International Fire Suppression Alliance

NFPA 13 Rules
for
Earthquake Protection
of
Fire Sprinkler Systems

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INTERNATIONAL CONFERENCE OF PROTECTION AGAINST FIRE

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NFPA 13 Rules for Earthquake Protection of Sprinkler Systems

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Seminar Goal

To be able to apply earthquake protection to fire sprinkler systems in accordance with NFPA 13

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Seminar Outline

- History
- Determining where protection is needed
- Allowing for seismic movement
- Finding the horizontal force
- Providing sway braces
- Adding restraint
- Hangers in seismic areas
- Questions

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History

- Although the NFPA sprinkler rules were first published in 1896, the first earthquake protection guidance appeared in the 1947 edition of NFPA 13
  - Intent to laterally brace for 50% of weight of water-filled piping
- Lessons were learned from the he 1971 San Fernando, California earthquake (6.6 on the Richter scale)
  - The Pacific Fire Rating Bureau (an insurance group) surveyed 973 sprinklered buildings afterward
  - The survey found that if a building fared well, so did its sprinkler system, but there were some vulnerabilities

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History (continued)

- 1971 San Fernando Lessons
  - C-type clamps without straps or lock nuts slid along or pulled off flanges
  - Lag bolts pulled out or snapped off
  - Flexible couplings failed at excessive deflection
  - Cast iron fittings broke at bullhead tees, and elbows at top of or first change in direction from riser
  - Breaks occurred at pronounced structural changes against restrained piping
  - Drop ceilings broke or bent sprinkler pipe drops and armovers, or dislocated or tore ceiling tiles

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History (continued)

- In 1977 the U.S. Congress passed the Earthquake Hazards Reduction Act of 1977, leading to the establishment of the "Building Seismic Safety Council," which developed rules for building codes
- The building code rules designate what buildings must be protected, and how severe the forces are expected to be in different parts of the country
- Those rules are now contained in a standard published as **ASCE/SEI 7**, adopted by reference by the building codes

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History (continued)

- A standardized approach was proposed by NFSA in 1984 including "zones of influence" to accumulate loads for brace locations and a concept of allowable brace/fastener loads based on angle from vertical
- In 1985 an NFPA 13 Earthquake Protection Subcommittee was formed, and fully adopted the NFSA concept by the 1989 edition
- In 1999 a new Committee on Hanging and Bracing was formed to bring in additional structural expertise

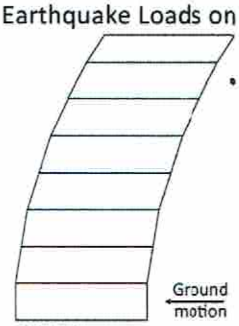
History (continued)

- In 2003 NFPA updated the seismic guidelines to coincide with the requirements of the building codes
- In 2007 NFPA 13 overhauled the requirements further to address the anticipated earthquake movement and stresses on the system piping
- At a 2007 Structural Engineering Institute conference, NFPA 13 was commended for being the first industry standard to fully coordinate its design and installation standard with the earthquake protection criteria used by the structural engineering community

NFPA 13 General Philosophy

- To minimize stresses in piping:
  - flexible couplings and fittings
  - special "seismic separation assemblies"
  - clearances around piping
- To minimize damaging forces:
  - sway bracing of mains and large branches
  - restraint of some branch piping

Exaggerated Displacement from Earthquake Loads on Metal Frame Building



- General EQ Concerns
  - Displacement
  - Cyclic motion
  - Continuity within the building structure
  - Vertical reactions

NFPA 13 Goal

- Section 9.3.1.1: "Where water-based fire protection systems are required to be protected against damage from earthquakes, the requirements of Section 9.3 shall apply..."

Alternative Methods

- Section 9.3.1.2: "Alternative methods of providing earthquake protection of sprinkler systems based on a seismic analysis certified by a registered professional engineer such that system performance will be at least equal to that of the building structure under expected seismic forces shall be permitted."

Steps for Earthquake Protection

1. Investigate if earthquake protection is needed
2. Verify acceptance of NFPA 13 criteria
3. Provide flexibility or clearances
4. Determine the horizontal force
5. Tentatively space braces
6. Calculate loads to braces
7. Tentatively configure brace attachments
8. Confirm adequacy of braces, fittings, and fasteners
9. Add restraint as required
10. Check proposed hanging arrangements

1. Is Earthquake Protection Needed?

- NFPA 13 says "how", not "where"
- Building codes generally say "where"
- Insurers such as FM Global provide worldwide maps
  - FM Data Sheet 1-2 *Earthquakes*
  - FM Data Sheet 2-8 *Earthquake Protection for Water-Based Fire Protection Systems*

FM Data Sheet 1-2 (2018) Earthquakes

Zones: Blue-50 yr; Red-100 yr; Gold-250 yr; Green-500 yr
Protection required in 50 yr through 500 yr zones

ASCE/SEI 7 Provides a Basis for Where Sprinkler Systems Must Be Protected

"For the purposes of this chapter, nonstructural components shall be assigned to the same Seismic Design Category as the structure that they occupy..."

- Categories A and B do not require seismic protection
- Categories C, D, E and F require seismic protection that must be adjusted for the seismic force (F_p)

How is a Building's Seismic Design Category Determined?

- Values of design accelerations S_{DS} (short period = 0.2 seconds) and S_{D1} (1 second period) are found using **mapped spectral accelerations S_s and S_1** in combination with site soil data
- Structures are then assigned to to the seismic design category based on the more severe category for short period design acceleration S_{DS} or 1 second period design acceleration S_{D1}, in combination with their occupancy **Risk Categories**, as presented in two tables

Mapped Spectral Accelerations

- Two types of Spectral Response Acceleration Parameters
  - Short Period (S_S)
  - One-Second Period (S_1)
- Determined from maps available for the US in ASCE/SEI 7
- Can also use maps from United States Geological Survey (USGS).
  - Values available by zip code

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What Are Spectral Accelerations?

