see table notes). The concrete strength used to develop the tables is at the low end of commonly-specified concrete strengths, so table values can be used even if the concrete strength is unknown. Note that the conditions in 2.2.1.3.6.5.B must be met. In the United States, an example of an acceptable local governing jurisdiction would be the International Conference of Building Officials (ICBO) evaluation services guide, and examples of acceptable testing protocols are the standards ACI 355.2 and ACI 355.4.

C. For anchorage to steel, Table 3.1.9-G (US Customary units) or Table 3.1.9-H (SI units)



Configuration 1
Horizontal brace force transfers to structure via shear (V). Perpendicular brace component causes tension/compression (T/C) in fastener. Fasteners could attach, for example, to bottom of a floor slab (horizontal pipe) or face of a wall (vertical pipe).

Configuration 2
Horizontal brace force transfers to structure via tension/compression (T/C). Perpendicular brace component causes shear (V) in fastener. Fasteners could attach, for example, to side of beam (horizontal pipe) or to side of a column (vertical pipe).

Configuration 3
Brace is directly in line with the face of the member to which it is attached. Both the horizontal brace force and the perpendicular brace component transfer to structure in shear (V). Fasteners could attach, for example, to side of beam (horizontal pipe) or to top of a wall girt (vertical pipe).

Brace to Structure Attachments
(Configurations shown for the right brace; left brace is opposite hand)

Fig. 3.1.9-G. Definition of attachment to structure configurations for Table 3.1.9-A through Table 3.1.9-H

Table 3.1.9-A. Maximum ASD Horizontal Load per Brace Attached with Through-Bolts in Wood, lb (US Customary Units)

Through Bolt Diameter, in.	*Length of Bolt in Timber, in.*	*Configuration 1*			*Configuration 2*			*Configuration 3*		
		Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
		A	B	C	D	E	F	G	H	I
		30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
½	1-½	368	368	368	212	368	637	210	344	503
	2-½	448	448	448	259	448	776	260	436	659
	3-½	560	560	560	323	560	970	321	530	783
⅝	1-½	432	432	432	249	432	748	248	412	612
	2-½	512	512	512	296	512	887	300	512	789
	3-½	640	640	640	370	640	1109	377	650	1019
	5-½	896	896	896	517	896	1552	506	821	1180
¾	1-½	496	496	496	286	496	859	287	482	726
	2-½	576	576	576	333	576	998	340	587	923
	3-½	704	704	704	406	704	1219	419	732	1171
	5-½	992	992	992	573	992	1718	577	977	1488
7 / 8	1-½	560	560	560	323	560	970	325	549	833
	2-½	640	640	640	370	640	1109	380	660	1050
	3-½	752	752	752	434	752	1303	452	800	1312
	5-½	1056	1056	1056	610	1056	1829	631	1107	1787
1	1-½	624	624	624	360	624	1081	363	616	940
	2-½	704	704	704	406	704	1219	420	735	1181
	3-½	848	848	848	490	848	1469	510	905	1487
	5-½	1184	1184	1184	684	1184	2051	716	1282	2139

Notes:
1. Attachments to members with less than 3½ in. (90 mm) least dimension are not allowed. Bolt values for thinner members are provided for reference.
2. Table is generated based on American Wood Council standard ANSI / AWC NDS-2005 for wood with specific gravity (SG) of 0.35 and including a 1.6 Load Duration Factor.
3. Use tabulated values for SG = 0.35 to 0.39. Tabulated values may be increased by the following factors for other specific gravity values:
    1.2 for SG = 0.40 to 0.46 (e.g., Hem Fir)
    1.4 for SG = 0.47 to 0.52 (e.g., Douglas Fir)
    1.6 for SG > 0.52 (e.g., Southern Pine)

Table 3.1.9-B. Maximum ASD Horizontal Load per Brace Attached with Through-Bolts in Wood, N (SI Units)

Through Bolt Diameter, mm	*Length of Bolt in Timber, mm*	*Configuration 1*			*Configuration 2*			*Configuration 3*		
		Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
		A	B	C	D	E	F	G	H	I
		30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
12	40	1637	1637	1637	943	1637	2834	934	1530	2237
	65	1993	1993	1993	1152	1993	3452	1157	1939	2931
	90	2491	2491	2491	1437	2491	4315	1428	2358	3483
16	40	1922	1922	1922	1108	1922	3327	1103	1833	2722
	65	2277	2277	2277	1317	2277	3946	1334	2277	3510
	90	2847	2847	2847	1646	2847	4933	1677	2891	4533
	140	3986	3986	3986	2300	3986	6904	2251	3652	5249
20	40	2206	2206	2206	1272	2206	3821	1277	2144	3229
	65	2562	2562	2562	1481	2562	4439	1512	2611	4106
	90	3132	3132	3132	1806	3132	5422	1864	3256	5209
	140	4413	4413	4413	2549	4413	7642	2567	4346	6619
22	40	2491	2491	2491	1437	2491	4315	1446	2442	3705
	65	2847	2847	2847	1646	2847	4933	1690	2936	4671
	90	3345	3345	3345	1931	3345	5796	2011	3559	5836
	140	4697	4697	4697	2713	4697	8136	2807	4924	7949
25	40	2776	2776	2776	1601	2776	4809	1615	2740	4181
	65	3132	3132	3132	1806	3132	5422	1868	3269	5253
	90	3772	3772	3772	2180	3772	6534	2269	4026	6614
	140	5267	5267	5267	3043	5267	9123	3185	5703	9515

Notes:
1. The notes for Table 3.1.9-A also apply to Table 3.1.9-B.

Table 3.1.9-C. Maximum ASD Horizontal Load per Brace Attached with Lag Screws in Wood, lb (US Customary Units)

Lag Bolt Diameter, in.	*Length of Bolt Under Head, in.*	*Configuration 1*			*Configuration 2*			*Configuration 3*		
		Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
		A	B	C	D	E	F	G	H	I
		30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
3⁄8	2	118	123	120	69	123	205	63	101	140
	3	179	195	194	112	195	310	105	166	232
	4	221	236	232	134	236	382	124	197	275
1⁄2	3	224	252	257	148	252	387	141	225	317
	4	301	346	358	207	346	521	199	318	447
	5	361	410	419	242	410	625	232	370	520
5⁄8	3	241	266	268	155	266	417	148	240	344
	4	328	371	379	219	371	568	211	342	491
	5	415	475	489	282	475	719	274	445	638
	6	488	553	565	326	553	845	316	512	735
3⁄4	4	358	404	412	238	404	621	231	378	550
	5	457	522	536	309	522	791	302	495	719
	6	555	639	659	381	639	961	374	611	888

Notes:
1. Make attachments to members with least dimension of 3½ in. (90 mm) or more. Lag screw length under the head of 8 times the screw diameter are preferred, in no case should the length under the head be less than 4 times the screw diameter.
2. Table is generated based on American Wood Council standard ANSI / AWC NDS-2005 for wood with specific gravity (SG) of 0.35 and including a 1.6 Load Duration Factor.
3. Use tabulated values for SG = 0.35 to 0.39. Tabulated values may be increased by the following factors for other specific gravity values:
   - 1.2 for SG = 0.40 to 0.46 (e.g., Hem Fir)
   - 1.4 for SG = 0.47 to 0.52 (e.g., Douglas Fir)
   - 1.6 for SG > 0.52 (e.g., Southern Pine)

Table 3.1.9-D. Maximum ASD Horizontal Load per Brace Attached with Lag Screws in Wood, N (SI Units)

Lag Bolt Diameter, mm	*Length of Bolt Under Head, mm*	*Configuration 1*			*Configuration 2*			*Configuration 3*		
		Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
		A	B	C	D	E	F	G	H	I
		30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
10	50	525	547	534	307	547	912	280	449	623
	75	796	867	863	498	867	1379	467	738	1032
	100	983	1050	1032	596	1050	1699	552	876	1223
12	75	996	1121	1143	658	1121	1721	627	1001	1410
	100	1339	1539	1592	921	1539	2318	885	1415	1988
	125	1606	1824	1864	1076	1824	2780	1032	1646	2313
16	75	1072	1183	1192	689	1183	1855	658	1068	1530
	100	1459	1650	1686	974	1650	2527	939	1521	2184
	125	1846	2113	2175	1254	2113	3198	1219	1979	2838
	150	2171	2460	2513	1450	2460	3759	1406	2277	3269
20	100	1592	1797	1833	1059	1797	2762	1028	1681	2447
	125	2033	2322	2384	1374	2322	3519	1343	2202	3198
	150	2469	2842	2931	1695	2842	4275	1664	2718	3950

Notes:
1. The notes for Table 3.1.9-C also apply to Table 3.1.9-D.

Table 3.1.9-E. Maximum ASD Horizontal Load per Brace Attached with Post-Installed Concrete Expansion or Wedge Anchors in 3000 psi Normal Weight Concrete[1,2,3], lb (US Customary Units)

Nominal Bolt Dia-meter, in.	*Minimum Nominal Embed-ment, in.*	*Configuration 1*			*Configuration 2*			*Configuration 3*		
		Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
		A	B	C	D	E	F	G	H	I
		30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
3⁄8	2-1⁄4	200	280	360	210	280	350	250	350	430
1⁄2	3-1⁄2	310	460	640	370	460	540	550	770	950
5⁄8	3-3⁄4	460	670	910	520	670	800	750	1060	1290
3⁄4	4-1⁄2	670	980	1330	770	980	1160	1100	1550	1900

Notes:
1. The table was generated using the following concrete Allowable Stress Design (ASD) expansion bolt capacities in 3000 psi (20.7 MPa) cracked normal weight concrete:

- 3/8 in. (10 mm): 450 lb (2.0 kN) tension; 500 lb (2.22 kN) shear
- 1/2 in. (12 mm): 600 lb (2.67 kN) tension; 1100 lb (4.89 kN) shear
- 5/8 in. (16 mm): 900 lb (4.0 kN) tension; 1500 lb (6.67 kN) shear
- 3/4 in. (20 mm): 1300 lb (5.78 kN) tension; 2200 lb (9.79 kN) shear

The above ASD capacities are based on 0.42 times the normally allowed LRFD capacity, accounting for a 0.7 ASD load factor adjustment and a 0.6 overstrength factor (Ω_o) adjustment (see text).

Manufacturers typically supply bolts in many lengths; choose bolts with a nominal embedment (i.e., the embedment before the anchor is set) at least equal to that shown in the table (nominal embedment values should typically be 6 to 7 times the bolt diameter [$6D_b$ to $7D_b$]).

2. Values in the table assume a minimum edge distance of 12 times the bolt diameter ($12D_b$).
3. Where attachments are made to light weight concrete (e.g., Configuration 1 attachments to light weight concrete-filled metal deck), use 50% of the table values

Table 3.1.9-F. Maximum ASD Horizontal Load per Brace Attached with Post-Installed Concrete Expansion or Wedge Anchors in 20.7 MPa Normal Weight Concrete[1], N (SI Units)

Nominal Bolt Diameter, mm	*Minimum Nominal Embedment, mm*	*Configuration 1*			*Configuration 2*			*Configuration 3*		
		Brace Angle (Θ)			Brace Angle (Θ)			Brace Angle (Θ)		
		A	B	C	D	E	F	G	H	I
		30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
10	60	910	1260	1620	930	1260	1570	1110	1560	1920
12	90	1400	2070	2850	1640	2070	2430	2440	3450	4230
16	100	2050	3000	4070	2350	3000	3560	3330	4710	5770
20	120	2980	4360	5930	3420	4360	5170	4890	6920	8470

Notes:
1. The notes for Table 3.1.9-E also apply to Table 3.1.9-F.

Table 3.1.9-G. Maximum ASD Horizontal Load per Brace Attached with Through-Bolts in Steel[1] (bolt perpendicular to mounting surface), lb (US Customary Units)

Through Bolt Diameter, in.	*Configuration 1*			*Configuration 2*			*Configuration 3*		
	Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
	A	B	C	D	E	F	G	H	I
	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
1⁄4	400	500	600	300	500	650	325	458	565
3⁄8	900	1200	1400	800	1200	1550	735	1035	1278
1⁄2	1600	2050	2550	1450	2050	2850	1300	1830	2260
5⁄8	2500	3300	3950	2250	3300	4400	2045	2880	3557

1. Table values are applicable for through-bolts installed in steel having a minimum thickness (t) of 0.25 in. For t between 0.1046 in. (12 gauge) and 0.25 in. the maximum horizontal load can be taken as the table values multiplied by t/0.25. The table is not applicable where the steel thickness is less than 0.1046 in. (e.g., light-gauge steel that is 13 gauge to 30 gauge).

Table 3.1.9-H. Maximum ASD Horizontal Load per Brace Attached with Through-Bolts in Steel[1] (bolt perpendicular to mounting surface), N (SI Units)

Through Bolt Diameter, mm	*Configuration 1*			*Configuration 2*			*Configuration 3*		
	Brace Angle (θ)			Brace Angle (θ)			Brace Angle (θ)		
	A	B	C	D	E	F	G	H	I
	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°	30-44°	45-59°	60-90°
6	1780	2224	2669	1334	2224	2891	1446	2037	2513
10	4003	5338	6227	3558	5338	6894	3269	4604	5685
12	7116	9118	11342	6450	9118	12677	5782	8140	10052
16	11120	14678	17570	10008	14678	19571	9096	12810	15821

1. Table values are applicable for through-bolts installed in steel having a minimum thickness (t) of 6.4 mm. For t between 2.65 mm and 6.4 mm the maximum horizontal load can be taken as the table values multiplied by t/6.4. The table is not applicable where the steel thickness is less than 2.65 mm (i.e., light-gauge steel).

3.1.10 Commentary for 2.2.1.4.8

When a horizontal pipe spans across a seismic expansion joint within a building, or spans between two independent buildings or structures, the horizontal movement to be accommodated should be provided by the building design engineer. Where this information is not available, it may be reasonable to assume the horizontal movement in any direction for each building section is equal to half of the seismic separation between the building sections (e.g., for a seismic separation of 8 in. [200 mm] assume each building section can move 4 in. [100 mm] in any horizontal direction). However, where the separation is unusually large or small, this method may incorrectly estimate the horizontal movement. In this case, the total relative horizontal movement at the floor where the pipe is located can be approximated as 2% to 3% of the height of that floor above grade (i.e., movement of each building would be 1% to 1.5% of the height above grade to the floor, and the buildings can move in opposite directions). For example, a pipe passing between separate building sections at a roof that is 30 ft (9.1 m) above grade would have to accommodate a total relative horizontal movement of 7.2 to 10.8 in. (180 to 275 mm), half from each structure.

Assuming no soil failures or settlement, the amount of relative vertical movement between separate buildings or building sections should be small. However, providing some allowance for vertical movement (e.g., 1 to 3 in. [25 to 75 mm] of total relative movement between the separate building sections) would be prudent.

Fig. 3.1.10-A illustrates an acceptable seismic separation assembly (SSA) (i.e., an arrangement of piping, flexible couplings, and elbows) for 4 in. (100 mm) horizontal piping crossing an 8 in. (200 mm) separation. When other pipe sizes or separation distances are used, the sizes and dimensions of equipment may differ. An acceptable alternative is to provide an FM Approved, manufactured pipe loop incorporating flexible piping similar to that shown in Fig. 3.1.10-B.

Horizontal movement of the SSA or loop will occur, so no braces should be attached to the SSA or loop itself; however, the end of the pipe on each side of the SSA or loop must be braced (e.g., for horizontal pipe, a lateral brace within 6 ft [1.8 m] of the end and a longitudinal brace within 40 ft [12.2 m] of the end). Any hanger supporting the SSA or loop itself should accommodate this horizontal movement (e.g., by providing a breakaway hanger).

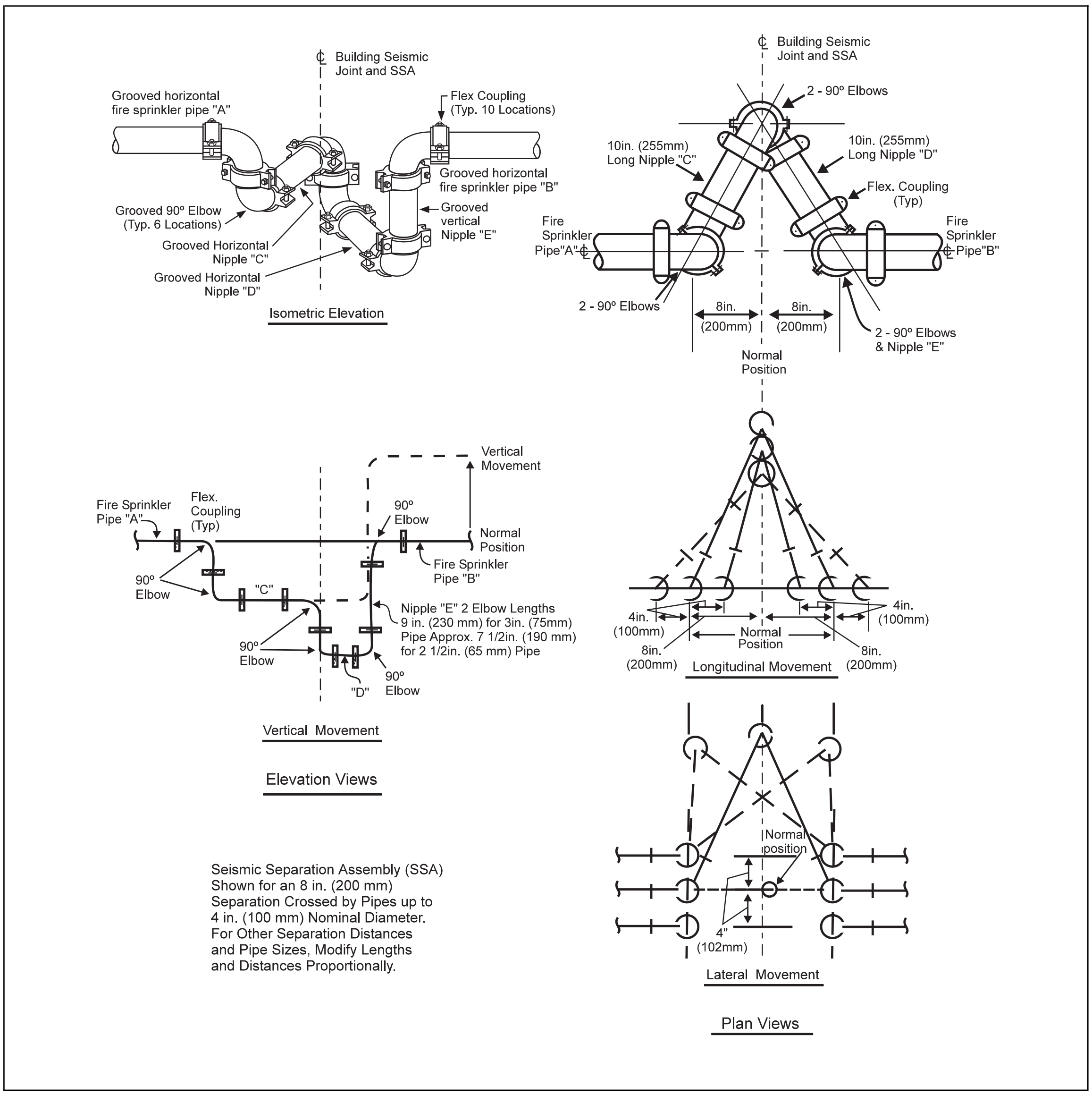


Fig. 3.1.10-A.. Seismic separation assembly for fire protection system horizontal piping that crosses a seismic building expansion joint above ground level

Fig. 3.1.10-B. Flexible pipe loop; possible alternative to a seismic separation assembly

Any alternate engineered method must allow adequate movement in two orthogonal horizontal directions as well as vertically. An assembly or manufactured coupling that does not allow these movements is not acceptable. For example, Fig. 3.1.10-C shows a system that does not provide adequate movement capacity in the direction parallel to the pipe axis. Furthermore, the reliability of a stack of couplings allowing large movement perpendicular to the pipe without leakage has not been established.

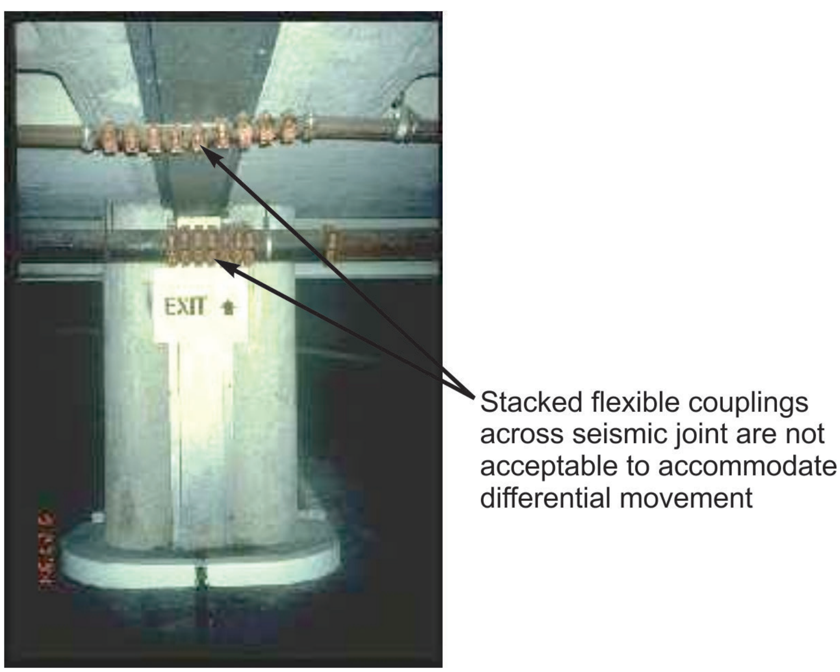


Fig. 3.1.10-C. Unacceptable alternative to a seismic separation assembly

When a riser spans between grade and the roof in a building, the differential movement between these two locations can be accommodated by providing flexible couplings at the top and bottom, allowing the pipe between these locations to remain straight. For example, assuming that the roof of the building moves 1.5% of the building height relative to its foundation, the flexible couplings would have to allow an angular deflection (β) equal to $\tan^{-1}$ (0.015) or about 0.9 degrees. Flexible couplings allow on the order of 1 degree (larger pipe) to 3 degrees (smaller pipe) of angular deflection, so most flexible couplings would be able to accommodate the required 0.9 degrees.

However, when a pipe drop from a ceiling system supplies water to an independent structure (e.g., to an independent interior mezzanine or to in-rack sprinklers in an independent storage rack), the angular deflection requirements for the flexible couplings increase. For this case, greater lateral differential movement must be accommodated (i.e., the lateral deflection of the building at the location of the overhead pipe plus the lateral deflection of the independent structure at the highest attachment point of the drop, since the structures can move in opposite directions). In addition, the length over which this differential movement must occur (i.e., the length of the drop between flexible couplings) is less. Assuming each structure can deflect 1.5% of its height (at the point of pipe attachment) the angular deflection that must be accommodated is:

$$\beta = \tan^{-1}\left[\frac{0.015\,(H_O + H_I)}{(H_O - H_I)}\right]$$

Where

β = required angular deflection
H_O = height from base of the building to the overhead pipe
H_I = height from the base of the building to the location of the highest attachment of the drop to the independent structure

If the pipe drop length equals one-third of the building height (i.e., H_I equals 2/3 of H_O) and each structure deflects horizontally 1.5%, then the required angular deflection of the flexible couplings would be 4.3 degrees, which likely exceeds the angular deflection capacity of most flexible couplings. If the pipe drop length equals one-half of the building height, the required angular deflection would be 2.6 degrees, which could be accommodated by some flexible couplings. If the amount of relative deflection is large when assuming lateral deflections of 1.5% of the height, there are four alternatives:

A. Determine whether less lateral deflection will occur (e.g., a concrete shear wall structure with concrete floor slabs may laterally deflect much less than 1.5% of the height)

B. Attach the drop at a lower point on the independent structure to maximize the drop length

C. Specify FM Approved flexible couplings having adequate angular deflection capacity (there may be limited choices), or use short, straight flexible pipe (this may require that the vertical pipe be independently supported for gravity loads); multiple flexible couplings (i.e., stacked flexible couplings) should not be used

D. Provide an FM Approved flexible loop that allows adequate deflection capacity at either the top or bottom of the drop

3.1.11 Commentary for 2.2.1.6.2

Suspended ceilings can swing during an earthquake and impact sprinklers or pipe drops to sprinklers that are within or that penetrate the ceiling. The use of flexible hose connections to the sprinklers does not negate the need for bracing of a suspended ceiling; these flexible hoses are designed assuming they are installed in braced ceilings. Ceilings that are not suspended (e.g., gypsum board applied under wood joists that span to wood walls) do not require bracing.

ASCE 7-10 provides guidance for earthquake protection of acoustical tile suspended ceilings. There are several requirements that need to be followed, as noted below. However, lateral restraint is mainly accomplished by providing, on 12 ft (3.7 m) centers and starting 6 ft (1.8 m) from walls, a brace assembly consisting of a vertical compression strut and four diagonal 12-gauge (0.106 in. [2.7 mm] diameter) steel splay wire braces (see Fig. 3.1.11). Each diagonal splay wire brace is positioned at a 45 degree angle (or more) from vertical, and the four wires are located 90 degrees apart in plan (i.e., so they resist forces in all horizontal directions).

The Seismic Design Category (SDC) is used in ASCE 7 as an indication of how extensive the seismic design must be for buildings and equipment. The SDC is based on the design spectral response acceleration parameters at a 0.2-second (short) period of vibration (i.e., S_{DS}) and at a 1-second period of vibration (i.e., S_{D1}). Generic values of S_{DS} and S_{D1} (expressed as a portion of the gravitational acceleration [g]) vs. the FM earthquake zone from Data Sheet 1-2 are repeated below:

- FM 50-year earthquake zone S_{DS} = 1.3(g) S_{D1} = 0.8(g)
- FM 100-year earthquake zone S_{DS} = 0.9(g) S_{D1} = 0.45(g)
- FM 250-year earthquake zone S_{DS} = 0.55(g) S_{D1} = 0.25(g)
- FM 500-year earthquake zone S_{DS} = 0.55(g) S_{D1} = 0.25(g)

SDC A and SDC B typically have few seismic design requirements for buildings or equipment. SDC C has many seismic requirements for buildings and requires bracing or anchorage of important equipment like fire protection systems. SDC D, SDC E and SDC F require full seismic design for buildings and most equipment. Per the ASCE 7 criteria, a facility will be at least in SDC D when either $S_{DS} \geq 0.5$(g) or $S_{D1} \geq 0.2$(g). Therefore, all facilities in FM 50-year through 500-year earthquake zones should be assumed to be at least SDC D and earthquake protection of suspended ceilings following SDC D guidelines in ASCE 7 would be appropriate.

The ASD horizontal load for suspended ceilings can be determined similarly to the method described for sprinkler piping in Section 3.1.6. Values of coefficients for ceilings differ from those applicable to sprinkler piping. For suspended ceilings, coefficients are: a_p = 1.0, R_p = 2.5 and Ip = 1.0. Substituting these values into the equation in Section 3.1.6 for F_p gives (for LRFD):

$$F_p = \frac{0.4 \cdot 1.0}{2.5}(3)\, S_{DS} \cdot 1.0 \cdot W_p = 0.48 \cdot S_{DS} \cdot W_p \qquad \text{(LRFD)}$$

ASD loads are 0.7 times LRFD loads, thus:

$$F_p = (0.7)\cdot(0.48)\cdot S_{DS}\cdot W_p = (0.336)\cdot S_{DS}\cdot W_p \qquad \text{(ASD)}$$

Essentially, the ASD horizontal loads for ceilings can be determined using half the "G" factors appropriate for sprinkler piping given in 2.2.1.2.2. That is, multiply the ceiling weight by:

- 0.45 in FM 50-year zones
- 0.32 in FM 100-year zones
- 0.2 in FM 250- and 500-year zones.

A 12-gauge wire oriented at 45 degrees can resist an ASD horizontal load of 150 lb (0.67 kN) based on its area (0.008825 in.^{2} [5.69 mm^2] multiplied by the allowable stress (0.4F_u, where the tensile strength [F_u] is 60,000 psi [414 MPa]) multiplied by sin 45°. Therefore, 12-gauge splay wires with compression strut assemblies at 12 ft (3.7 m) on center can brace ceilings having weights up to:

- 2.3 psf (110 N/m^2) in FM 50-year zones
- 3.3 psf (160 N/m^2) in FM 100-year zones
- 5.2 psf (250 N/m^2) in FM 250- and 500-year zones.

Heavier ceilings would require that bracing assemblies be spaced closer together, or would require the use of larger wires. For example, 10-gauge (0.135 in. [3.4 mm] diameter) wire can resist an ASD horizontal load of 240 lb (1.07 kN) or 60% more than a 12-gauge wire.

From ASCE 7 and its referenced ASTM International (ASTM) standards: ASTM C635 (*Standard Specification for the Manufacture, Performance, and Testing of Metal Suspension Systems for Acoustical Tile and Lay-in Panel Ceilings*), ASTM C636 (*Standard Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels*) and Section 5 (covering SDC D, E, and F) of ASTM E580 (*Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions*), key requirements for seismic protection of suspended acoustical tile ceilings include the following:

A. Ceilings up to 144 ft^2 (13.4 m^2)

1. No requirements if surrounded by walls or soffits that are laterally braced to the structure. Otherwise, bracing may be needed.

B. Ceilings greater than 144 ft^2 (13.4 m^2) and up to 1000 ft^2 (92.9 m^2)

1. Grid must be heavy duty as defined in ASTM C635

2. Strength of main tee connections and cross tee intersection connections must be at least 180 lb (0.8 kN)

3. Vertical hanger wires must be at least 12 gauge (0.106 in. [2.7 mm] diameter) at a maximum of 4 ft (1.2 m) on center. The hanger wire is attached to the structure with a connection capable of resisting at least 100 lb (0.44 kN) and the free end of the wire is wrapped around the vertical wire with three turns in 3 in. (75 mm) or less to secure it.

4. Perimeter closure moldings must be at least 2 in. (50 mm) wide unless a smaller width is approved. Two adjacent sides of the ceiling grid must be attached to the wall or perimeter closure. The other two adjacent sides must allow at least ¾ in. (19 mm) movement toward or away from the wall. At a distance not exceeding 8 in. (203 mm) from the wall, the perimeter tees must be supported by vertical hanger wires and tied together to prevent spreading.

5. Light and mechanical fixtures must be positively attached to the grid. A slack safety wire (12 gauge [0.106 in. (2.7 mm) diameter]) to the structure must be provided on light fixtures weighing up to 10 lb (4.5 kg). Two slack safety wires are required on larger light fixtures weighing up to 56 lb (25.4 kg) and on mechanical fixtures weighing 20 to 56 lb (9.1 to 25.4 kg). Heavier fixtures must be independently supported by hangers from the structure.

6. Sprinkler penetrations must allow for 1 in. (25 mm) movement in any direction unless an integral ceiling sprinkler system (e.g., incorporating flexible sprinkler drops) is designed.

7. Partitions must not be braced to the suspended ceiling.

8. Lateral bracing (e.g., splay wires and compression struts) is not required if all other requirements above are met.

C. Ceilings greater than 1000 ft^2 (92.9 m^2) and up to 2500 ft^2 (232 m^2)

1. In addition to the above, lateral bracing (e.g., splay wires and compression struts) with minimum brace connection strength of 250 lb (1.1 kN) are required within 2 in. (50 mm) of main tee/cross tee intersections, located at 12 ft (3.7 m) on center, starting 6 ft (1.8 m) from walls. Steel splay wires must be at least 12 gauge (0.106 in. [2.7 mm] diameter). Aside from the 250 lb (1.1 kN) strength requirement, splay wire end connections are not specified, however, common details (see Fig. 3.1.11) suggest four tight wraps of the end of the wire around the brace wire within 1½ in. (40 mm) will develop this force (note that vertical hanger wires are specified above to be wrapped with three turns to develop at least 100 lb [0.44 kN], and Fig. 3.1.11 also shows three turns for these vertical hanger wires).

D. Ceilings greater than 2500 ft^2 (232 m^2)

1. Seismic separation joints allowing at least ¾ in. (19 mm) axial movement, or full height partitions breaking the ceiling up into areas not exceeding 2500 ft^2 (232 m^2) each with a ratio of the long to short dimension of 4 or less, are required.

3.1.12 Commentary for 2.2.1.7.2

When it is not possible to avoid the use of a plain-end fitting in areas that are highly susceptible to water damage (e.g., cleanrooms), a method to prevent separation of the pipe at the fitting should be considered. One option would be to provide a pipe clamp on either side of the fitting connected by rods (see Fig. 3.1.12).

3.1.13 Commentary for 2.2.1.9.1

Sprinkler pipe is most commonly made of steel; this is therefore the material for which most sprinkler pipe earthquake performance data are available. The earthquake performance of steel piping braced in accordance with traditional requirements (e.g., lateral braces and four-way braces spaced at 40 ft [12.2 m]) has generally been good. It is therefore judged that the earthquake performance of other metal piping will likely be satisfactory if it is designed such that: (1) pipe deflections under lateral forces are reasonably similar to those of steel pipe; and (2) the ratio of actual longitudinal stress in the pipe (due to internal water pressure plus bending under gravity forces plus bending under lateral forces) to allowable longitudinal stress is similar to the ratio for steel and reasonable for the material being used.