- Ground motion accelerations are represented by coefficients developed from the response spectra
- Like the spectrum of light has different colors relating to different frequencies, ground motion has a spectrum of accelerations relating to different frequencies
- Current earthquake rules use two points from the spectrum, similar to a two-point sprinkler design

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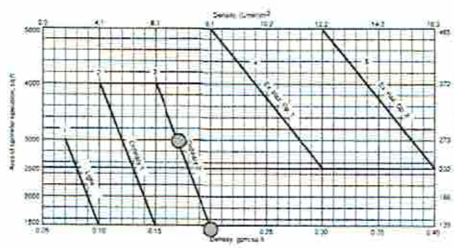
Two-Point Sprinkler Design

Lower point intended to result in high density over small area (might be below actual curve, i.e. 4 sprinkler criterion)
Upper point would ensure adequate discharge in event of high degree of shielding or similar circumstance



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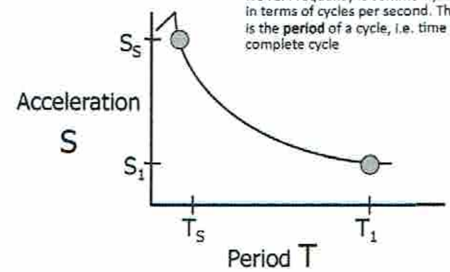
Two-Point Seismic Accelerations

NOTE: Frequency is commonly expressed in terms of cycles per second. The inverse is the **period** of a cycle, i.e. time for a complete cycle



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Mapped Spectral Accelerations

- In the United States, the Geological Survey issues maps for both maximum expected short-period (0.2 second) and 1-second accelerations
- They are respectively denoted S_S and S_1, and are given as a percentage of gravity
- The USGS formerly provided data worldwide, but no longer does so

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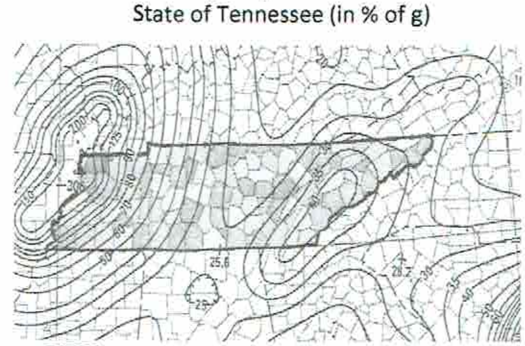
Short Period (0.2 s) Accelerations for the State of Tennessee (in % of g)



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Latitude and Longitude of a Point

Information Formerly Available at

https://earthquake.usgs.gov/designmaps/us/application.php

How Do You Calculate the Seismic Design Accelerations S_{DS} and S_{D1}?

- Soil site class is determined by test boring or shearwave velocity tests:
  - Fa = Short-period site coefficient
  - Fv = 1-second period site coefficient
- $S_{DS} = 2/3\ Fa\ S_s$
- $S_{D1} = 2/3\ Fv\ S_1$

What Are Risk Categories?

- Category IV – Essential facilities required for post-earthquake recovery and those containing substantial amounts of hazardous materials
- Category III – Structures for which failure would result in a substantial public hazard
- Category II – Structures not assigned to Risk Categories IV, III, or I
- Category I – Buildings with few occupants or limited exposure, such as agricultural sheds

Seismic Design Category Based on Short Period Design Acceleration

Value of S_{DS}	Risk Category I or II	Risk Category III	Risk Category IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D	D	D

Seismic Design Category Based on 1 Second Period Design Acceleration

Value of S_{D1}	Risk Category I or II	Risk Category III	Risk Category IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \leq S_{D1} < 0.133g$	B	B	C
$0.133g \leq S_{D1} < 0.20g$	C	C	D
$0.20g \leq S_{D1}$	D	D	D

Is Earthquake Protection Needed?

Ideally each jurisdiction would require the design professional to specify the following on the front or main submittal plan sheet:

- Seismic Design Category (A through F)
- Occupancy/Risk Category (and site Zip Code in the US)
  - Category I, II, III or IV
- Seismic Soil Class (A through F)
- Short Period Spectral Response Acceleration Parameter (S_s)
- Seismic Design Force (F_p)

Hard Rock Sites
Requiring Earthquake Protection of Sprinkler Systems in Risk Category I, II, III and IV Structures

Soft Soil Sites
Requiring Earthquake Protection of Sprinkler Systems in Risk Category IV Essential Facilities

Steps for Earthquake Protection

1. Investigate if earthquake protection is needed
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2. Is NFPA 13 Criteria Acceptable?

- NFPA 13 is now widely recognized for its earthquake protection criteria
- Although FM Global publishes its own Data Sheet 2-8, it includes a Section 2-3.1 by which the 2016 edition of NFPA 13 is acceptable with certain modifications

FM Modifications of NFPA 13 Rules

- Examples:
  - No omission of braces from mains or from branch lines 4 inch (100 mm) and larger based on short hanger exemption
  - Wraparound U-hangers are not permitted to brace mains, although U-bolts are permitted
  - Longitudinal bracing is required on branch lines 2-1/2 inches (65 mm) and larger
  - Cable and wire bracing is not permitted

FM Global Data Sheet Factors

Zone	S_{DS}	S_{D1}	C_p
50-year	1.3	0.8	0.9
100-year	0.9	0.45	0.65
250-year	0.55	0.25	0.4
500-year	0.55	0.25	0.4

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3. Provide Flexibility or Clearances

- Flexible couplings or fittings are required at top and bottom of riser (for each story), drops to parts of systems, hose stations and in-rack sprinklers, where piping penetrates concrete or rated walls or floors (both sides in lieu of clearances), and at expansion joints
- Seismic separation assemblies required for seismic separations above ground level

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Flexible Couplings

- Flexible coupling: "a listed coupling or fitting that allows axial displacement, rotation, and at least 1 degree of angular movement of the pipe without inducing harm on the pipe. For pipe diameters of 8 inches (203 mm) or larger the angular movement shall be permitted to be less than 1 degree but not less than 0.5 degree."