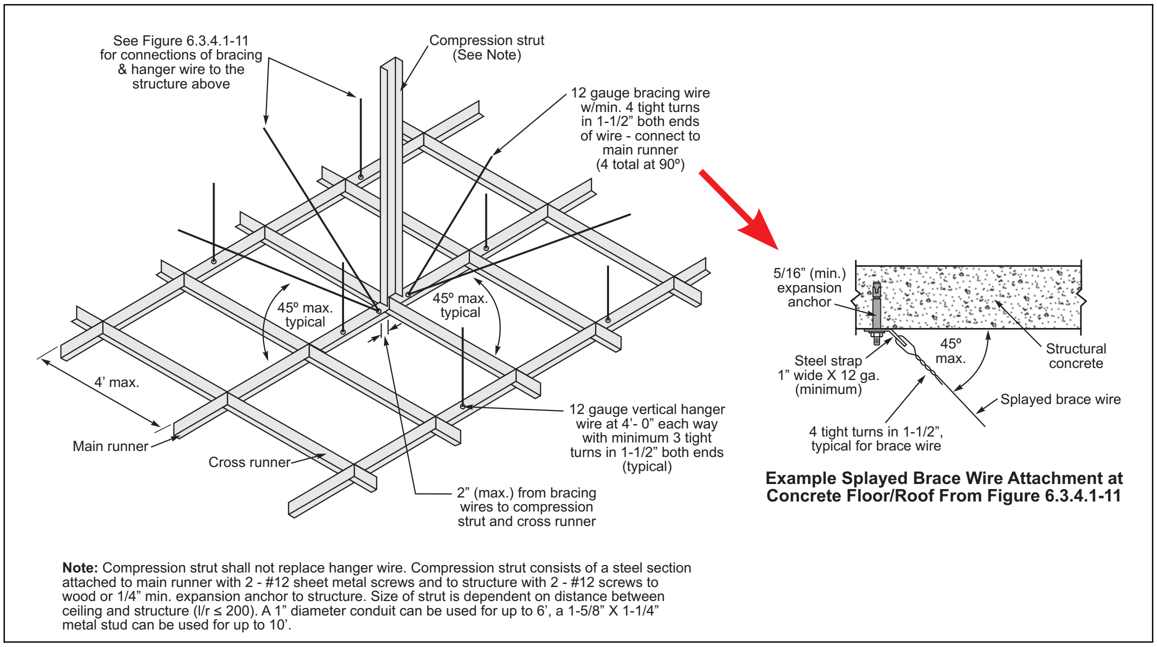


Fig. 3.1.11. Example of a lateral splay wire bracing assembly on a suspended acoustic lay-in panel ceiling (source: FEMA E-74, December 2012, Figure 6.3.4.1-9 and Figure 6.3.4.1-11)

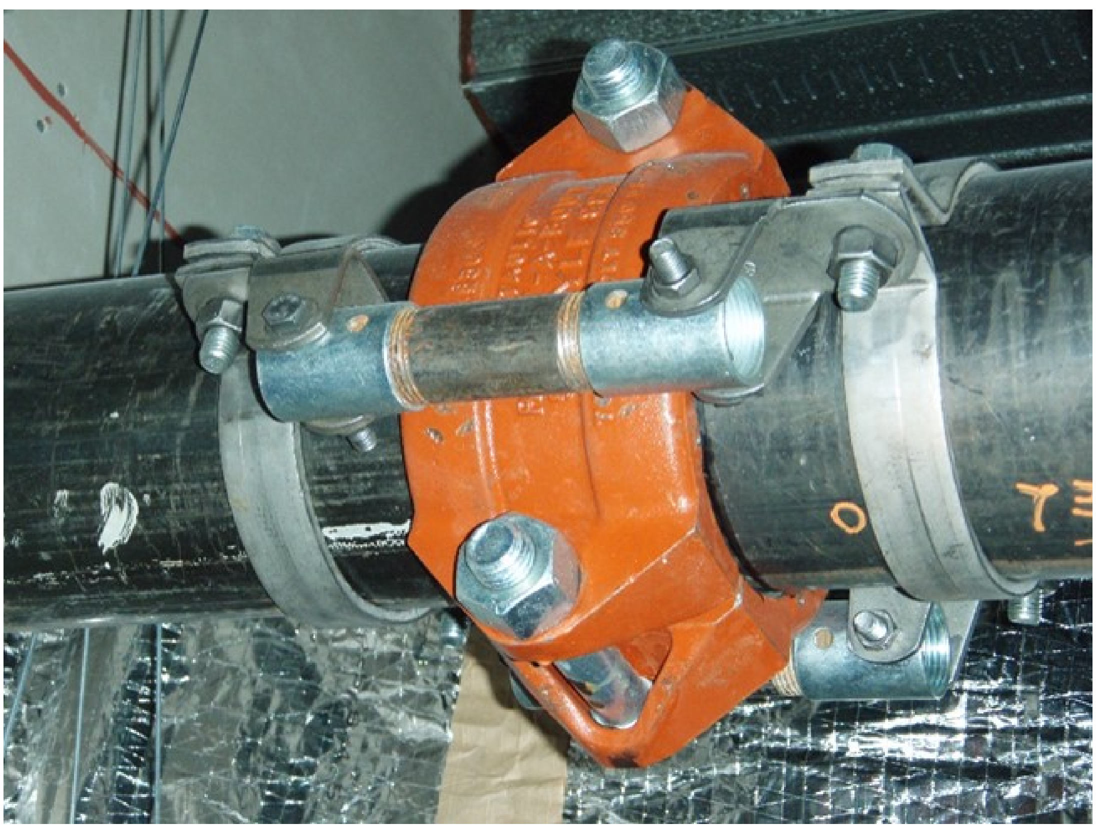


Fig. 3.1.12. Example of strengthening weak pipe connections (e.g., plain-end fittings) to prevent separation

Other common metal pipe materials (e.g., copper) have properties that vary from those of steel pipe. For example, the water-filled weight per unit length (w_p) of Type M copper pipe is roughly 40-65% of w_p for Schedule 40 steel pipe, depending on pipe diameter. The modulus of elasticity (E), upon which deflection depends, of copper (17,000,000 psi [117,200 MPa]) is about 60% of that for steel (29,000,000 psi [200,000 MPa]). The tensile strength (F_u) of copper pipe is about 60% of F_u for steel pipe (common F_u values are 36,000 psi [250 MPa] for copper vs. 58,000 psi [400 MPa] for steel). The ratio of F_u also implies that the allowable longitudinal stress for copper pipe is about 60% of the allowable longitudinal stress for steel. This comparison is based on assuming an allowable stress equal to $0.25 \cdot F_u$, resulting in allowable longitudinal stress of 9000 psi (62 MPa) for copper and 15,000 psi (103 MPa) for steel. Note that for steel structural design (e.g., building members), allowable longitudinal stress is typically based on the yield stress (F_y) and has traditionally been taken as about $0.60 \cdot F_y$ (tension loads) to $0.66 \cdot F_y$ (bending), or 18,000 psi (124 MPa) to 24,000 psi (165 MPa) for F_y in the range of 30,000 to 36,000 psi (210 to 250 MPa). However, for consistency in comparing different pipe materials, allowable longitudinal stresses equal to $0.25 \cdot F_u$ will be adopted here.

Assuming the horizontal earthquake force is applied as a uniformly distributed load along the length of pipe between lateral braces, the pipe lateral deflection (Δ) is proportional ($\propto$) to w_p, E, cross sectional moment of inertia (I) and the distance between braces (L) as shown below:

$$\Delta \propto \frac{w_p L^4}{EI}$$

In order to have similar deflections of copper pipe and steel pipe of the same diameter, the length between lateral braces on copper piping (L_{Copper}) can be estimated relative to the length between lateral braces on steel piping (L_{Steel}) by:

$$L_{Copper} = L_{Steel} \cdot \sqrt[4]{\left(\frac{w_{pSteel}}{w_{pCopper}}\right)\left(\frac{E_{Copper}}{E_{Steel}}\right)\left(\frac{I_{Copper}}{I_{Steel}}\right)}$$

Comparing Type M copper pipe to the same diameter Schedule 40 steel pipe, assume the weight per unit length (w_p) for steel is twice w_p of copper, E for steel is 1.7 times E for copper, and I for steel is 3.5 times I for copper. For this condition, the distance between lateral braces on copper pipe would need to be about 75% of the distance between lateral braces on steel pipe to result in the same deflection (i.e., 30 ft [9.1 m] instead of 40 ft [12.2 m]).

Maximum lateral brace spacing may also be controlled by bending stresses in the pipe resulting from horizontal earthquake forces. In a pipe where contents are under pressure, as little as half of the total allowable longitudinal stress is available to resist bending since longitudinal stresses caused by internal pressure will already be present. Longitudinal stresses due to internal pressure are half of the hoop stresses caused by this pressure, therefore, for a pipe sized such that hoop stresses are at the maximum allowed, half of the total allowable longitudinal stress is already used. For comparison purposes then, bending stresses should be limited to half of 15,000 psi (103 MPa) for steel pipe and half of 9000 psi (62 MPa) for copper pipe. Since gravity bending moments stress different fibers than lateral bending moments, these two loads are assumed to be independent from each other.

Using the “G” factor discussed in 2.2.1.2, lateral braces spaced “L” apart and assuming that the lateral force is applied as a uniformly distributed load, the bending moment (M) in the pipe from horizontal earthquake forces is given by $M=0.1 \cdot G \cdot w_p \cdot L^2$ and the bending stress would be this moment divided by the section modulus (S) of the pipe.

When the lateral forces are taken as half the weight of the water-filled pipe, bending stress in 2-1/2 in. (65 mm) diameter steel pipe approaches the assumed allowable (i.e., 7500 psi [52 MPa]). In order to limit bending stresses in 2½ in. (65 mm) diameter copper pipe to 4500 psi (31 MPa), the spacing limitation for lateral braces needs to be about 25 ft (7.6 m). This is therefore the maximum spacing for lateral and riser sway bracing adopted for copper piping in 2.2.1.9.1.

3.1.14 Commentary for 2.2.1.9.2

CPVC piping has properties that differ substantially from steel (and other metal) piping. The water-filled weight (w_p) of Schedule 40 CPVC pipe is roughly 35-50% of w_p for Schedule 40 steel pipe, which is reasonably similar to the difference in weight of copper vs. steel pipe as discussed in Section 3.1.13. However, F_u, and therefore the allowable longitudinal stress, for CPVC pipe is in the range of 8,000 psi (55 MPa), which is only about 15% of F_u for steel pipe. More importantly, steel pipe is about 70 times as stiff as CPVC pipe based on the modulus of elasticity (E), which is about 415,000 psi (2,860 MPa) for CPVC pipe vs. 29,000,000 psi (200,000 MPa) for steel pipe.

There is relatively little history with respect to earthquake performance of CPVC piping and the large differences in material properties (particularly the modulus of elasticity, resulting in CPVC pipe deflections much larger than those of steel pipe) make determining the performance of CPVC piping during earthquakes uncertain. Therefore, at this time use of CPVC pipe above grade is not allowed in earthquake zones.

3.2 Loss History

Although the primary goal of the guidance in this data sheet is to minimize the probability that fire protection systems will be impaired and unavailable to control post-earthquake fires, loss history related to fire protection systems damaged by earthquakes shows that deficiencies in earthquake protection primarily result in losses from water damage. Thus, the information below relates to water damage loss. Loss history with respect to fire following earthquake is presented in Data Sheet 1-11, *Fire Following Earthquake.* Damage to, or caused by, non-fire protection system components or equipment is not addressed here.

Based on FM experience, and confirmed by data from outside sources (e.g., *Analysis of Fire Sprinkler System Performance in the Northridge Earthquake,* NIST-GCR-98-736, January 1998), primary causes of the majority of water damage losses are:

A. Broken above-ground fire protection system piping due to lack of bracing, flexibility, and clearance to other structures or equipment, or failure of weak hanger attachments (e.g., powder-driven fasteners or C-clamps without retaining straps)

B. Broken sprinklers below suspended ceilings due to unbraced ceilings and/or armovers with excessive unsupported cantilever, or due to impact with roof structural members or other unrestrained nonstructural elements

C. Broken above-ground fire protection system piping resulting from excessive movement or overturning of storage racks having in-rack sprinkler systems

Water damage related to other fire protection system components, such as pumps, tanks, and reservoirs, has been relatively small. However, when adequate earthquake protection is not present, these components frequently sustain major damage (e.g., buckling or tearing of unanchored ground-supported suction tank walls) that can create significant impairments to the overall fire protection system.

The primary conclusions that can be derived from past experience are the following:

A. Providing sway bracing, flexibility, and clearance where needed for sprinkler systems, and providing adequate hanger attachments, will greatly reduce the potential for water damage from pipe breakage or separation during an earthquake, while also greatly increasing the odds that the system will remain intact and operational after an earthquake.

B. Bracing suspended ceilings will greatly reduce the potential for broken sprinklers or broken connections where the pipe drops connect to the overhead piping. A large number of losses have occurred in department stores and offices that had suspended ceilings in most areas.

C. Restraining branch lines (e.g., through the use of wraparound U-hooks as pipe hangers when U-hook-type hangers are necessary) at their free end and where they are in close proximity to structural or nonstructural elements will greatly reduce the potential for damage to sprinklers due to differential movement between the sprinkler piping and the structural or nonstructural elements.

D. Restraining other items to prevent water damage (e.g., storage racks with in-rack sprinklers) and/or impairment of the fire protection system (e.g., suction tanks and controllers) is important at sites where these items exist.

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-11, *Fire Following Earthquake*
Data Sheet 1-56, *Cleanrooms*

Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 3-2, *Water Tanks for Fire Protection*
Data Sheet 3-4, *Embankment-Supported Fabric Tanks*
Data Sheet 3-6, *Lined Earth Reservoirs for Fire Protection*
Data Sheet 7-7, *Semiconductor Fabrication Facilities*
FM Approval Standard Class Number 1637, *Approval Standard for Flexible Sprinkler Hose with Threaded End Fittings*
FM Approval Standard Class Number 1950, *Approval Standard for Seismic Sway Braces for Pipe, Tubing and Conduit*
FM Approval Standard Class Number 4020, *Approval Standard for Steel Tanks for Fire Protection*
Approval Guide, an online resource of FM Approvals

4.2 Other

American Concrete Institute (ACI). *Building Code Requirements for Structural Concrete and Commentary*. Standard ACI 318.

American Concrete Institute (ACI). *Qualification of Post-Installed Adhesive Anchors in Concrete and Commentary*. Standard ACI 355.4.

American Concrete Institute (ACI). *Qualification of Post-Installed Mechanical Anchors in Concrete and Commentary*. Standard ACI 355.2.

American Institute of Steel Construction (AISC). *Specification for Structural Steel Buildings*. Standard AISC 360.

American Society of Civil Engineers (ASCE). *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. Standard ASCE 7.

American Society of Civil Engineers (ASCE). *Structural Applications of Steel Cables for Buildings*. Standard ASCE 19.

American Water Works Association (AWWA). *Factory Coated Bolted Steel Tanks for Water Storage*. Standard AWWA D103.

American Water Works Association (AWWA). *Welded Steel Tanks for Water Storage*. Standard AWWA D100.

American Welding Society (AWS). *Structural Welding Code - Steel*. Standard ANSI/AWS D1.1.

American Wood Council (AWC). *National Design Specification (NDS) for Wood Construction*. Standard ANSI/AWC NDS.

ASTM International (ASTM). *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions*. Standard ASTM E580.

ASTM International (ASTM). *Standard Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels*. Standard ASTM C636.

ASTM International (ASTM). *Standard Specification for the Manufacture, Performance, and Testing of Metal Suspension Systems for Acoustical Tile and Lay-in Panel Ceilings*. Standard ASTM C635.

Federal Emergency Management Agency (FEMA). *Reducing the Risks of Nonstructural Earthquake Damage - A Practical Guide*. FEMA E-74.

National Fire Protection Association (NFPA). *Standard for the Installation of Sprinkler Systems*. NFPA 13.

National Institute of Standards and Technology (NIST), U.S. Department of Commerce. *Analysis of Fire Sprinkler System Performance in the Northridge Earthquake*. NIST-GCR-98-736.

APPENDIX A GLOSSARY OF TERMS

Allowable Stress Design (ASD): A method of designing structural members such that computed stresses produced by normal gravity design loads (e.g., the weight of the building and usual occupancy live loads) do not exceed allowable stresses that are typically below the elastic limit of the material (e.g., in steel these are typically well below the yield stress, Fy). Although not common currently, in the past normal allowable stresses were often increased by a factor (often a one-third increase was used) when design included extreme environmental loads such as earthquakes. (Also called working stress design or elastic design).

Elastic: A mode of structural behavior in which a structure displaced by a force will return to its original state upon release of the force.

Elastic design: See Allowable Stress Design

FM Approved: Products or services that have satisfied the criteria for FM Approval. Refer to the Approval Guide, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Four-way bracing: Sway bracing intended to resist differential movement of the piping system in all horizontal directions. Most often used on vertical pipe. When applied to horizontal piping, it is essentially a lateral and a longitudinal brace in the same location

Importance factor: A factor used in building codes to increase, for example, the usual wind or earthquake design forces for important or essential structures or equipment, tending to make them more resistant to those phenomena.

Lateral brace: A sway brace intended to resist differential movement perpendicular to the axis of a horizontal pipe. Sometimes referred to as a transverse brace.

Load and Resistance Factor Design (LRFD): A method of designing structural members such that computed stresses produced by service design loads multiplied by load factors do not exceed the theoretical nominal member strength multiplied by a strength reduction (resistance) factor. (Also called strength design or ultimate strength design).

Longitudinal brace: A sway brace intended to resist differential movement parallel to the axis of a horizontal pipe.

Powder-driven fastener: A fastener (alternatively known as a power-driven fastener, an explosive-driven fastener, a powder-actuated fastener or a gas-actuated fastener) that is shot (propelled) into a concrete or steel base, usually by the explosion of chemicals (e.g., gun powder) in a small cartridge, similar to the process that discharges a firearm. The end entering the concrete or steel is similar in shape to a wood nail and resists forces via friction between the fastener and the base material.

Steel, light-gauge: Steel that is less than 0.1046 in. (2.65 mm) thick (i.e., 13 to 30 gauge). Larger gauge numbers equate to thinner steel (e.g., uncoated 20-gauge steel is 0.0359 in. [0.91 mm] thick). Light-gauge members (e.g., steel “C” or “Z” roof purlins or wall studs) are usually cold-formed.

Strength Design: See Load and Resistance factor design.

Sway brace: An assembly, consisting typically of a pipe-attached component, a brace member and structure-attached component, used to resist the seismic forces imparted to the sprinkler system and prevent excessive differential movement of the piping system.

Transverse brace: See Lateral Brace.

Two-way bracing: Either lateral or longitudinal sway bracing intended to resist the perpendicular or the parallel two-way differential movement with respect to the axis of a horizontal pipe. Where a single sway brace acts as a two-way brace, it must resist both tension and compression forces. .

Ultimate Strength Design: See Load and Resistance Factor Design.

Working Stress Design: See Allowable Stress Design.

Yield stress: The stress (usually designated by F_y) at which there is a decided increase in the deformation or strain without a corresponding increase in stress. The strain is inelastic resulting in permanent deformation.

APPENDIX B DOCUMENT REVISION HISTORY

October 2017. This data sheet has been revised with editorial corrections and clarifications throughout, as well as several technical changes. The most significant editorial and technical changes are enumerated below.

A. Editorial corrections and clarifications

1. Revised Section 1.0, Scope.
2. Added Section 1.1, Hazards.

3. Relocated and updated substantial amounts of text, along with supporting tables and figures, from Section 2.0, Loss Prevention Recommendations into Section 3.1 as commentary. Commentary is provided for:

a. Section 2.1, Introduction

b. Section 2.2.1.1, Sway Bracing Locations for Steel Piping (Recommendations 2.2.1.1.1, 2.2.1.1.2, 2.2.1.1.4)

c. Section 2.2.1.2, Horizontal Seismic Loads for Sway Bracing Design (Recommendations 2.2.1.2.1, 2.2.1.2.2, 2.2.1.2.3)

d. Section 2.2.1.3, Configuration and Design of Sway Bracing (Recommendations 2.2.1.3.5, 2.2.1.3.6)

e. Recommendation 2.2.1.4.8 (flexibility across seismic separations and between independent structures)

f. Recommendation 2.2.1.6.2 (restraint of suspended ceilings)

g. Recommendation 2.2.1.7.2 (plain end fittings)

h. Section 2.2.1.9, Pipe Material Other Than Steel (Recommendations 2.2.1.9.1, 2.2.1.9.2)

4. Updated Section 2.1, Introduction; Section 4.0, References; Appendix A, Glossary of Terms; and Appendix C, Supplemental Information.

5. Renumbered all tables and relocated most tables that were in Section 2.0 to Section 3.1. Clarifications were added to Table 3.1.5 (old Table 1), and to Table 3.1.9-G and Table 3.1.9-H (old Table 15 and Table 16).

B. Technical Revisions

1. Revised the clearance requirements that allow a structural floor to be considered as a four-way brace for a riser or vertical pipe (Recommendation 2.2.1.1.2.2).

2. Added a requirement for lateral restraint at ends of branch lines that do not require bracing (Recommendation 2.2.1.1.6).

3. Revised the minimum “G” factors used to determine horizontal design loads for sway braces (Recommendation 2.2.1.2.2 and its commentary in Section 3.1).

4. Provided guidance on sizing steel U-bolts used as braces (Recommendation 2.2.1.3.2).

5. Added requirements for positioning sway braces on horizontal and vertical piping (Section 2.2.1.3.5 and its commentary in Section 3.1).

6. Added references for calculating capacities of attachments to structures and clarified types of structural members to which attachments should not be made (Recommendation 2.2.1.3.6). Revised Table 3.1.9-E and Table 3.1.9-F (old Table 13 and Table 14), reducing the maximum allowed horizontal loads for structure attachments using post-installed concrete anchors (to account for updated concrete expansion anchor capacities and the required overstrength factor [Ω_o] now included in ASCE 7).

7. Provided additional guidance regarding flexibility needed on pipe drops to racks and independent mezzanines (Recommendations 2.2.1.4.5.4 and 2.2.1.4.6.5 and the commentary in Section 3.1.10).

8. Added the option of using an FM Approved flexible pipe loop or other engineered method to accommodate differential movement across a building seismic separation or between buildings (Recommendation 2.2.1.4.8 and its commentary in Section 3.1).

9. Added statement allowing the use of FM Approved flexible sprinkler hose in suspended ceilings (Recommendation 2.2.1.5.3.1) and modified requirements for restraint of acoustical tile suspended ceilings having sprinklers (Recommendation 2.2.1.6.2 and its commentary in Section 3.1).

10. Noted that the use of FM Approved plain-end fittings may be disallowed by other data sheets and provided guidance where their use is unavoidable (Recommendation 2.2.1.7.2 and its commentary in Section 3.1).

11. Added a requirement that concrete anchors used for hangers be qualified for use in seismic applications (Recommendation 2.2.1.8.1.2).

12. Added guidance for earthquake protection of copper pipe (Recommendation 2.2.1.9.1 and its commentary in Section 3.1) and explanatory information on earthquake performance of CPVC pipe (commentary in Section 3.1 for Recommendation 2.2.1.9.2).

13. Added references to other data sheets having additional seismic design requirements for water storage tanks and reservoirs (Section 2.2.6).

14. Revised the changes needed to a NFPA 13-designed fire protection system (NFPA 13, 2016) in order for the installation to be considered essentially equivalent to the Data Sheet 2-8 provisions (Section 2.3.1.1).

15. Summarized data sheet recommendations in Table D.1, Outline of Data Sheet 2-8 Recommendations (job aid located in Appendix D).

16. Renumbered all figures and relocated many of the figures previously in Section 2.0 to Section 3.1. Extensively revised Fig. 2.2.1.3.5-A (combines old Fig. 3 and Fig. 5), Fig. 2.2.1.3.5-B (combines old Fig. 4 and Fig. 6), Fig. 2.2.1.3.6-A (combines old Fig. 14 and Fig. 15), Fig. 3.1.1-A (old Fig. 17), Fig. 3.1.9-B (old Fig. 9), Fig. 3.1.9-C (old Fig. 11), Fig. 3.1.9-D (old Fig. 13) and Fig. 3.1.9-G (previously unnumbered figure). Deleted old Fig. 8, Fig. 10 and Fig. 12. Added Fig. 2.2.1.3.5-C, Fig. 3.1.1-B, Fig. 3.1.1-D, Fig. 3.1.9-A, Fig. 3.1.9-E, Fig. 3.1.9-F, Fig. 3.1.10-B, Fig. 3.1.10-C, Fig. 3.1.11, and Fig. 3.1.12.

May 2010. This data sheet has been revised in its entirety to provide a consistent format. Editorial corrections (such as revising metric sizes) were made throughout the document. Several technical revisions were made as well, the most significant of which include the following:

- Clarified that design basis is Allowable Stress Design (Section 1.0).
- Changed the design coefficient “G” for FM Global 50-year, 250-year, and 500-year zones (Section 2.2.1.2.2).
- Modified information on attachments to concrete in Section 2.2.1.3.6.
- Added flexibility guidelines for unanchored suction tanks (Section 2.2.6.1.4).
- Added Section 2.3 regarding the use of other standards.
- Added references in Section 4.0.
- Added glossary terms to Appendix A.
- Relocated commentary to Appendix C.
- Updated Figs. 2-6, 8, 10, 12, 14-16, and 18-29.
- Revised brace capacities (Tables 2-7), wood through-bolt and lag-screw capacities (Tables 9-12) and concrete anchor capacities (Tables 13 and 14).
- Made minor revisions to Tables 1, 8, and 15-19.

January 2001. This revision of the document has been reorganized to provide a consistent format.

May 1999. The following major changes apply to May 1999 edition:

1. In certain cases, single diagonal sway bracing is now accepted without the need to address the net vertical uplift force component resulting from the horizontal seismic load. When the single brace angle from the vertical is such that one-half the weight of the piping within the zone of influence for that brace equals or exceeds the net vertical uplift force component, a single diagonal sway brace will suffice. For a “G” factor of 0.5, sway brace angles of 45 degrees or more from the vertical will qualify for this approach. For higher “G” factors, correspondingly higher sway brace angles from the vertical will be needed.

2. Tension-only sway bracing using brace members with an l/r = 300 or less is now accepted. In those cases two opposing diagonal braces are needed, and additionally, a vertical brace is needed to resist any net vertical uplift force component resulting from the horizontal seismic load.

3. Revised guidelines are provided for sway bracing for branch lines 2-½ in. (65 mm) and larger. Previously, sway bracing was recommended only for these branch lines on gridded sprinkler systems. Now, sway bracing

is needed for 2-½ in. (65 mm) and larger branch lines on all types of systems. These revised guidelines will apply to any branch lines or portion of branch lines that exceed 20 ft (6.1 m) in length for lateral sway bracing, and 25 ft (7.6 m) in length for longitudinal sway bracing.

4. A reference to “C” and “Z” purlins has been added in Section 2.2.1.1.2, **Step 4** to clarify that these structural members also need to be evaluated for acceptability as attachment points for sway bracing.

5. Additional guidance has been provided in Sections 2.2.1.2.2 and 2.2.1.2.3 to clarify the use of flexible couplings in multistory buildings or where piping passes through walls in relation to whether proper clearances are provided.

6. Section 2.2.1.4.8 has been revised to clarify that piping passing between two buildings that are not attached also needs a seismic separation assembly.

7. Section 2.2.1.4.1 has been revised to delete the recommendation for anchorage of riser stubs to underground elbows.

8. Section 2.2.1.6.1, item 4, has been revised to disallow the use of c-clamp hangers on purlins with upward lips.

9. Section 2.2.1.7 has been revised; it recommends against the use of non-metallic pipe in aboveground installations.

10. Section 5.2.2 is added to provide guidance for determining loss expectancies for water damage in multi-story buildings.

11. Tables C-5.2(a) through (d) have been simplified by clearly focusing on each deficiency for determining scenarios.

December 1998. This data sheet was issued superseding information contained in the FM Global Loss Prevention Handbook.

September 1998. This data sheet was converted to electronic format.

APPENDIX C SUPPLEMENTAL INFORMATION

Appendix C contains additional commentary and examples related to Section 2.0, Loss Prevention Recommendations.

C.1 General Concepts of Sway Bracing Design

There are four steps to properly design sway bracing:

- Step 1: Lay out sway bracing locations with respect to the sprinkler piping and to the structural members to which the bracing will be attached.
- Step 2: Calculate the seismic design load for the sway bracing locations.
- Step 3: Select the proper sway bracing shape, angle of attachment, size and maximum length based on the horizontal design load.
- Step 4: Select the proper method to attach the sway bracing to the structure and to the piping.

Step 1: Lay Out Sway Bracing Locations (Section 2.2.1.1)

Bracing is needed on all risers, feedmains and crossmains (i.e., regardless of size), and on those branch lines that are 2-½ in. (65 mm) and larger in diameter. For risers and overhead sprinkler piping, there are two sway bracing designs: two-way and four-way.

Two-way braces are either lateral or longitudinal, depending on their orientation with the axis of the horizontal pipe (see Fig. 2.2.1.3.5-A and Fig. 2.2.1.3.5-B). Lateral and longitudinal braces resist movement perpendicular and parallel, respectively, to the axis of horizontal pipe. When located close enough to a change in direction of the pipe, a lateral brace can also act as a longitudinal brace (and vice versa) for an attached perpendicular pipe of the same or smaller diameter.

Four-way sway bracing resists movement in all horizontal directions, and is typically provided on risers and drops. When located close enough to a change in direction of the pipe, a four-way brace on a vertical pipe can also act as a longitudinal and lateral brace for an attached horizontal pipe of the same or smaller diameter.

Four-way bracing on a horizontal pipe is simply a location where lateral and longitudinal sway bracing coincide. This four-way bracing may be used to satisfy lateral and longitudinal design requirements for horizontal piping at changes of direction.

A key concept is that, regardless of the direction the earthquake motion, the combination of lateral and longitudinal sway bracing that is properly located will result in a ***sway bracing system*** that has the best chance to minimize potential damage to the system. For example, if the lateral sway bracing is aligned in the north-south axis, and the longitudinal sway bracing is aligned in the east-west axis, an earthquake that creates movement in the northwest-southeast axis will require proper interaction of the entire ***sway bracing system*** to minimize potential damage. Neither the lateral nor longitudinal sway bracing by itself would be expected to handle non-axial seismic loading.

Sway bracing layout locations will usually need to coincide with the structural members to which the sway braces will be attached.

The maximum spacing between sway braces given in Section 2.2.1.1 may need to be reduced depending upon the actual seismic design load determined for each sway bracing location in Step 2.

Step 2: Calculate the Seismic Design Load for the Sway Bracing Locations (Section 2.2.1.2)

The design load for each sway bracing location is calculated by multiplying the cumulative total weight of the piping within the zone of influence for that bracing location times the appropriate horizontal acceleration "G" factor. The zone of influence for a sway bracing location includes all piping to be included in the load distribution calculation for that particular bracing location, based on the layout of all the bracing on the system. It is usually helpful to prepare a brace location schedule with the calculated loads to help with Steps 3 and 4. As a practical matter, braces are typically sized based on a few controlling zones of influence; a unique brace design is not used for every sway bracing location.

For example, assume Longitudinal Brace "B" on a 6 in. (150 mm) Schedule 10 feedmain between adjacent Longitudinal Braces "A" 80 ft (24.4 m) away on one side and "C" 60 ft (18.3 m) away on the other side. The tributary length for Longitudinal Brace "B" would be ½ x 80 ft (24.4 m) plus ½ x 60 ft (18.3 m) or 70 ft (21.3 m) total. 70 ft (21.3 m) of pipe has a total weight of 70 ft (21.3 m) x 23.0 lb/ft (338 N/m) = 1610 lb (7200 N). For a "G" factor of 0.75, 1610 lb (7200 N) x 0.75 = 1208 lb (5400 N), which is the horizontal design load for that sway bracing location.

The commentary in Section 3.1.7 provides guidance on the piping that should be included in the zone of influence for various brace configurations. Note that when a brace is used to restrain both the pipe upon which the brace is located as well as a perpendicular pipe (e.g., a riser and its connected main), the zone of influence includes tributary weights from both.

Step 3: Select the Proper Sway Bracing Shape, Size and Maximum Length (Section 2.2.1.3)

Actual design of sway bracing is based on the horizontal seismic load determined in Step 2. Acceptable sway bracing type, orientation, and attachment methods (to both the sprinkler pipe and the structure) need to simultaneously provide adequate resistance to both the horizontal seismic load and the *net* vertical uplift force component resulting from the horizontal seismic load minus any effective offset to that vertical force component due to sprinkler piping dead weight.

For sway bracing configurations using one diagonal compression brace, that brace and its fastener(s) must resist the full horizontal seismic design load (H). Likewise, for two opposing tension only diagonal braces, the full horizontal seismic design load (H) is distributed to each brace and its fastener(s) because neither brace is being considered as capable of resisting compression. For sway bracing configurations using two opposing tension and compression diagonal braces, the percent of the seismic load (H) based on proportional distribution, but not less than a minimum of one-half the horizontal seismic load (H/2), is distributed to each brace and its fastener(s). Using less than half of the horizontal seismic load (H) is undesirable because of the indeterminacy of the load at any given time and the criticality of successful brace and fastener performance to successful system performance.

Table 3.1.8-A through Table 3.1.8-F provide maximum lengths and allowable horizontal design loads for some common brace types. Other brace shapes can be used, but the maximum lengths and allowable horizontal design loads for these would need to be calculated.

Step 4: Select the Proper Method to Attach the Sway Bracing to the Structure and to the Piping (Section 2.2.1.3)

Proper attachment of sway bracing to the structure and to the piping is a critical performance point for the sway bracing system. In general, FM Approved proprietary manufactured connection hardware is used at the pipe (e.g., see Fig. 3.1.1-B) and at the structure (e.g., see Fig. 3.1.1-C).

The two primary recommendations to ensure proper attachment of the brace (usually via the FM Approved connector) to the structure are: 1) verify that the structural member to which the sway bracing is attached and the actual location of the attachment to that member have been determined by qualified personnel to be capable of withstanding the anticipated seismic load, and 2) verify that the fasteners used are capable of withstanding the anticipated seismic load and are properly installed.

The type of fastener used will depend on whether the sway bracing will be attached to wood, concrete or steel structural members, and to a certain extent on what type of brace is being used. Regardless of the type of structural member used as an attachment point, there are three possible fastener attachment configurations, all of which create different shear and tension loadings on the fastener. These configurations are shown in Fig. 3.1.9-G: Configuration 1-Fastener attached to the underside or side of the structural member with the horizontal seismic design load (H) applied parallel to the member, causing shear and tension in anchors; Configuration 2-Fastener attached to the side of the structural member with the horizontal seismic design load (H) applied perpendicular to the member, causing shear and tension in anchors; Configuration 3-Fastener attached to the face of the structural member with the horizontal seismic design load (H) applied parallel to the member, causing only shear in anchors.

These three fastener configurations are used with two possible sway bracing configurations (two opposing diagonal braces or one diagonal and one vertical brace). Fig. 3.1.9-A shows horizontal seismic loads for a single diagonal brace with a vertical brace. Fig. 3.1.9-B to Fig. 3.1.9-D show the corresponding derivation of shear and tension loading on fasteners to the structure, which are dependent on the calculated horizontal seismic design load (H) determined from Step 2, the brace angle from the vertical, and the fastener configuration. In Fig. 3.1.9-B to Fig. 3.1.9-D, seismic design load (H) is shown occurring in a direction to the left of the page, for the purpose of illustrating the derivation of shear and tension loading as a result of seismic load (H) in that direction. In an actual earthquake, the motion could also occur in the opposite direction (as shown in Fig. 3.1.9-A). Shear and tension load derivations will not change, but will change direction with a change in direction of seismic load (H).

Horizontal seismic loads where two diagonal tension-compression braces are used are shown for horizontal pipe in Fig. 3.1.9-E and for vertical pipe in Fig. 3.1.9-F. The corresponding derivation of shear and tension loads on fasteners are not shown, but would be determined in a manner similar to that used in Fig. 3.1.9-B to Fig. 3.1.9-D. Note, however that four-way braces on vertical pipe can be loaded in any horizontal direction, and anchor configuration will differ for the two primary perpendicular axes (i.e., anchor configuration for forces along the north-south axis will not be the same as anchor configuration for forces along the east-west axis).

For different brace shapes, attachment methods may vary. In general FM Approved proprietary manufactured connectors are used at the attachment to the structure (e.g., the special fitting as shown in Fig. 3.1.1-C) but in certain cases a brace, such as a steel angle oriented in Configuration 3, may have a hole for the fastener in the member itself. Wraparound U-hooks for use as lateral sway bracing on branch lines will generally have holes to accommodate the fastener. Rods and flats are not common for use due to length restrictions, but if used need an appropriate means to allow proper fastening to the structure.

Attachment to Wood Members. It is recommended that sway braces be connected to wood components with through-bolts whenever practicable because they provide a positive means of attachment, take advantage of the full strength of the wood member and can be visually verified in the field as to correct installation. When roof configuration or other factors make the use of through-bolts impractical, lag screws may be used but careful attention to correct installation practices is necessary to ensure proper performance. It should be noted that all values in Table 3.1.9-A through Table 3.1.9-D are derived from the *National Design Specification for Wood Construction*, American Wood Council, 2005 edition.