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Which Coupling Is Flexible?

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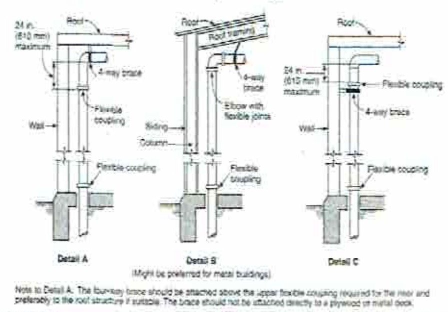
Flexible Couplings at Riser



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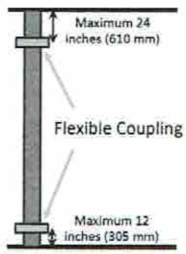
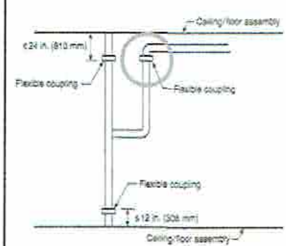
Flexible Coupling Location on Risers

- For multi-story buildings, flexible couplings are required within 12 inches (305 mm) above the floor and within 24 inches (610 mm) below the floor on each story.

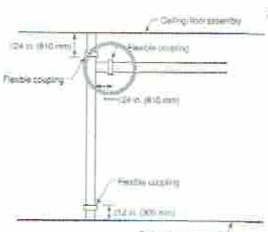


Additional Flexible Coupling on Tie-In Piping



- Where the top flexible coupling is above the tie-in to the main supplying that floor, an additional flexible coupling must be provided on the vertical portion of the tie-in piping.

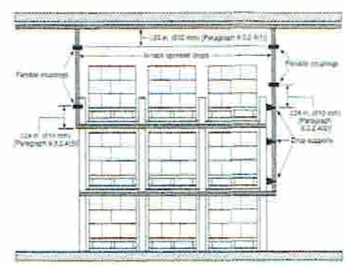
Additional Flexible Coupling on Tie-In Piping



- Where the top flexible coupling is above the tie-in to the main supplying that floor, an additional flexible coupling must be provided on the horizontal piping within 24 inches (610 mm).

Flexible Couplings on Drops

- Within 24 inches (610 mm) of the top of the drop
- Within 24 inches of:
  - The bottom of the drop with no additional supports
  - Above the uppermost support



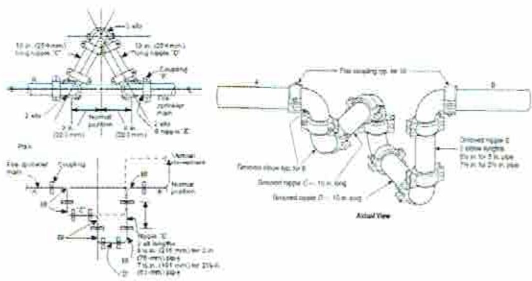
Seismic Separation Assemblies

- Used where piping crosses a seismic separation, i.e. a gap between two structures expected to move differentially during an earthquake
- Consist of six flexible elbows or a special listed flexible assembly intended to accommodate movement in any direction

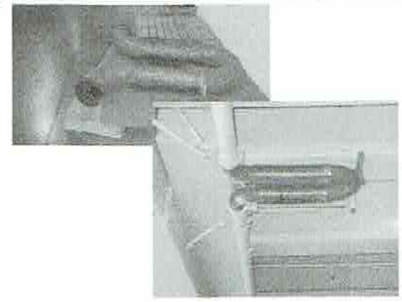
Seismic Separation Assemblies

- Required for all pipe sizes, even branch lines
- Use can be minimized with multiple risers
- Must have 4-way braces within 6 ft (1.8 m) on both sides of the assembly

Seismic Separation Assembly



Special Listed Flexible Assembly



Clearances

- Required around piping extending through walls, floors, platforms and foundations
  - Exception: Non-rated frangible construction (gypsum wallboard or similar materials)
- Required hole diameter is 2 inches (50 mm) larger than pipe diameter, 4 inches (100 mm) larger for 4-inch (100 mm) nominal and larger pipe

Clearances (continued)

- Clearances are not required if flexible couplings are provided within 12 inches (305 mm) on both sides
- NOTE: Building codes generally require sealants around penetrations through fire rated assemblies

No Clearance Required

No Clearance Required

Clearances (continued)

- Clearance from structural members not penetrated or used, collectively or independently, to support the piping shall be at least 2 in. (50mm)

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Steps for Earthquake Protection

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Horizontal Seismic Force

- Horizontal Force (Section 9.3.5.9.3)

  $F_{pw} = C_p W_p$
  - C_p = Seismic Coefficient
  - W_p = 1.15 x weight of water-filled pipe

NOTE: The weight of water-filled pipe is determined from the zone of influence of the brace (Step 6 of the 10-step process)

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Find Seismic Coefficient C_p

Table 9.3.5.9.3

S_s	C_p
0.33 or less	0.35
0.50	0.40
0.75	0.42
0.95	0.50
1.00	0.51
1.25	0.58
1.50	0.70
2.00	0.93
2.40	1.12
3.00	1.40

- S_s is the short period acceleration value (response parameter)
  - Obtained from project engineer, AHJ or seismic maps
  - Linear interpolation is permitted
- If no other value is available, use C_p = 0.5

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FM Global Data Sheet Factors

Zone	S_{DS}	S_{D1}	C_p
50-year	1.3	0.8	0.9
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Load Determination using ASCE/SEI 7

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

For sprinkler systems:

a_p= component amplication factor = **2.5** (ASCE/SEI 7)

S_{DS} = short period design acceleration **(from maps)**

R_p= component response modification factor = **4.5** (for limited-deformability pipes joined by threading or couplings)

I_p= component importance factor = **1.5** (ASCE/SEI 7)