Attachment to Concrete Components. Several different types of post-installed concrete anchors are available, including expansion or wedge, sleeve, shell or drop-in, undercut and adhesive. Not all post-installed concrete anchors are appropriate for use in resisting seismic forces. In particular, powder-driven fasteners have not proven to be reliable due to their inability to remain in place during the dynamic loading that occurs during an earthquake.

Probably the most common type of post-installed concrete anchor is the expansion or wedge anchor. Capacities for these anchors must be determined for a service load (i.e., Allowable Stress Design [ASD]) condition. Currently, calculation of acceptable shear and tension loads is based on a very complex methodology (e.g., such as that found in ACI 318, *Building Code Requirements for Structural Concrete*) and depends on multiple variables (concrete strength, depth of embedment, edge distance, bolt spacing, placement of steel reinforcement, etc.). It is therefore difficult to provide generic capacities for post-installed anchors. FM Approved expansion anchors are rated on the basis of their capacity for use with sprinkler hangers of the same size, and may or may not be capable of resisting sway brace seismic loads.

Table 3.1.9-E (Table 3.1.9-F for SI units) provides maximum horizontal design loads for expansion or wedge anchors in 3000 psi (20.7 MPa) normal weight concrete, determined based on average anchor capacities across several manufacturers ((see table notes) for various configurations of the fastener with respect to the structural member and the angle of the brace from the vertical.

C.2 Examples of Sway Bracing Design

Figure C.2 shows a plan view of a building that has three separate occupancies and three types of sprinkler systems, which will all be used as examples to illustrate the concept of sway bracing design for sprinkler systems described in Section 2.2.1.1 through Section 2.2.1.3. All three risers are located in the same area, which would be typical when a single underground lead-in would be used to supply all the risers. Because of this arrangement, sway bracing considerations will have to address changes in directions and long feedmains for System Nos. 1 and 2. Note that the layout in the examples incorporates maximum allowable spacings between braces in some instances, and lesser spacings in others, with symmetrical zones of influence where possible. In reality, sway bracing locations will be determined equally by both the sway bracing location criteria in Section 2.2.1.1, and the locations of structural members that serve as the points of attachment for the sway bracing. Non-uniform spacings will commonly occur because of either of these considerations.

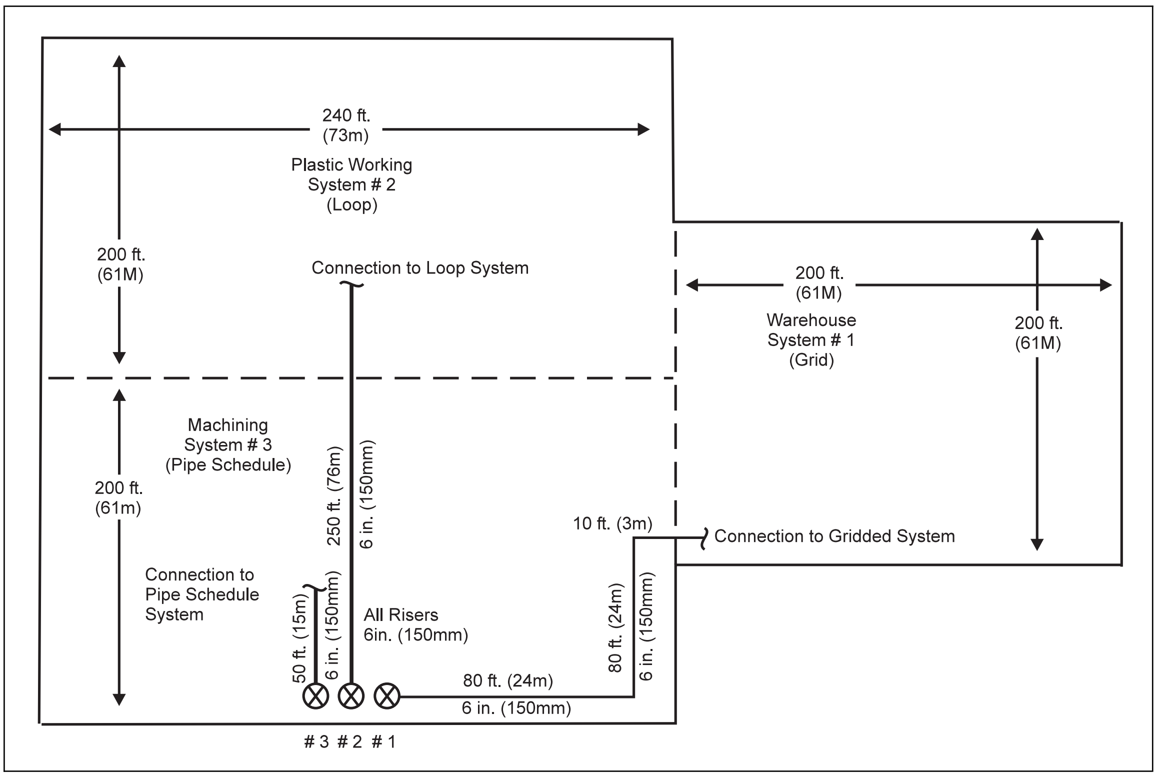


Fig. C.2. Example of building with three sprinkler risers and three types of sprinkler system configurations

C.2.1 Gridded System (System No. 1)

Step 1. Layout and orientation of braces. Fig. C.2.1-A shows the layout of the two-way lateral braces, and a four-way brace at the riser. Figure C.2.1-B shows the layout of the two-way longitudinal braces. In both figures, the dashed lines indicate the zone of influence for piping to be used to calculate horizontal seismic design load for each bracing location. In this example, the location of lateral and longitudinal sway bracing on

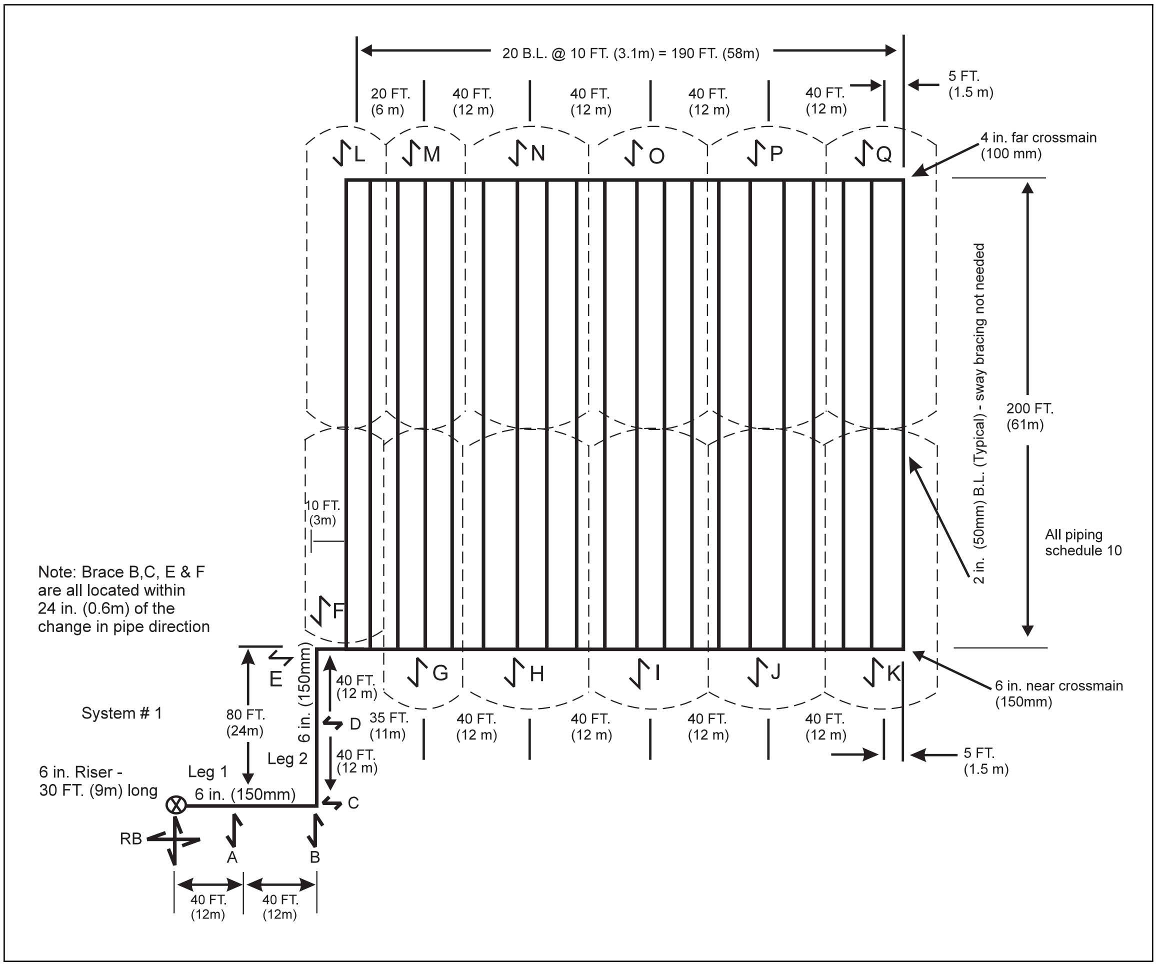


Fig. C.2.1-A. Layout and zones of influence for lateral and four-way riser sway bracing for System #1.

the actual piping grid is fairly straightforward. However, because of the long feedmain, and the changes in direction, lateral bracing is strategically located within 2 ft (0.6 m) of the changes of direction, and will be used both as lateral bracing on the pipe to which it is attached, and as longitudinal bracing for the run of piping after the change in direction. This will be illustrated in Step 2.

Step 2. Calculate design loads. In this example, a horizontal acceleration “G” factor = 0.5 (the “G” factor can vary - see 2.2.1.2.2) will be used for calculation purposes. Assume sprinkler piping is Schedule 10. Using weights per length of water-filled pipe from Table 3.1.5, horizontal seismic design loads for each sway bracing location can be determined as shown in Table C.2.1.

Step 3. Select the proper brace type, size, and maximum length. Based on the configuration of the brace connection to the structure, the angle of the brace , and the calculated horizontal design load, the brace type, size, and maximum length can be selected from Table 3.1.8-A through Table 3.1.8-F.

Step 4. Using the Step 2 design loads, and the brace angle, select an appropriate attachment to the pipe (e.g., an FM Approved manufactured pipe-attached component or a standard U-bolt) and the appropriate type (e.g., an FM Approved manufactured structure-attached component) and size of fastener for attachment to the building structure.

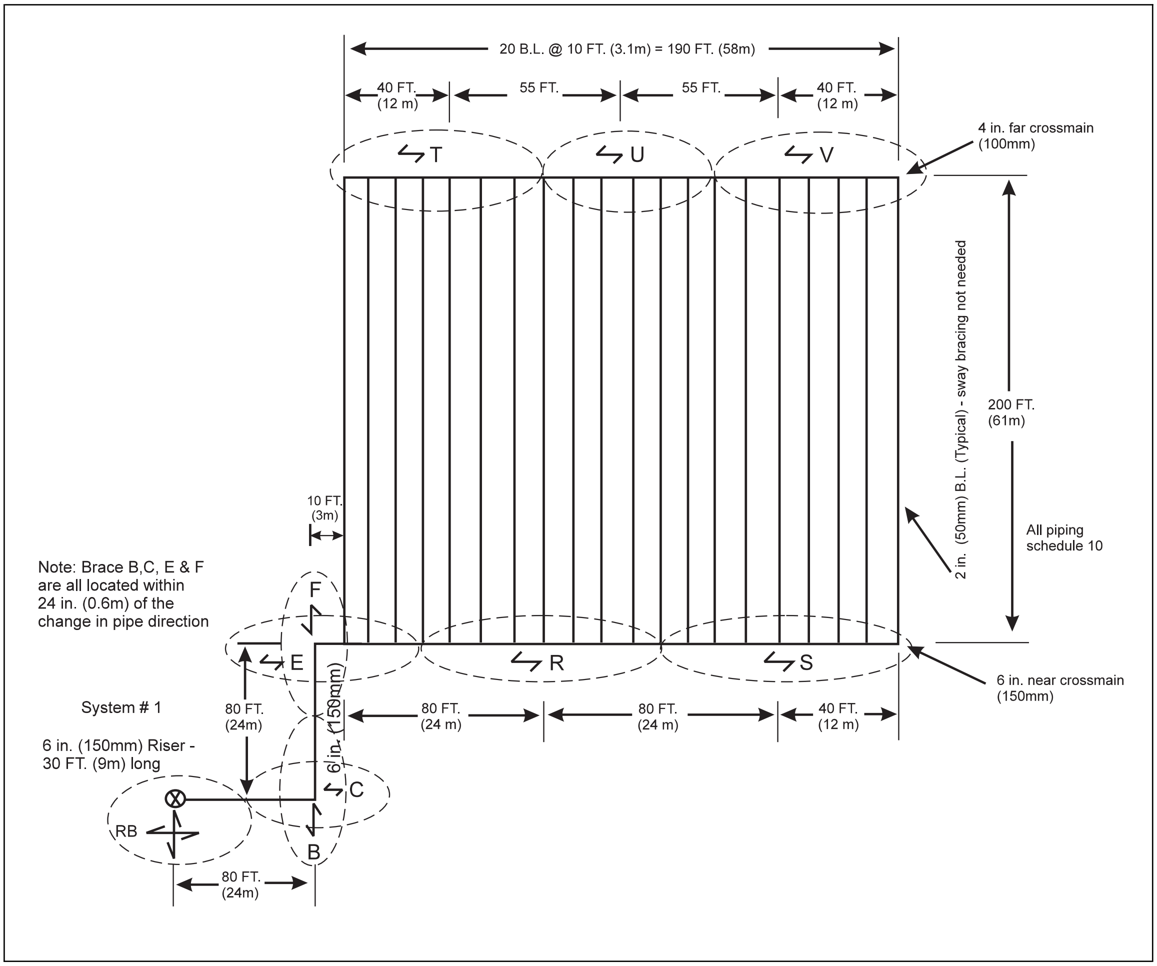


Fig. C.2.1-B. Layout and zones of influence for longitudinal and four-way riser sway bracing for System #1

Table C.2.1. Horizontal Seismic Design Loads for System No. 1.

Brace Location	*Nominal Diameter, in. (mm)*	*Number x Length, ft (m) x Weight/Length, lb/ft (N/m) x G =*	*Force, lb (N)*
1. Riser Bracing **(RB)**			
Lateral	6	1 x 15 x 23.0 x 0.5	= 175 lb
	(150)	(1 x 4.6 x 338 x 0.5)	= (780 N)
	6	1 x 20 x 23.0 x 0.5	= 230
	(150)	1 x 6.1 x 338 x 0.5	= (1030)
			= 405 lb
			= (1810 N)
Longitudinal	6	1 x 15 x 23.0 x 0.5	= 175 lb
	(150)	(1 x 4.6 x 338 x 0.5)	= (780 N)
	6	1 x 40 x 23.0 x 0.5	= 460
	(150)	(1 x 12.2 x 338 x 0.5)	= (2060)
			= 635 lb
			= (2840 N)

(The riser bracing will need to be designed to withstand simultaneously a 405 lb [1810 N] lateral and 635 lb [2840 N] longitudinal horizontal seismic load.)

2. Feedmain Bracing			
A-lateral	6	1 x 40 x 23.0 x 0.5	= 460 lb
	(150)	(1 x 12.2 x 338 x 0.5)	= (2060 N)
B-lateral	6	1 x 20 x 23.0 x 0.5	= 230 lb
(on leg 1)	(150)	(1 x 6.1 x 338 x 0.5)	= (1030 N)
longitudinal	6	1 x 40 x 23.0 x 0.5	= 460
(on leg 2)	(150)	(1 x 12.2 x 338 x 0.5)	= (2060)
			= 690 lb
			= (3090 N)

(Brace **B** is a lateral brace on leg 1, but is also acting as longitudinal brace for 40 ft [12.2 m] of leg 2 [assuming brace is located within 24 in. (0.6 m) of change in direction]. Thus, design should be for total of 690 lb. [3090 N].)

C-lateral	6	1 x 20 x 23.0 x 0.5	= 230 lb
(on leg 2)	(150)	(1 x 6.1 x 338 x 0.5)	= (1030 N)
longitudinal	6	1 x 40 x 23.0 x 0.5	= 460
(on leg 1)	(150)	(1 x 12.2 x 338 x 0.5)	= (2060)
			= 690 lb
			= (3090 N)

(Brace **C** is a lateral brace on leg 2, but is also acting as a longitudinal brace for leg 1 [assuming brace is located within 24 in. (0.6 m) of change in direction]. This design should be for total of 690 lb. [3090 N]).

D-lateral	6	1 x 40 x 23.0 x 0.5	= 460 lb
	(150)	(1 x 12.2 x 338 x 0.5)	= (2060 N)
E-lateral	6	1 x 20 x 23.0 x 0.5	= 230 lb
(on leg 2)	(150)	(1 x 12.2 x 338 x 0.5)	= (1030 N)
-longitudinal	6	1 x 40 x 23.0 x 0.5	= 460
(on near crossmain)	(150)	(1 x 12.2 x 338 x 0.5)	= (2060)
			= 690 lb
			= (3090 N)

(Brace **E** is a lateral brace on leg 2, and also acts as a longitudinal brace for 40 ft [12.2 m] of the near crossmain. Thus, design should be for total of 690 lb. [3090 N]).