W_p = component operating weight

NOTE: z is height of system within building h tall

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Ultimate Strength v. Allowable Stress

- Two methods exist for determining strength of materials
- ASCE/SEI 7 states: "Where a reference document provides a basis for the earthquake resistant design of a particular type of system or component, and the same reference document defines acceptance criteria in terms of allowable stresses rather than strengths, that reference document is permitted to be used...The earthquake loads determined in accordance with Section 13.3.1 shall be multiplied by a factor of 0.7...The component or system shall also accommodate the relative displacements specified in Section 13.3.2."
- *NOTE: Previous codes note to divide the loads in the reference standard by 1.4, which is equivalent to multiplying by 0.7.*

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Sway Bracing

- 9.3.5.1.1 The system piping shall be braced to resist both lateral and longitudinal horizontal seismic loads and to prevent vertical motion resulting from seismic loads.
- 9.3.5.1.2 The structural components to which bracing is attached shall be determined to be capable of carrying the added applied seismic loads.

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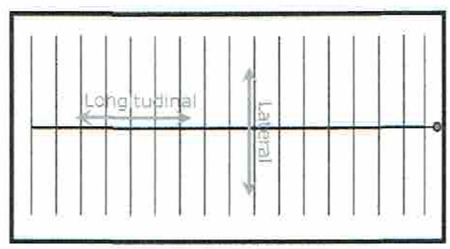
Longitudinal and Lateral Movement for a Sprinkler System Main



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Sway Bracing

Which direction does this sway brace protect?

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Tentatively Space Lateral Braces

- Maximum spacing of 40 ft (12 m) for all mains and branch lines greater than or equal to 2 ½-inch (65 mm)
- Last brace maximum 6 ft (1.8 m) from end
- Last length of pipe for mains must have lateral brace
- No lateral brace required for 2 ½-inch (65 mm) starter pieces less than 12 ft (3.6 m)
- Runs less than 12 ft (3.6 m) included with adjacent runs
- Braces within 2 ft (0.6 m) of turn can serve both mains

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Tentatively Space Lateral Braces

- Exceptions:
  - Omitted for pipes supported by rods less than 6 inches (152 mm), measured between top of pipe and point of attachment (Not allowed in 2016 edition for C_p> 0.5 or for feed mains > 6 in. or cross mains > 4 in.)
  - Omitted when U-type hooks (wraparound or tight to structure) provided legs are bent out a minimum of 30 degrees from vertical and complies with slenderness length limits of rods used for braces

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Tentatively Space Longitudinal Braces

- Longitudinal Bracing
  - Longitudinal bracing at maximum 80 ft (24 m) for all mains
  - Last brace maximum 40 ft (12 m) from end
- Braces within 2 ft (0.6 m) of turn can serve both mains

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Tentatively Space Sway Braces

- Risers
  - Both lateral and longitudinal bracing (4-way) required at the top of all risers
  - Maximum distance 25 ft (7.6 m) between 4-way braces for tall risers
  - 4-way bracing not required where risers penetrate intermediate floors in multistory buildings and clearance is not more than that required in 9.3.4.

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Excessive Flexible Couplings

- A lateral sway brace is required within 24 inches (610 mm) of every other flexible coupling installed on mains for reasons other than earthquake protection requirements, but not more than 40 ft (12.2 m) on center.
- Too much flexibility can allow excessive movement when subject to earthquake forces

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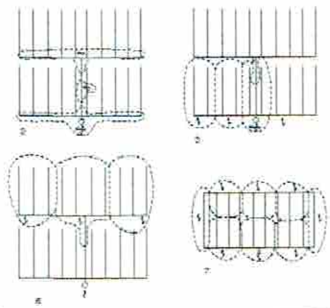
Calculate Loads to Braces

- Zone of influence (ZOI) method is required
  - Zone of influence of a longitudinal brace includes contribution of mains halfway to next brace
  - Zone of influence of a lateral brace includes contribution of mains and branch lines connected to that section of the main halfway to next brace

Zone of Influence Examples

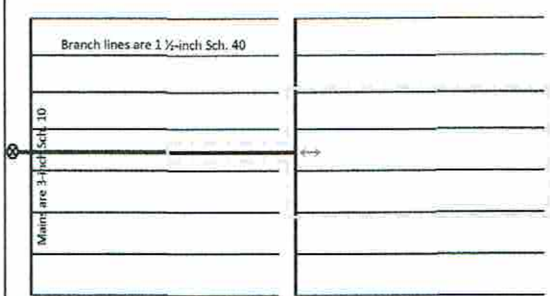


Calculate Loads to Braces

- If C_p = 0.5 for a site, then F_{pw} = 0.5 x W_p
  - Use horizontal force factors based on the site information (and S_s) or required values from the authority having jurisdiction
- NOTE: W_p is the weight of water-filled pipe times 1.15 to account for valves and fittings.

Table A.9.3.5.6 Piping Weights for Determining Horizontal Load	
Schedule 40 Pipe (in.)	Weight of Water-Filled Pipe (lb/ft)
1	2.05
1 ¼	2.93
1 ½	3.61
2	5.13
2 ½	7.89
3	10.82
4	16.40
6	31.69
8*	47.70

Load Calculation Example



 NOTE: All other bracing omitted for drawing clarity

Load Calculation Example (continued)

- Lateral Brace, near 90-degree turn in pipe
- C_p = 0.5, therefore F_{pw} = 0.5W_p
- Lateral Direction Load
  - Mains: 35 ft, Branch lines: 4 x 100 ft
- Longitudinal Direction Load
  - Mains: 40 ft
- Total Load to brace:

  F_{pw} = 0.5 [((35ft+40ft)(7.94 lb/ft)+400ft(3.61 lb/ft))*1.15]

  F_{pw} = 0.5 [(595.5 lb+1444 lb)*1.15] = 0.5 [2345.5 lb] = 1173 lbs

  NOTE: Without 15% for fittings, load would be 1020 lbs.