F-longitudinal	6	1 x 40 x 23.0 x 0.5	= 460 lb
(on leg 2)	(150)	(1 x 12.2 x 338 x 0.5)	= (2060 N)
-lateral	6	1 x 17.5 x 23.0 x 0.5	= 200 lb
(on near crossmain)	(150)	(1 x 5.3 x 338 x 0.5)	= (895 N)
	2	2 x 100 x 4.2 x 0.5	= 420
	(50)	(2 x 31 x 62 x 0.5)	= (1922)
			= 1080 lb
			= (4877 N)

(Brace **F** is a longitudinal brace for leg 2, and also a lateral brace for 17.5 ft [5.3 m] of crossmain and two branchline on the near crossmain. Design is for total of 1080 lb [4877 N]).

3. Crossmain Bracing

K-lateral	6	1 x 25 x 23.0 x 0.5	= 288 lb
	(150)	(1 x 7.6 x 338 x 0.5)	= (1284 N)
	2	3 x 100 x 4.2 x 0.5	= 630
	(50)	(3 x 31 x 62 x 0.5)	= (2883)
			= 918 lb
			= (4167 N)
Q-lateral	4	1 x 25 x 11.8 x 0.5	= 148 lb
	(100)	(1 x 7.6 x 173 x 0.5)	= (657 N)
	2	3 x 100 x 4.2 x 0.5	= 630
	(50)	(3 x 31 x 62 x 0.5)	= (2883)
			= 778 lb
			= (3450 N)

(Braces **K** and **Q** are provided at ends of crossmain to laterally brace crossmain and branchlines in zone of influence, with design loads as indicated.)

L-lateral	4	1 x 15 x 11.8 x 0.5	= 89 lb
	(100)	(1 x 4.6 x 173 x 0.5)	= (398 N)
	2	2 x 100 x 4.2 x 0.5	= 420
	(50)	(2 x 31 x 62 x 0.5)	= (1922)
			= 509 lb
			= (2320 N)

(Brace **L** is also an end-of-crossmain brace, with a combined crossmain/branchline design of 509 lb [2320 N].)

G-lateral	6	1 x 37.5 x 23.0 x 0.5	= 430 lb
	(150)	(1 x 11.4 x 338 x 0.5)	= (1927 N)
	2	3 x 100 x 4.2 x 0.5	= 630
	(50)	(3 x 31 x 62 x 0.5)	= (2883)
			= 1060 lb
			= (4810 N)
	4	1 x 30 x 11.8 x 0.5	= 177 lb
M-lateral	(100)	(1 x 9.1 x 173 x 0.5)	= (787 N)
	2	3 x 100 x 4.2 x 0.5	= 630
	(50)	(3 x 31 x 62 x 0.5)	= (2883)
			= 807 lb
			= (3670 N)

(Braces **G** and **M** are lateral braces which could be spaced up to 40 ft [12.2 m] apart, but because of sway bracing location layout, are bracing less than 40 ft [12.2 m] of crossmain and three branchline portions, with design loads as indicated)

H,I,J-lateral	6 (150)	1 x 40 x 23.0 x 0.5 (1 x 12.2 x 338 x 0.5)	= 460 lb = (2062 N)
	2 (50)	4 x 100 x 4.2 x 0.5 (4 x 31 x 62 x 0.5)	= 840 = (3844) = 1300 lb = (5906 N)
N,O,P-lateral	4 (100)	1 x 40 x 11.8 x 0.5 (1 x 12.2 x 173 x 0.5)	= 236 lb = (1055 N)
	2 (50)	4 x 100 x 4.2 x 0.5 (4 x 31 x 62 x 0.5)	= 840 = (3844) = 1076 lb = (4899 N)

(Braces **H, I, J, N, O** and **P** are lateral braces at maximum 40 ft [12.2 m] spacing, with crossmain/branchline portions and design loads as indicated.)

R,S-longitudinal	6 (150)	1 x 80 x 23.0 x 0.5 (1 x 24.4 x 338 x 0.5)	= 920 lb = (4124 N)
T,V-longitudinal	4 (100)	1 x 67.5 x 11.8 x 0.5 (1 x 20.6 x 173 x 0.5)	= 398 lb = (1782 N)
U, longitudinal	4 (100)	1 x 55 x 11.8 x 0.5 (1 x 16.8 x 173 x 0.5)	= 325 lb = (1453 N)

(Braces **R, S, T, U,** and **V** are longitudinal braces for crossmain portions, with the design loads indicated. Spacing between brace locations is nonuniform for the near and far crossmains because of the use of Brace E for a part of the longitudinal bracing for the near crossmain.)

C.2.2 Looped System (System No. 2)

Step 1. Layout and orientation of braces. Figure C.2.2-A shows the layout of the two-way lateral braces, and a four-way brace at the riser. Fig. C.2.2-B shows the layout of the two-way longitudinal braces. Dashed lines indicate the portion of the piping system (zones of influence) to be calculated for each bracing location.

Step 2. Calculate design loads. For the purpose of this example, assume a horizontal acceleration “G” factor = 0.5 (the “G” factor can vary see 2.2.1.2.2) to be applied to the weight of pipe within the zone of influence for each brace. Assume that sprinkler piping is Schedule 40. Using weights of water-filled pipe from Table 3.1.5, horizontal seismic design loads for each sway bracing location can be determined as shown in Table C.2.2.

Step 3. Select the proper brace type, size, and maximum length. Based on the configuration of the brace connection to the structure, the angle of the bracel, and the calculated horizontal design load, the brace type, size, and maximum length can be selected from Table 3.1.8-A through Table 3.1.8-F.

Step 4. Using the Step 2 design loads, and the brace angle, select an appropriate attachment to the pipe (e.g., an FM Approved manufactured pipe-attached component or a standard U-bolt) and the appropriate type (e.g., an FM Approved manufactured structure-attached component) and size of fastener for attachment to the building structure.

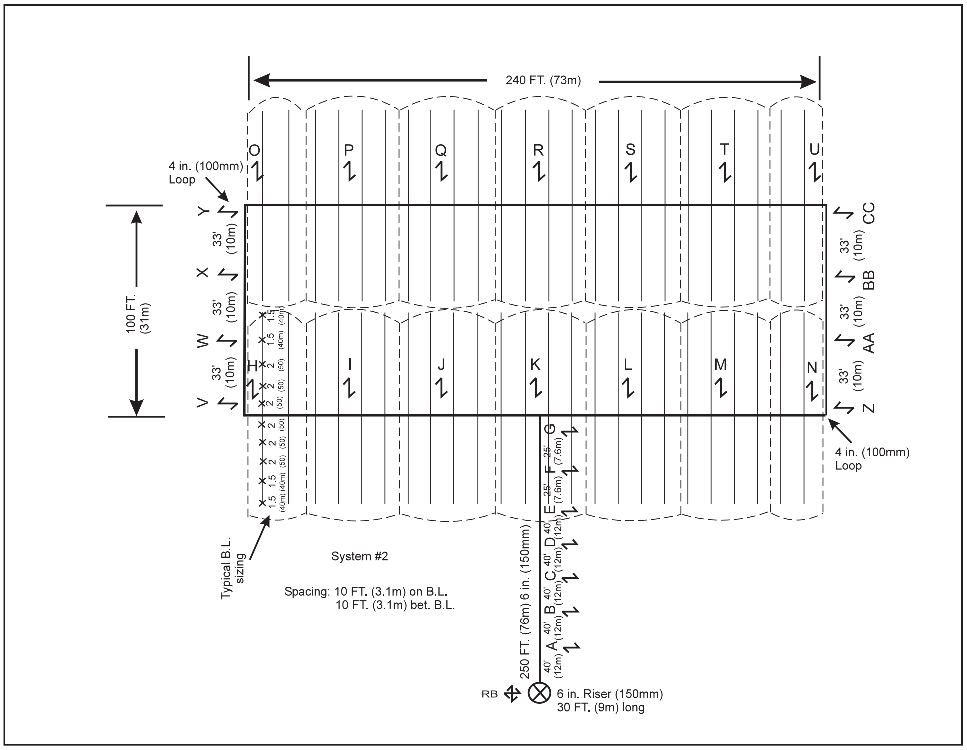


Fig. C.2.2-A. Layout and zones of influence for lateral and four-way riser sway bracing for System #2.

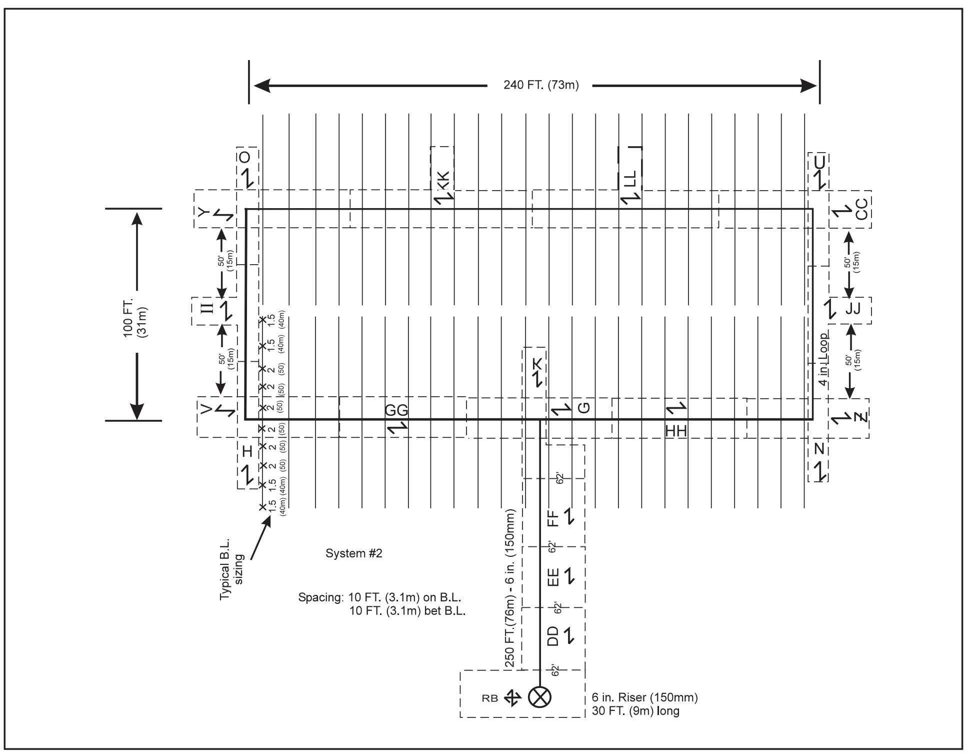


Fig. C.2.2-B. Layout and zones of influence for longitudinal and four-way riser sway bracing for System #2.

Table C.2.2. Horizontal Seismic Design Loads for System No. 2.

Brace Location	*Nominal Diameter, in. (mm)*	*Number x Length, ft (m) x Weight/Length, lb/ft (N/m) x G=*	*Force, lb (N)*
1. Riser Bracing **(RB)**			
Lateral	6	1 x 15 x 31.7 x 0.5	= 238 lb
	(150)	(1 x 4.6 x 465 x 0.5)	= (1070 N)
	6	1 x 20 x 31.7 x 0.5	= 317
	(150)	(1 x 6.1 x 465 x 0.5)	= (1418)
			= 555 lb
			= (2488 N)
Longitudinal	6	1 x 15 x 31.7 x 0.5	= 238 lb
	(150)	(1 x 4.6 x 465 x 0.5)	= (1070 N)
	6	1 x 31 x 31.7 x 0.5	= 491
	(150)	(1 x 9.5 x 465 x 0.5)	= (2209)
			= 729 lb
			= (3279 N)

(The riser bracing will need to be designed to withstand simultaneously a 555 lb [2488 N] lateral and 729 lb [3279 N] longitudinal horizontal seismic design load.)

2. Feedmain Bracing			
A,B,C,D- lateral	6	1 x 40 x 31.7 x 0.5	= 634 lb
	(150)	(1 x 12.2 x 465 x 0.5)	= (2837 N)
E-lateral	6	1 x 32.5 x 31.7 x 0.5	= 515 lb
	(150)	(1 x 9.9 x 465 x 0.5)	= (2302 N)
F-lateral	6	1 x 25 x 31.7 x 0.5	= 396 lb
	(150)	(1 x 7.6 x 465 x 0.5)	= (1767 N)
G-lateral	6	1 x 12.5 x 31.7 x 0.5	= 198 lb
(on feedmain)	(150)	(1 x 3.8 x 465 x 0.5)	= (884 N)
-longitudinal	4	1 x 60 x 16.4 x 0.5	= 492
(on crossmain)	(100)	(1 x 18.3 x 241 x 0.5)	= (2205)
			= 690 lb
			= (3089 N)

(Brace **G** is a lateral brace for 12.5 ft [3.8 m] of feedmain, and [assuming it is located within 24 in. [0.6 m] of feedmain connection to looped crossmain], also a longitudinal brace for 60 ft [18.3 m] of crossmain. Thus, design should be as a lateral brace for a total load of 690 lb [3089 N].)

DD,EE,FF	6	1 x 62 x 31.7 x 0.5	= 983 lb
- longitudinal	(150)	(1 x 18.9 x 465 x 0.5)	= (4394 N)

3. Crossmain Bracing

H,N,O,U	4	1 x 20 x 16.4 x 0.5	= 164 lb
	(100)	(1 x 6.1 x 241 x 0.5)	= (735 N)
-lateral	1½	8 x 10 x 3.6 x 0.5	= 144
	(40)	(8 x 3.1 x 53 x 0.5)	= (657)
	2	10 x 10 x 5.1 x 0.5	= 255
	(50)	(10 x 3.1 x 75 x 0.5)	= (1163)
			= 563 lb
			= (2555 N)
-longitudinal	4	1 x 25 x 16.4 x 0.5	= 205 lb
	(100)	(1 x 7.6 x 241 x 0.5)	= (916 N)
		Total	= 768 lb
			= (3471 N)

(Braces **H, N, O,** and **U** are end-of-crossmain lateral braces, located within 24 in. [0.6 m] of end of crossmain, and also act as longitudinal braces for 25 ft [7.6 m] of the crossmain loop piping. Design should be as lateral braces with total crossmain and branchline load of 768 lb [3471 N].)

I,J,L,M,	4	4 x 10 x 16.4 x 0.5	= 328 lb
P,Q,R,S,T	(100)	(4 x 3.1 x 241 x 0.5)	= (1494 N)
-lateral	1½	16 x 10 x 3.6 x 0.5	= 288
	(40)	(16 x 3.1 x 53 x 0.5)	= (1314)
	2	20 x 10 x 5.1 x 0.5	= 510
	(50)	(20 x 3.1 x 75 x 0.5)	= (2325)
			= 1126 lb
			= (5133 N)

(These are all lateral braces with crossmain/branchline portions for total design load of 1126 lb [5133 N].)

K	4	4 x 10 x 16.4 x 0.5	= 328 lb
	(100)	(4 x 3.1 x 241 x 0.5)	= (1494 N)
-lateral	1½	16 x 10 x 3.6 x 0.5	= 288
	(40)	(16 x 3.1 x 53 x 0.5)	= (1314)
	2	20 x 10 x 5.1 x 0.5	= 510
	(50)	(20 x 3.1 x 75 x 0.5)	= (2325)
			= 1126 lb
			= (5133 N)
-longitudinal			
	6	1 x 31 x 31.7 x .5	= 491 lb
	(150)	(1 x 9.5 x 465 x 0.5)	= (2209 N)
		Total	= 1617 lb
			= (7342 N)

(Brace **K** is a lateral brace for the crossmain as well as a longitudinal brace for 31 ft [9.5 m] of the feedmain, and should be designed as a lateral brace with a total load of 1617 lb [7842 N].)

V,Y,Z,CC	4	1 x 16.5 x 16.4 x 0.5	= 135 lb
-lateral	(100)	(1 x 5.0 x 241 x 0.5)	= (603 N)
-longitudinal	4	1 x 40 x 16.4 x 0.5	= 328 lb
	(100)	(1 x 12.2 x 241 x 0.5	= (1740 N)
		Total	=
			= 463 lb
			(2073 N)

(Braces **V, Y, Z** and **CC** are end-of-crossmain lateral braces, located within 24 in. [0.6 m] of end of crossmain, and also act as longitudinal braces for 40 ft [12.2 m] of the crossmain loop piping. Design should be as lateral braces with total load of 463 lb [2073 N].)

W,X,AA,BB -lateral	4 (100)	1 x 33 x 16.4 x 0.5 (1 x 10.1 x 241 x 0.5)	= 271 lb = (1217 N)
GG,HH -longitudinal	4 (100)	1 x 60 x 16.4 x 0.5 (1 x 18.3 x 241 x 0.5)	= 492 lb = (2205 N)
II,JJ -longitudinal	4 (100)	1 x 50 x 16.4 x 0.5 (1 x 15.3 x 241 x 0.5)	= 410 lb = (1844 N)
KK,LL -longitudinal	4 (100)	1 x 80 x 16.4 x 0.5 (1 x 24.4 x 241 x 0.5)	= 656 lb = (2940 N)

C.2.3 Tree System (System No. 3)

Step 1. Layout and orientation of braces. Figure C.2.3-A shows the layout for the two-way lateral braces, and a four-way brace at the riser. Figure C.2.3-B show the layout of the two-way longitudinal braces. Dashed lines indicate the portions of the piping system (zone of influence) to be calculated for each brace.