Maximum Lateral Brace Loads

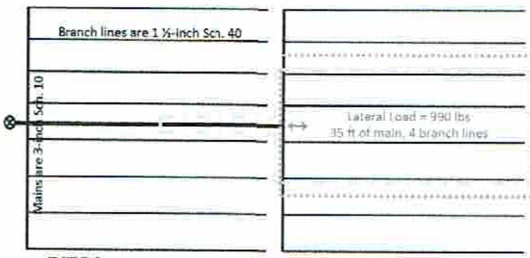
- Due to limits on pipe beam strength, the tentative load calculated for a lateral brace needs to be compared to the loads in Tables 9.3.5.5.2
- Spacing may need to be adjusted

Table shown is for Schedule 10 Steel Pipe

Sprinkler Pipe (in)	Lateral Sway Brace Spacing (ft)				
	20'	25'	30'	35'	40'
1	111	89	73	63	52
1 ¼	176	141	116	99	83
1 ½	241	193	158	136	114
2	390	312	256	219	183
2 ½	641	513	420	360	301
3	966	773	633	543	454
3 ½	1281	1025	840	720	603
4	1634	1307	1071	918	769
5	2814	2251	1844	1581	1324
6 and larger	4039	3231	2647	2269	1900

Lateral Brace Loads (continued)

- Only the lateral portion of a load needs to be considered for comparison with the Tables 9.3.5.3.2.



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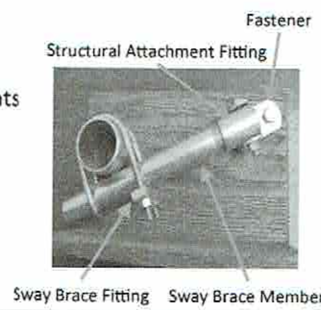
Tentatively Configure Braces

- Select type of brace and listed brace attachments (to pipe and to structure)
- Select fasteners



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UL Brace Listing Criteria

- UL 203A Definition:
  - Sway Brace Assembly - A structural system consisting of a sway brace fitting attached directly to the sprinkler pipe and one end of a sway brace, and a structure attachment fitting attached directly to the building structure and the other end of a sway brace...

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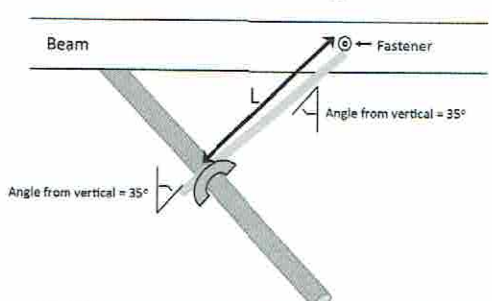
Lateral Brace Configuration



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Acceptable Materials

- Sway brace members are made of:
  - Pipe
  - Angles
  - Rods
  - Flats
  - Other structural members with slenderness ratio limited to maximum l/r = 300
- Special listed tension-only bracing systems

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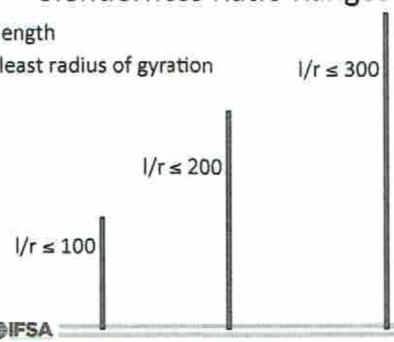
Slenderness Ratio Ranges

l = length

r = least radius of gyration



Tentatively Configure Braces (continued)

- Determine angle of brace from vertical based on pipe and point of structural attachment and the length of the brace (minimum 30°)
- The larger the angle from vertical, the more efficient the brace, and the greater the capacity

Brace Angle Zones from Vertical

Note: Zone angle strength reductions are factored into NFPA 13 tables for braces and fasteners, but must be applied to listed loads for brace fittings

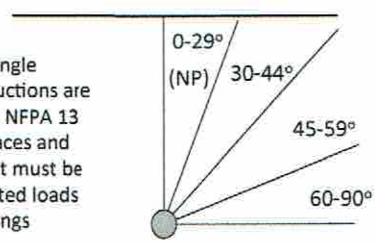


Table 9.3.511.8 (b)

Shape and Size Pipe (Schedule 40)	Maximum Length for l/r = 200	Maximum Horizontal Load (lb.)		
		30° - 44° Angle from Vertical	45° - 59° Angle from Vertical	60° - 90° Angle from Vertical
1 in	7 ft 0 in	926	1310	1604
1 ¼ in	9 ft 0 in	1254	1774	2173
1 ½ in	10 ft 4 in	1498	2119	2595
2 in	13 ft 1 in	2006	2837	3475

Table 9.3.5.11.8 Comparisons

Pipe Size (Schedule 40)	Maximum Length for:	Maximum Horizontal Load (lb.)		
		30° - 44° Angle from Vertical	45° - 59° Angle from Vertical	60° - 90° Angle from Vertical
1 inch	l/r = 100 3 ft – 6 in	3150	4455	5456
1 inch	l/r = 200 7 ft – 0 in	926	1310	1604
1 inch	l/r = 300 10 ft – 6 in	412	582	713

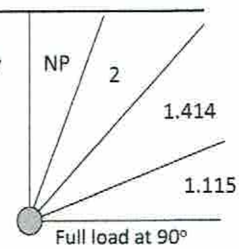
Sway Bracing - Brace Fittings

- Fittings must be listed for maximum load at horizontal position (90-degree angle with vertical)
- Reductions for braces and fasteners are in tables, but must be applied to fittings
- Fasten tight and concentric
  - Avoid eccentric loadings
- Welded tab attachment acceptable for longitudinal braces

Table 9.3.5.2.3 Allowable Horizontal Load on Brace Assemblies	
Brace Angle from Vertical	Allowable Horizontal Load
30° - 44°	Divide listed load rating by 2.000
45° - 59°	Divide listed load rating by 1.414
60° - 89°	Divide listed load rating by 1.155
90°	Listed load rating

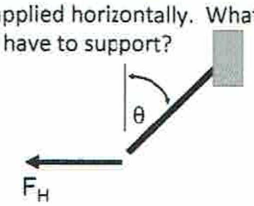
Brace Fitting Load Reductions

Listed load capability must be divided by:



Brace Fitting Reduction Factor Origin

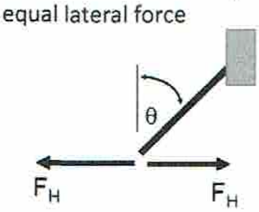
- Assume a listed brace installed at θ has 100 lb load applied horizontally. What does the brace have to support?



Brace Fitting Reduction Factor Origin

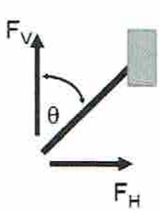
(continued)

- Horizontal load is resisted by brace in tension with equal lateral force



Brace Fitting Reduction Factor Origin

(continued)

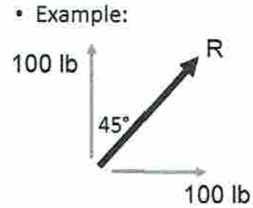


$$\tan\theta = \frac{F_H}{F_V}$$

There must be a vertical component to force due to brace angle

Brace Fitting Reduction Factors

- Example:



$$\sin\theta = \frac{F_H}{R}$$

$$\sin 45 = \frac{100}{R}$$

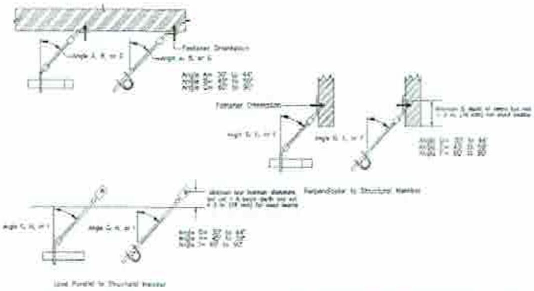
R = 141 lb

141 lb / 1.41 = 100 lb to account for higher loads

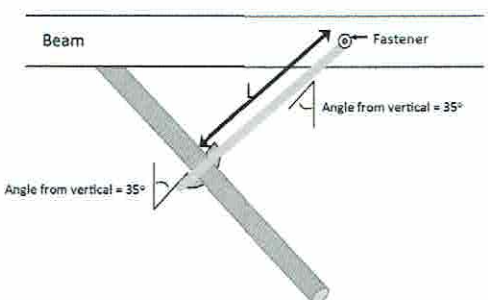
Sway Bracing - Fasteners

- Structural components must be capable of carrying the added applied loads.
- Pipe must not be fastened to building sections which will move differently.
- Fastener load tables based on various orientation/angle conditions of lag screws in wood, through bolts in wood, expansion shields in concrete and through bolts in steel.

Figure 9.3.5.12.1 Maximum Loads for Various Fasteners to Structure



Fastener Category?



Sway Bracing – Fasteners (continued)

- C-type clamps (with or without retaining straps) prohibited from brace attachment
- Powder-driven fasteners not permitted to attach braces unless specifically listed for this service.
- Concrete anchors used for sway braces must be qualified by ACI 355.2
  - This is a cracked concrete test to ensure strength of fasteners should the concrete crack due to seismic forces

Vertical Loads

- Normally expected to be handled by gravity, with excessive uplift addressed by the braces in combination with system hangers
- Where horizontal force factors exceed 0.5 W_p and the brace angle is less than 45 degrees from vertical, or where the horizontal force factor exceeds 1.0 W_p and the brace angle is less than 60 degrees from vertical, braces must be arranged to resist the net vertical reaction produced by the horizontal load

Steps for Earthquake Protection

1. Investigate if earthquake protection is needed
2. Verify acceptance of NFPA 13 criteria
3. Provide flexibility or clearances
4. Determine the horizontal force
5. Tentatively space braces
6. Calculate loads to braces
7. Tentatively configure braces
8. **Confirm adequacy of braces, fittings, and fasteners**
9. Add restraint as required
10. Check proposed hanging arrangements

Confirm Adequacy of Braces, Fittings and Fasteners

- Allowable loads for brace assemblies are based on "weakest link" of braces, brace fittings, and fasteners
- The brace itself (pipe, angle, rod, etc.) generally has greater capacity than the fittings or fasteners
- Allowable loads reduced with length and increased with angle from vertical

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Seismic Bracing Calculation Form

- Annex figures A.9.3.5 (a) and (b) of NFPA 13 aid in the preparation of bracing calculations

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Steps for Earthquake Protection

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2. Verify acceptance of NFPA 13 criteria
3. Provide flexibility or clearances
4. Determine the horizontal force
5. Tentatively space braces
6. Calculate loads to braces
7. Tentatively configure braces
8. Confirm adequacy of braces, fittings, and fasteners
9. **Add restraint as required**
10. Check proposed hanging arrangements

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Restraint

- Restraint is a lesser degree of preventing movement than a brace
- Restraining devices are NOT required to be listed
- Restraint is required:
  - At ends of branch lines
  - Along branch lines, spacing based on C_p
  - For sprigs (sprig-ups) over 4 ft (1.2 m) in length

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Mexico City Earthquake Sept 2017

Unrestrained sprigs pounded against structural members, opening two sprinklers in the exhibition hall during the AMRACI fire sprinkler conference

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Restraint Options

- Listed sway brace assembly
- Wrap around U-hook
- No. 12 wire on both sides
- Hanger at 45 degrees or more from vertical with a maximum l/r of 400 for the rod in the assembly
- Other approved means