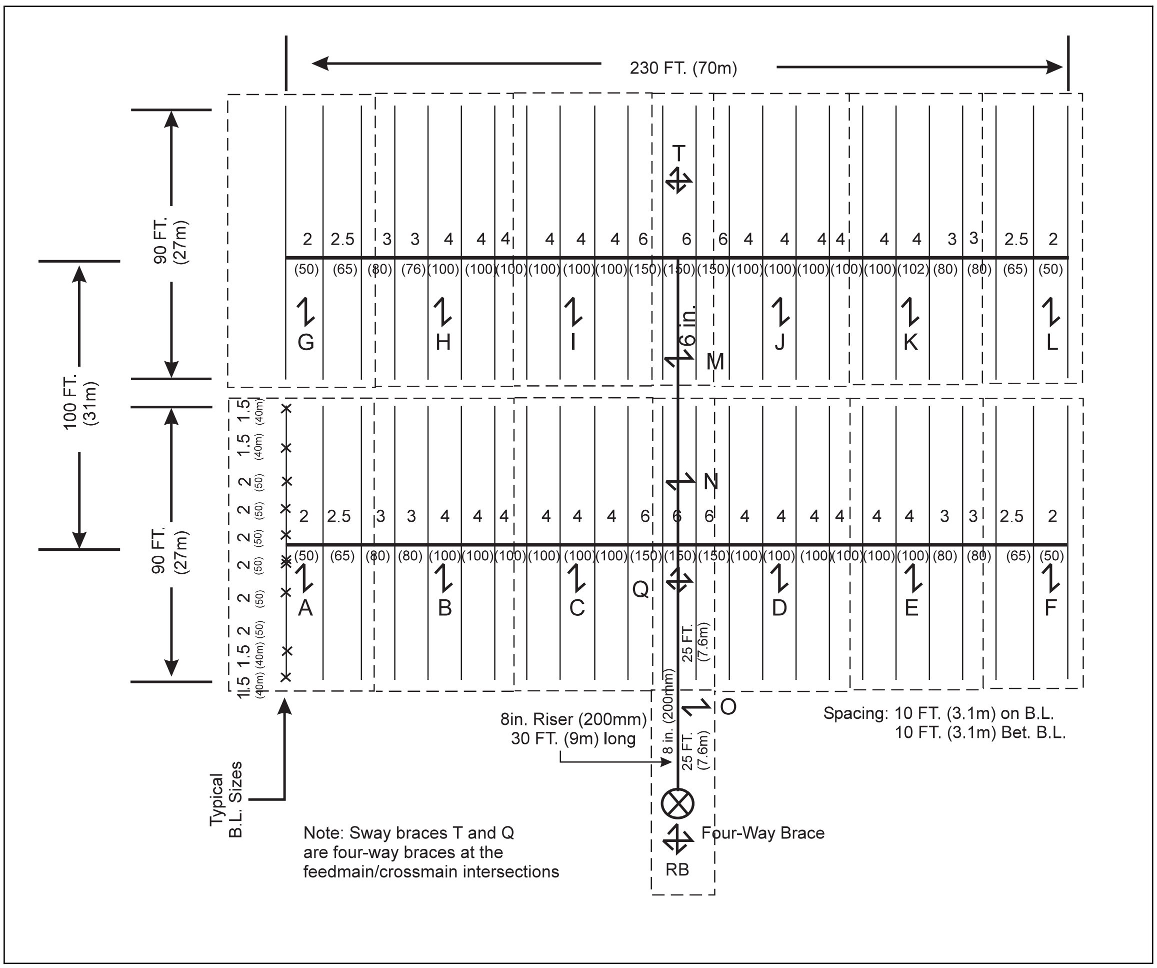


Fig. C.2.3-A. Layout and zones of influence for lateral and four-way riser sway bracing for System #3.

Step 2. Calculate design loads. Using a “G” factor = 0.5 (the “G” factor can vary see 2.2.1.2.2) and Schedule 40 pipe, horizontal seismic design loads on each brace will be as shown in Table C.2.3.

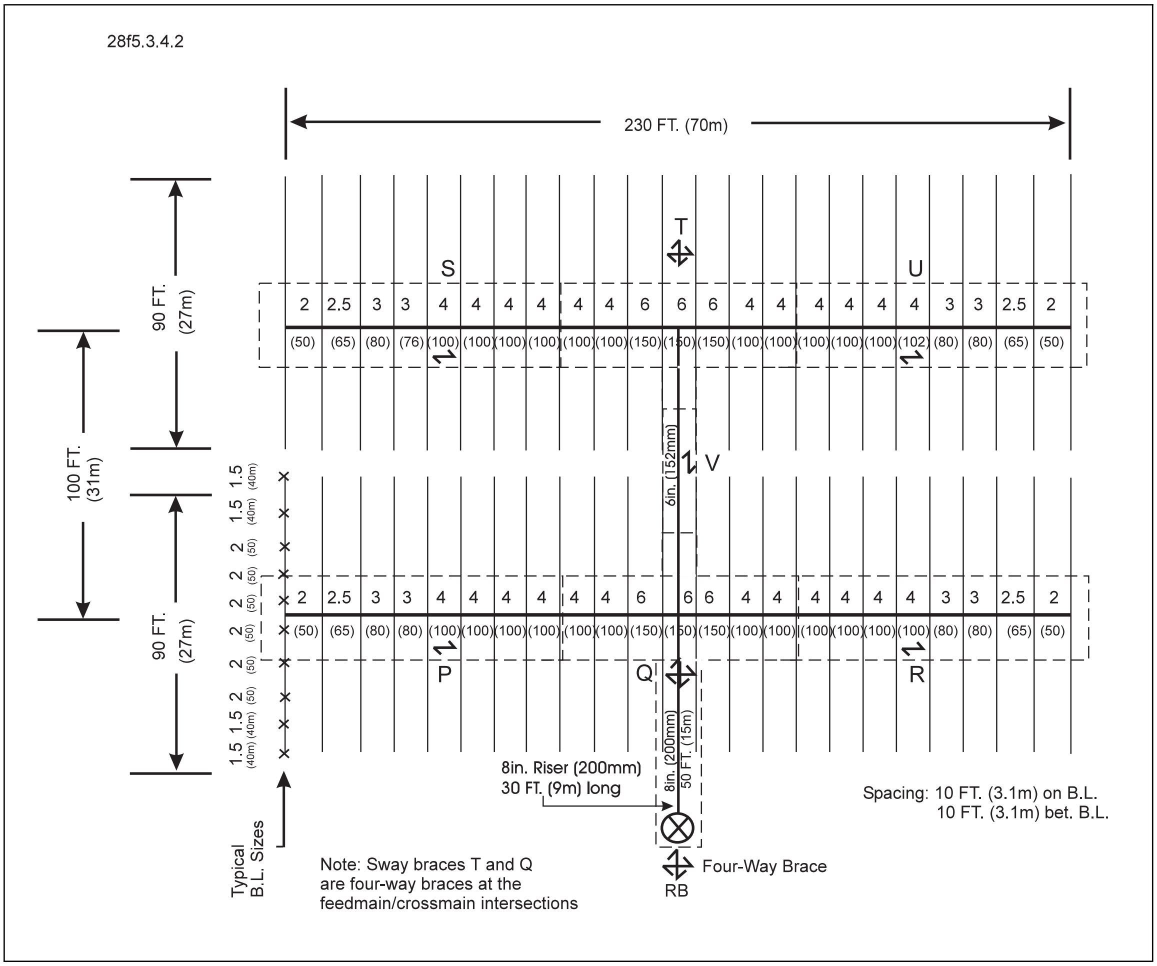


Fig. C.2.3-B. Layout and zones of influence for longitudinal and four-way riser sway bracing for System #3.

Step 3. Select the proper brace type, size, and maximum length. Based on the configuration of the brace connection to the structure, the angle of the brace, and the calculated horizontal design load, the brace type, size, and maximum length can be selected from Table 3.1.8-A through Table 3.1.8-F.

Step 4. Using the Step 2 design loads, and the brace angle, select an appropriate attachment to the pipe (e.g., an FM Approved manufactured pipe-attached component or a standard U-bolt) and the appropriate type (e.g., an FM Approved manufactured structure-attached component) and size of fastener for attachment to the building structure.

Table C.2.3. Horizontal Seismic Design Loads for System No. 3.

Brace Location	*Nominal Diameter, in. (mm)*	*Number x Length, ft (m) x Weight/Length, lb/ft (N/m) x G =*		*Force, lb (N)*
1. Riser Bracing (**RB**)				
Lateral	8	1 x 150 x 47.7 x 0.5	=	358 lb
	(200)	(1 x 4.6 x 700 x 0.5)	=	(1610 N)
	8	1 x 12.5 x 47.7 x 0.5	=	<u>298</u>
	(200)	(1 x 3.8 x 700 x 0.5)	=	<u>(1330)</u>
			=	656 lb
			=	(2940 N)
Longitudinal	8	1 x 15 x 47.7 x 0.5	=	358 lb
	(200)	(1 x 4.6 x 700 x 9.5)	=	(1610 N)
	8	1 x 25 x 47.7 x 0.5	=	<u>596</u>
	(200)	(1 x 7.6 x 700 x 0.5)	=	<u>(2660)</u>
			=	954 lb
			=	(4270 N)

(The riser bracing will need to be designed to withstand simultaneously a 656 lb (2940 N) lateral and 954 lb [4270 N] longitudinal horizontal seismic load.)

2. Feedmain Bracing				
M,N,	6	1 x 33 x 31.7 x 0.5	=	523 lb
-lateral	(150)	(1 x 10 x 465 x 0.5)	=	(2325 N)

(Braces **M** and **N** pick up the lateral load for 33 ft [10 m] of feedmain piping. Four-way braces T and Q will pick up the 16.5 ft (5 m) of piping north of Brace M and south of Brace N, respectively.)

O	8	1 x 25 x 47.7 x 0.5	=	596 lb
-lateral	(200)	(1 x 7.6 x 700 x 0.5)	=	(2660 N)
V	6	1 x 50 x 31.7 x 0.5	=	793 lb
-longitudinal	(150)	(1 x 15 x 465 x 0.5)	=	(3488 N)
3. Four-way Feedmain/Crossmain Bracing				
Q				
East-to-West Portion				
lateral	8	1 x 12.5 x 47.7 x 0.5	=	298 lb
	(200)	(1 x 3.8 x 700 x 0.5)	=	(1330 N)
	6	1 x 16.5 x 31.7 x 0.5	=	262
	(150)	(1 x 5.0 x 465 x 0.5)	=	(1163)
longitudinal	6	3 x 10 x 31.7 x 0.5	=	476
	(150)	(3 x 3.1 x 465 x 0.5)	=	(2162)
	4	4 x 10 x 16.4 x 0.5	=	<u>328</u>
	(100)	(4 x 3.1 x 241 x 0.5)	=	<u>(1494)</u>
		East-to-West Total Load	=	1364 lb
			=	(6149 N)

North-to-South Portion	1½	8 x 10 x 3.6 x 0.5	= 144 lb
lateral	(40)	(8 x 3.1 x 53 x 0.5)	= (657 N)
	2	10 x 10 x 5.1 x 0.5	= 255
	(50)	(10 x 3.1 x 75 x 0.5)	= (1163)
	6	3 x 10 x 31.7 x 0.5	= 476
	(150)	(3 x 3.1 x 465 x 0.5)	= (2162)
	8	1 x 25 x 47.7 x 0.5	= 596
	(200)	(1 x 7.6 x 700 x 0.5)	= (2660)
	6	1 x 25 x 31.7 x 0.5	= 396
	(150)	(1 x 7.6 x 465 x 0.5)	= (1767)
		North-to-South Total Load	= 1867 lb
			= (8409 N)

(Brace **Q** needs a design to withstand simultaneously a 1364 lb [6149 N] load in the east-west direction and 1867 lb [8409 N] load in the north-south direction. Alternatively, two separate sway braces may be used, and should be located within 24 in. [0.6 m] of the tee.)

T-			
East-to-West Portion			
lateral	6	1 x 16.5 x 31.7 x 0.5	= 262 lb
	(150)	(1 x 5.0 x 465 x 0.5)	= (1163 N)
longitudinal	6	3 x 10 x 31.7 x 0.5	= 476
	(150)	(3 x 3.1 x 465 x 0.5)	= (2162 N)
	4	4 x 10 x 16.4 x 0.5	= 328
	(100)	(4 x 3.1 x 241 x 0.5)	= (1494)
		East-to-West Total Load	= 1066 lb
			= (4819 N)
North-to-South Portion			
lateral	1½	8 x 10 x 3.6 x 0.5	= 144 lb
	(40)	(8 x 3.1 x 53 x 0.5)	= (384 N)
	2	10 x 10 x 5.1 x 0.5	= 255
	(50)	(10 x 3.1 x 75 x 0.5)	= (1163)
	6	3 x 10 x 31.7 x 0.5	= 476
	(150)	(3 x 3.1 x 465 x 0.5)	= (2162)
	6	1 x 25 x 31.7 x 0.5	= 396
	(150)	(1 x 7.6 x 465 x 0.5)	= (1767)
		North-to-South Total Load	= 1271 lb
			= (5749 N)

(Brace **T** needs to be designed to withstand simultaneously a 1066 lb [4819 N] load in the east-west direction and a 1271 lb [5749 N] load in the north-south direction. Alternatively, two separate sway braces may be used and should be located within 24 in. [0.6 m] of the tee.)

4. Crossmain Bracing

A,F,G,L	1½	12 x 10 x 3.6 x 0.5	= 216 lb
-lateral	(40)	(12 x 3.1 x 53 x 0.5)	= (986 N)
	2	15 x 10 x 5.1 x 0.5	= 383
	(50)	(15 x 3.1 x 75 x 0.5)	= (1744)
	2	1 x 10 x 5.1 x 0.5	= 26
	(50)	(1 x 3.1 x 75 x 0.5)	= (116)
	2½	1 x 10 x 7.9 x 0.5	= 40
	(65)	(1 x 3.1 x 116 x 0.5)	= (180)
	3	1 x 5 x 10.8 x 0.5	= 27
	(80)	(1 x 1.5 x 159 x 0.5)	= (120)
			= 692 lb
			= (3146 N)

(Braces **A, F, G,** and **L** are end-of-crossmain braces located within 6 ft [1.8 m] of end of crossmain, with crossmain/ branchline portions for a total design load of 692 lb [3146 N].)

B,E,H,K-	1½	16 x 10 x 3.6 x 0.5	= 288 lb
lateral	(40)	(16 x 3.1 x 53 x 0.5)	= (1314 N)
	2	20 x 10 x 5.1 x 0.5	= 510
	(50)	(20 x 3.1 x 75 x 0.5)	= (2325)
	3	1 x 15 x 10.8 x 0.5	= 81
	(80)	(1 x 4.5 x 159 x 0.5)	= (358)
	4	2.5 x 10 x 16.4 x 0.5	= 205
	(100)	(2.5 x 3.1 x 241 x 0.5)	= (934)
			= 1084 lb
			= (4931 N)
C,D,I,J	1½	16 x 10 x 3.6 x 0.5	= 288 lb
-lateral	(40)	(16 x 3.1 x 53 x 0.5)	= (1314 N)
	2	20 x 10 x 5.1 x 0.5	= 510
	(50)	(20 x 3.1 x 75 x 0.5)	= (2325)
	4	3.5 x 10 x 16.4 x 0.5	= 287
	(100)	(3.5 x 3.1 x 241 x 0.5	= (1307)
	6	0.5 x 10 x 31.7 x 0.5	= 80
	(150)	(0.5 x 3.1 x 465 x 0.5)	= (360)
			= 1165 lb
			= (5306 N)
P,R,S,U	2	1 x 10 x 5.1 x 0.5	= 26 lb
- longitudinal	(50)	(1 x 3.1 x 75 x 0.5)	= (116 N)
	2½	1 x 10 x 7.9 x 0.5	= 40
	(65)	(1 x 3.1 x 116 x 0.5)	= (180)
	3	2 x 10 x 10.8 x 0.5	= 108
	(80)	(2 x 3.1 x 159 x 0.5)	= (493)
	4	4 x 10 x 16.4 x 0.5	= 328
	(100)	(4 x 3.1 x 241 x 0.5)	= (1494)
			= 502 lb
			= (2283 N)

C.3 Ground-Supported, Flat-Bottom Steel Tanks

The most common type of tank used in areas where seismic protection is required is the ground-supported, flat-bottom steel tank. The tank can either provide a suction supply for an adjacent fire pump, or act as a gravity tank to provide sufficient water pressure for the fire protection system. Only tanks that are FM Approved for the appropriate earthquake zone (see Data Sheet 1-2) should be installed. Note that FM Approval typically covers the tank and not the foundation. Foundation design is usually done separately from the tank design.

For ground-level tanks, there are four main seismic considerations. These include:

1. Proper steel thickness near the base of the tank to avoid “elephant-footing”,
2. Anchorage of the tank and foundation to prevent horizontal and vertical displacement,
3. Flexibility of pipe connections to the tank, and
4. Clearance around pipe penetrations through pump house or other structural walls.

Items 3 and 4 are covered in 2.2.6 of this data sheet. Except for the design of the foundation itself, using a tank that is FM Approved for the appropriate seismic zone will accomplish Items 1 and 2. More information on the design of these tanks and their foundations can be found in Data Sheet 3-2, *Water Tanks for Fire Protection*.

In strong ground shaking areas, unanchored tanks may have significant vertical and horizontal displacements. Depending on the diameter of the tank and the height-to-diameter ratio, these expected displacements may vary. However, the main point is that unanchored tanks can create displacements that may not only damage the tank, but also rupture the attached piping.

C.4 Other Codes and Standards

Other codes and standards may contain guidance for earthquake protection of fire protection systems. As these are reviewed, the results will be added to Section 2.3 to aid in the evaluation and review of systems that are designed using these standards.

NFPA 13, *Standard for the Installation of Sprinkler Systems*, includes guidelines for protecting sprinkler systems from damage in areas subject to earthquake. The guidelines contained in this data sheet for the sprinkler system itself are similar in most respects to the NFPA standard. However, NFPA 13 does not address earthquake protection of some items such as water supplies, pump systems and equipment that can impact sprinkler systems.

Section 2.3.1 provides guidance on limitations, exceptions, changes, and additions necessary to bring systems designed in accordance with NFPA 13 substantially into compliance with this data sheet.