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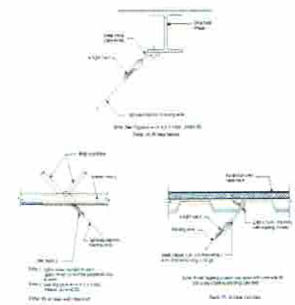
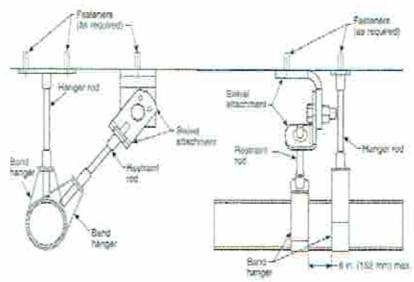
Maximum Restraint Spacing

Pipe (in.)	Restraint Distance for Steel Pipe (ft)		
	$C_p \le 0.5$	$0.5 < C_p \le 0.71$	$C_p > 0.71$
1	43	36	26
1 ¼	46	39	27
1 ½	49	41	29
2	53	45	31

Use of Splayed Wire for Restraint



Hanger as Restraint



Steps for Earthquake Protection

1. Investigate if earthquake protection is needed
2. Verify acceptance of NFPA 13 criteria
3. Provide flexibility or clearances
4. Determine the horizontal force
5. Tentatively space braces
6. Calculate loads to braces
7. Tentatively configure braces
8. Confirm adequacy of braces, fittings, and fasteners
9. Add restraint as required
10. **Check proposed hanging arrangements**

Hanger Limitations

- C-type clamps used for hanging pipe must be equipped with retaining straps
  - 16-gauge steel strap minimum 1 inch (25 mm) wide for pipe up to 8-inch (200 mm) diameter
- Powder-driven fasteners not permitted for hanging pipe in strong earthquake areas (F_{pw}>0.5W_p) unless specially listed
- Concrete anchors may need to be prequalified by ACI 355.2 in high seismic risk areas

Sprinkler Escutcheons

- Seismic Design Categories D, E, and F with suspended ceilings
  - 2-inch (50-mm) oversized hole required for sprinkler penetrations
    - Unless the ceiling system is braced in accordance with ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions*
    - Unless a flexible connection is used

Steps for Earthquake Protection

1. Investigate if earthquake protection is needed
2. Verify acceptance of NFPA 13 criteria
3. Provide flexibility or clearances
4. Determine the horizontal force
5. Tentatively space braces
6. Calculate loads to braces
7. Tentatively configure braces
8. Confirm adequacy of braces, fittings, and fasteners
9. Add restraint as required
10. Check proposed hanging arrangements

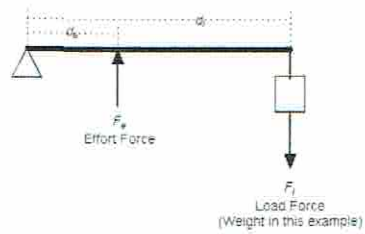
Recent Changes to NFPA 13

- Tables of Maximum Loads for Wedge Anchors provided for:
  - 3000 psi lightweight cracked concrete on metal deck
  - 3000 psi lightweight cracked concrete
  - 3000 psi normal weight cracked concrete
  - 4000 psi normal weight cracked concrete
  - 6000 psi normal weight cracked concrete
- Also Table for Undercut Anchors in 3000 psi normal weight cracked concrete
- Tables include consideration of prying factors

Prying Factors

3.11.9 (Added by TIA August 2015) – A factor based on fitting geometry and brace angle from vertical that results in an increase in tension load due to the effects of prying between the upper seismic brace attachment fitting and the structure.

Class 3 Lever



$F_e d_e = F_l d_l$ so $F_e = F_l d_l / d_e$

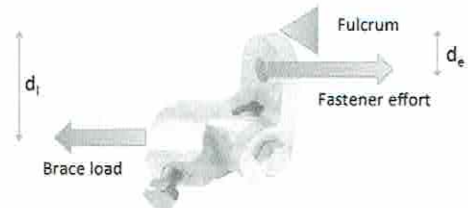
Sway Brace Attachment Loads

This sway brace attachment would place the anchoring fastener mostly in shear (G,H, or I)

Sway Brace Attachment Loads

With a brace coming in at 90 degrees, the fastener would be challenged in tension

Sway Brace Attachment Loads



$F_e = F_l\, d_l / d_e$

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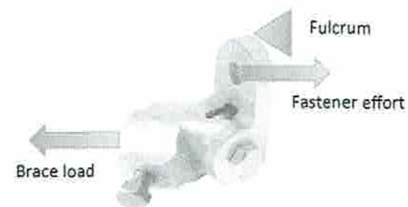
Sway Brace Attachment Loads



$F_e = F_l\, d_l / d_e$ Since $d_l > d_e$ then $F_e > F_l$ (the loading on the fastener exceeds the load of the brace). Therefore the "allowable load" of the fastener must be must be reduced by a prying factor

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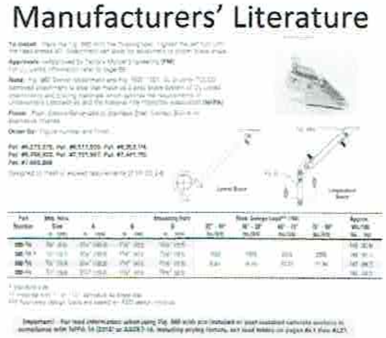
Manufacturers' Literature



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Comparing to NFPA 13 Values

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Questions?

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Thank you for attending!

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Exercise #1 – Seismic Separation Assembly

Annex Figure A-9.3.3 (a) details a seismic separation assembly for an 8-inch (200 mm) separation crossed by 4-inch (100 mm) diameter sprinkler pipe.