Other NFPA standards that address the fire protection systems discussed in this data sheet are:

- NFPA 14, Installation of Standpipe and Hose Systems
- NFPA 15, Water Spray Fixed Systems for Fire Protection
- NFPA 16, Installation of Foam-Water Sprinkler and Foam-Water Spray Systems
- NFPA 20, Installation of Stationary Pumps for Fire Protection
- NFPA 22, Water Tanks for Private Fire Protection

APPENDIX D JOB AID FOR SECTION 2.2 RECOMMENDATIONS

Table D.1 below is intended to be used as an aid to more easily identify the main requirements for earthquake protection of fire protection systems. Although Table D.1 outlines major Section 2.2 recommendations, every pertinent detail could not be included and sections referenced may not contain every requirement related to the recommendation. Therefore, Table D.1 should not be used without considering the specific information in Data Sheet 2-8, Section 2.2.

Table D.1. Outline of Data Sheet 2-8 Recommendations

Data Sheet 2-8 Pipe Bracing Recommendations for Steel Pipe	*Section(s)*
Risers/Standpipes (Regardless of Size)	
Risers and standpipes, provide 4-way bracing: • At top (within 2 ft [0.6 m]). • At intermediate floors (within 2 ft [0.6 m]) - structural floors can brace pipe if clearance does not allow more than ½ in. (13 mm) of horizontal movement in any direction. • At supply mains between intermediate floors (within 2 ft [0.6 m]). • On straight runs at 40 ft (12.2 m) on center maximum. • At every other extra flexible coupling (within 2 ft [0.6 m]. Horizontal manifold piping feeding base of risers • Provide lateral bracing within 2 ft (0.6 m) of the end when: - The manifold length exceeds 6 ft (1.8 m), OR - A flexible coupling exists on the horizontal manifold pipe or the riser stub. Miscellaneous • A single 4-way brace may restrain no more than 2 risers.	2.2.1.1 2.2.2 2.2.3 2.2.4 2.2.5
Vertical Feed Mains and Cross Mains (Regardless of Size)	
If 6 ft (1.8 m) long or more, provide 4-way bracing: • At top and bottom and at any intermediate supply mains (within 2 ft [0.6 m]) • On straight runs at 40 ft (12.2 m) on center maximum. • At every other extra flexible coupling (within 2 ft [0.6 m]) . If less than 6 ft (1.8 m) long: • Provide 4-way bracing within 3 ft (0.9 m) of turns equipped with flexible couplings.	2.2.1.1 2.2.3 2.2.4 2.2.5
Horizontal Feed Mains and Cross Mains (Regardless of Size)	
For straight runs, provide: • Lateral bracing at 40 ft (12.2 m) on center maximum. • Lateral bracing at every other extra flexible coupling (within 2 ft [0.6 m] • Longitudinal bracing at 80 ft (24.4 m) on center maximum. At changes in direction: • If the pipe run is 6 ft (1.8 m) or more adjacent to change in direction, provide lateral and longitudinal bracing within 2 ft (0.6 m) of the change in direction. • Regardless of length of adjacent pipe run, provide lateral bracing within 2 ft (0.6 m) of any change in direction where flexible couplings are used. At ends (including adjacent to seismic separation assemblies or flexible pipe loops), provide: • Lateral bracing within 6 ft (1.8 m). • Longitudinal bracing within 40 ft (12.2 m). Miscellaneous • U-hangers (even wraparound types) may not be used as braces. • Use of short rod hangers does not eliminate the need for bracing of mains. • Braces on branch lines may not be used to brace cross mains.	2.2.1.1 2.2.1.3 2.2.3 2.2.4 2.2.5
Drops	
For drops from overhead piping feeding more than one sprinkler, see vertical feed mains and cross mains.	2.2.1.1 2.2.1.4

Table D.1 (continued). Outline of Data Sheet 2-8 Recommendations

Data Sheet 2-8 Pipe Bracing Recommendations for Steel Pipe (Continued)	*Section(s)*
Branch Lines	
<u>Bracing may be omitted as follows:</u> • Branch lines less than 2-½ in. (65 mm) diameter require no bracing but require end restraint (see Clearance, Support and Miscellaneous section). • On short pipe runs: ≤ 20 ft (6.1 m) length no lateral; ≤ 40 ft (12.2 m) length no longitudinal. • Lateral bracing is not required on branch lines less than 4 in. (100 mm) diameter where hangers are short (< 6 in. [150 mm]) rods with ≤ ½ in. (13 mm) space from rod to pipe. <u>Lateral bracing for branch lines 2-½ in. (65 mm) or greater in diameter:</u> • On straight runs, provide: - At 40 ft (12.2 m) on center maximum (first brace 10-40 ft [3.1-12.2 m] from cross main). - At extra flexible couplings (brace within 2 ft [0.6 m] of every other flexible coupling). • Within 6 ft (1.8 m) of changes in direction (exception: within 2 ft [0.6 m] of any change in direction where flexible couplings are used). • Within 6 ft (1.8 m) of ends, including adjacent to seismic separation assemblies or flexible pipe loops. • Properly sized and attached wraparound U-hangers may be used as as lateral braces; other U-hangers should not be considered to be lateral braces. • May not act as longitudinal bracing for cross main. <u>Longitudinal bracing for branch lines 2-½ in. (65 mm) or greater in diameter:</u> • On straight runs at 80 ft (24.4 m) on center maximum (first brace 20-80 ft [6.1-24.4 m] from crossmain). • Within 40 ft (12.2 m) of changes in direction. • Within 40 ft (12.2 m) of ends, including adjacent to seismic separation assemblies or flexible pipe loops. • May not act as lateral brace for cross main.	2.2.1.1 2.2.1.3 2.2.3 2.2.4
Common Bracing Recommendations	
• A lateral brace may act as a longitudinal brace (and vice versa) for a perpendicular pipe of equal or lesser diameter if it is within 2 ft (0.6 m) of the change in direction (branch lines may not brace mains). • A 4-way brace on a vertical pipe may act as the initial lateral and longitudinal brace for an attached horizontal pipe of the same or smaller diameter that is within 2 ft (0.6 m). • Where pipe diameters differ at changes of direction, locate bracing on the larger pipe. • A properly sized and attached U-bolt that fastens the pipe directly and tightly against a structural member may be used as a lateral brace or a four-way, but not as longitudinal, brace. • Orient diagonal braces for horizontal pipe at least 30° (preferably 45°) from vertical. • Where two diagonal compression braces are used on horizontal pipe, make the angle from vertical for each brace as equal as possible - the difference may not exceed 15°. • When two diagonal braces are used as four-way braces on risers or vertical pipe, orient them 90° apart if possible, but in no case less than 60° nor more than 120° apart. • Compression braces must have a slenderness ratio (l/r) ≤ 200. • Tension braces must have l/r ≤ 300 (cable bracing does not qualify). • Make brace connections to the pipe and structure with positive, mechanical attachments or FM Approved connectors; do not attach with C-clamps (even with retaining straps) or powder-driven fasterners. • Do not attach braces to wood members less than 3-½ in. (90 mm) thick or to other marginal members, such as open web joists. • All post-installed concrete anchors & cast-in-place concrete inserts must be specifically qualified for use in seismic applications. • Resist the upward reaction from a lateral or longitudinal diagonal brace that exceeds ½ of W_p by a vertical brace, a 2nd diagonal brace, or a substantial (e.g., clevis) hanger designed to resist upward force; attach one of these within 6 in. (150 mm) of the diagonal brace. • Calculate the horizontal seismic design load (H) as “G” factor multiplied by the weight of water-filled pipe in the zone of influence (W_p). Use “G” = 0.9 (FM 50-year zones), 0.65 (FM 100-year zones), and 0.4 (FM 250- and 500-year zones). Can use “G” = $0.7S_{DS}$ if S_{DS} value different from the generic S_{DS} values in Data Sheet 1-2 can be justified. Use a higher “G” if required by the local building code.	2.2.1.1 2.2.1.2 2.2.1.3 2.2.2 2.2.3 2.2.4 2.2.5

Table D.1 (continued). Outline of Data Sheet 2-8 Recommendations

Data Sheet 2-8 Flexibility Recommendations for Steel Pipe (See Additional Recommendations in the Equipment and Tank Seismic Section)	**Section(s)**
Risers/Standpipes (Regardless of Size)	
Provide flexible couplings: • Within 2 ft (0.6 m) of the top and bottom (where risers and mains are fully welded, the flexible coupling at the top may be omitted). • At elevated floors in multistory buildings: - Within 1 ft (0.3 m) above OR below floors if no floor penetration or if clearance as specified in the pipe clearance section below is provided. - Within 1 ft (0.3 m) above AND below floors if less clearance than specified in the pipe clearance section below is provided. - Except, locate flexible coupling below the floor below any main supplying that floor. • Within 2 ft (0.6 m) above or below other intermediate bracing (exception: where risers and mains are fully welded, these flexible couplings may be omitted). Miscellaneous • Where risers are fed from a horizontal manifold pipe, the base of the riser is at the top of the manifold.	2.2.1.4 2.2.2 2.2.3 2.2.4 2.2.5
Vertical Feed Mains and Cross Mains (Regardless of Size)	
Provide flexible couplings on vertical pipe 6 ft (1.8 m) or longer (exception: where risers and mains are fully welded, these flexible couplings may be omitted): • Within 2 ft (0.6 m) of the top and bottom. • At intermediate bracing (within 2 ft [0.6 m] above or below the bracing).	2.2.1.4 2.2.3 2.2.4 2.2.5
Horizontal Feed Mains and Cross Mains (Regardless of Size)	
Provide a seismic separation assembly or flexible pipe loop in pipe that: • Crosses a building seismic joint or spans between buildings. Provide flexible couplings: • Within 1 ft (0.3 m) on each side of a wall if the recommended clearance (as specified in the pipe clearance section below) through the wall is not met (exception: where risers and mains are fully welded, these flexible couplings may be omitted).	2.2.1.4 2.2.3 2.2.4 2.2.5
Drops (Regardless of Size)	
For in-rack sprinklers, provide flexible couplings: • On the vertical pipe: - Within 2 ft (0.6 m) below the cross main or armover. - Within 2 ft (0.6 m) above the initial attachment to the rack. - Confirm adequate angular deflection capacity of couplings & provide alternative flexibility if necessary • On the horizontal in-rack pipe within 2 ft (0.6 m) on each side of the vertical pipe. For other drops supplying more than one sprinkler, provide flexible couplings: • On vertical pipe exceeding 2 ft (0.6 m) in length: - Within 2 ft (0.6 m) below the cross main or armover. - Within 2 ft (0.6 m) above and/or below any lateral supports on the drop if needed to accommodate differential movement. - At drops between two independent structures, confirm adequate angular deflection capacity of couplings and provide alternative flexibility if necessary. • On the horizontal pipe fed from the drop within 2 ft (0.6 m) each side of its connection to the vertical pipe. Drops greater than 2 ft (0.6 m) to hose racks, provide flexible couplings: • On the vertical pipe within 2 ft (0.6 m) below the cross main or armover.	2.2.1.4 2.2.3 2.2.4
Branch Lines (Regardless of Size)	
Provide a seismic separation assembly or flexible pipe loop in pipe that: • Crosses a building seismic joint or spans between buildings.	2.2.1.4 2.2.3 2.2.4
Common Flexibility Recommendations	
Use rigid couplings except where flexibility is needed as noted above.	2.2.1.7

Table D.1 (continued). Outline of Data Sheet 2-8 Recommendations

Data Sheet 2-8 Pipe Clearance, Support, and Miscellaneous Recommendations for Steel (Unless Noted Otherwise) Pipe - See Also Equipment and Tank Section)	*Section(s)*
Risers/Standpipes (Regardless of Size)	
See the "Common Clearance, Support, and Miscellaneous Recommendations" below.	
Vertical Feed Mains and Cross Mains (Regardless of Size)	
See the "Common Clearance, Support, and Miscellaneous Recommendations" below.	
Horizontal Feed Mains and Cross Mains (Regardless of Size)	
See the "Common Clearance, Support, and Miscellaneous Recommendations" below.	
Drops	
In addition to the "Common Clearance, Support, and Miscellaneous Recommendations" below, Provide hangers that can resist vertical uplift within 2 ft (0.6 m) of the vertical drop at: • All armovers supplying in-rack sprinklers or more than one sprinkler. • Armovers greater than 2 ft (0.6 m) long that supply one sprinkler.	2.2.1.4 2.2.1.8 2.2.3 2.2.4
Branch Lines	
In addition to the "Common Clearance, Support, and Miscellaneous Recommendations" below, Provide clearance at sprinklers: • 1 in. (25 mm) preferred, but not less than ½ in. (13 mm), gap around suspended ceiling penetrations (i.e., diameter of hole is 1-2 in. [25-50 mm] larger than diameter of sprinkler or pipe through ceiling) or appropriate alternative (e.g., use FM Approved flexible sprinkler hose) • 2 in. (50 mm) horizontally and vertically from structural and non-structural elements (horizontal clearance of 4 in. [100 mm] to 6 in. [150 mm] to sprinklers is preferred if possible) unless installation will prevent impact damage (e.g., by using FM Approved flexible sprinkler hose). Provide hangers on branch lines that can also resist vertical uplift: • At the last hanger on dead end lines. • Where less than 2 in. (50 mm) clearance exists both horizontally and vertically to a sprinkler. • For in-rack sprinkler branch lines. • At armovers: within 2 ft (0.6 m) of the drop for all that supply more than one sprinkler, and for those greater than 2 ft (0.6 m) long that supply one sprinkler. • At every other gridded system hanger. Provide lateral restraint on branch lines that don't require bracing: • Provide a restraint or a short hanger within 6 ft (1.8 m) of the end of dead end branch lines.	2.2.1.1.6 2.2.1.5 2.2.1.8 2.2.3 2.2.4
Common Clearance, Support, and Miscellaneous Recommendations	
Provide a hole or sleeve through non-frangible or fire-rated walls/floors/roofs (or flexible couplings both sides) with a nominal diameter: • 2 in. (50 mm) larger than the pipe for pipes from 1 to 3.5 in. (25 to 90 mm) nominal diameter. • 4 in. (100 mm) larger than the pipe for pipes 4 in. (100 mm) or larger nominal diameter. Provide 2 in. (50 mm) clearance: • From the ends of pipes to walls or structural members. • Between any wall/member and a pipe running parallel to it when the pipe passes through the wall/structural member and then turns 90°. • From flanges, fittings, etc., on pipes that pass through walls or structural members. Hanger attachments to structure: • Provide retaining straps on all C-clamp hanger attachments. • Do not use powder-driven fasteners. • All post-installed concrete anchors and cast-in-place concrete inserts must be specifically qualified for use in seismic applications. Other miscellaneous recommendations • Do not use plain end couplings (2 semicircular halves, no torque-indicating devices, not FM Approved). FM Approved plain end fittings (1 piece with torque-indicating set screws) may be used except where disallowed by another data sheet. • For copper pipe, follow steel pipe requirements except space lateral braces & four-way braces at 25 ft (7.6 m). • Do not use nonmetallic pipe above ground. • Provide plans and calculations showing all earthquake protection features of the fire protection system.	2.2.1.5 2.2.1.7 2.2.1.8 2.2.1.9 2.2.2 2.2.3 2.2.4 2.2.5 2.2.7

Table D.1 (continued). Outline of Data Sheet 2-8 Recommendations

Data Sheet 2-8 Fire Protection Equipment and Tank Seismic Recommendations	*Section(s)*
Anchorage (Note: only items affecting fire protection are included below)	
Suspended ceilings having sprinklers • Brace (for example with 45° splay wires and vertical compression struts) ceilings greater than 1000 ft^2 (92.9 m^2). Brace ceilings having a smaller area that are not adequately constructed and restrained by walls or soffits. Storage racks having in-rack sprinklers • Anchor and/or otherwise restrain racks. Fire pump systems, anchor the following: • Pumps and drivers • Controllers • Emergency generators/transfer switch supplying jockey pumps or electric fire pump drivers • Fuel tanks • Starter batteries Water storage tanks (see Data Sheets 3-2, 3-4, 3-6 for additional guidance) • Provide ground-supported steel suction tanks having the following: - FM Approval for the proper FM earthquake zone - Anchorage per FM Approval (unless adequately designed to allow omission) - Adequate foundations • Provide elevated tanks per requirements of Data Sheet 3-2. • Provide embankment supported fabric tanks per the requirements of Data Sheet 3-4. • Provide lined earth reservoirs per requirements of Data Sheet 3-6. Also restrain: • Other fire protection equipment (foam tanks, etc.). • Equipment that can impact sprinkler piping or fire protection equipment.	2.2.1.6 2.2.4 2.2.5 2.2.6
Flexibility (Note: Use rigid couplings except where flexibility is required as noted below)	
Fire protection water tank piping: • Provide a flexible coupling close to the tank wall. • Provide a flexible coupling within 2 ft (0.6 m) of the fire pump or entrance into ground. • For suction tanks that don't require anchorage, unless otherwise calculated, provide flexibility in piping connections adequate to accommodate 2 in. (50 mm) of horizontal displacement in any direction and 4 in. (100 mm) of upward vertical movement at the base of the tank. Fire pump suction and discharge piping; provide flexible couplings: • As for sprinkler piping when pumps are located in a building above the ground floor. Fuel line connections • Provide adequate flexibility where fuel lines attach to fuel tanks, pump drivers, and emergency generators.	2.2.5 2.2.6
Clearance	
Fire pump and tank piping; provide a hole or sleeve through non-frangible or fire-rated walls/floors (or flexible couplings both sides) with a nominal diameter: • 2 in. (50 mm) larger than the pipe for pipes from 1 to 3.5 in. (25 to 90 mm) nominal diameter. • 4 in. (100 mm) larger than the pipe for pipes 4 in. (100 mm) or larger nominal diameter.	2.2.1.5 2.2.5 2.2.6