If a 6-inch (150 mm) separation is crossed using a 6-inch (150 mm) pipe, determine:

a) the lengths of nipples C, D, and E

b) the distance from centerline of the two end elbows when in the "normal position" as shown in the elevation view

Hint: The take-out for a 6-inch (150 mm) elbow is 6.5 inches (165 mm)

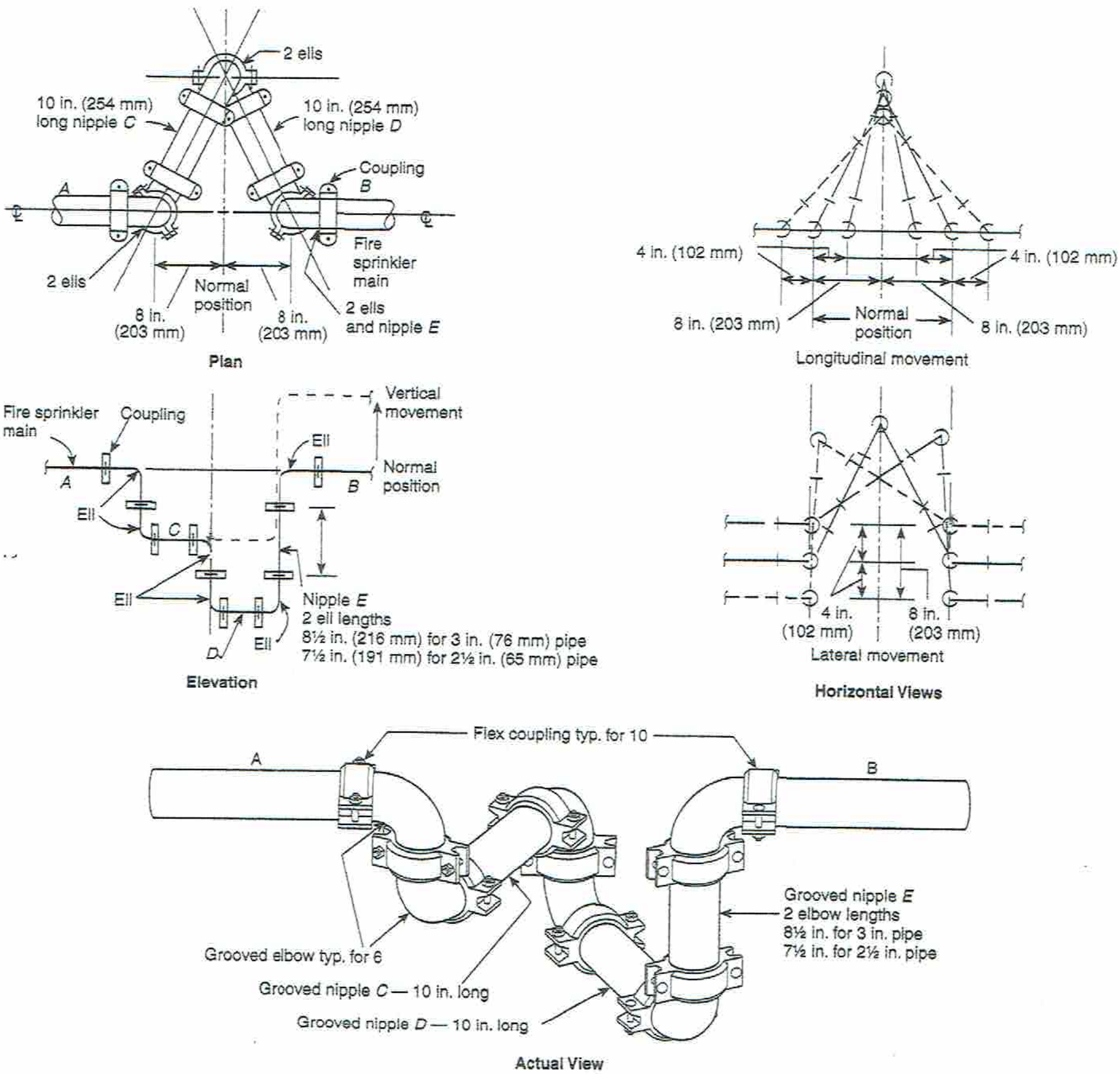
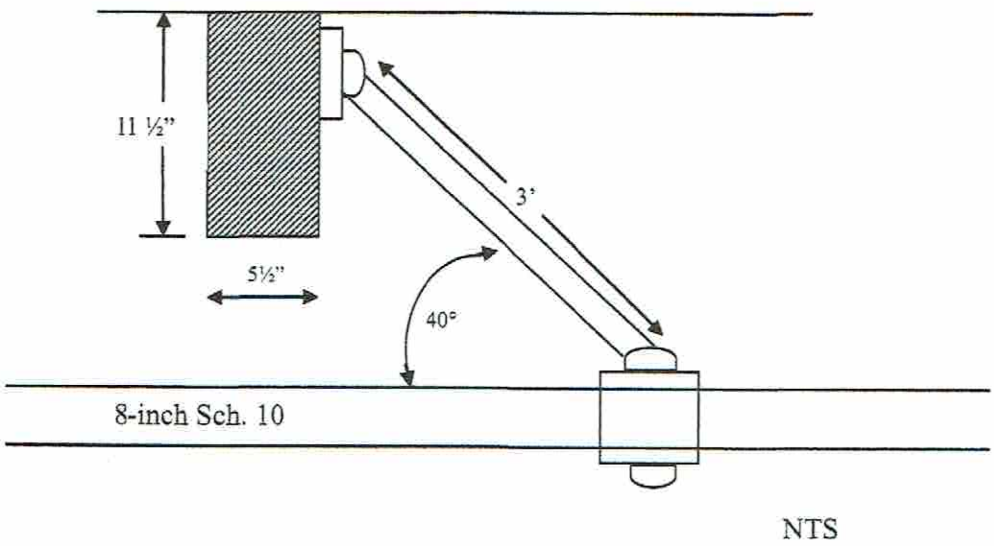


FIGURE A.9.3.3(a) Seismic Separation Assembly in which 8 in. (203 mm) Separation Crossed by Pipes Up to 4 in. (102 mm) in Nominal Diameter. (For other separation distances and pipe sizes, lengths and distances should be modified proportionally.)

Exercise #2 – Allowable Sway Brace Assembly Loads

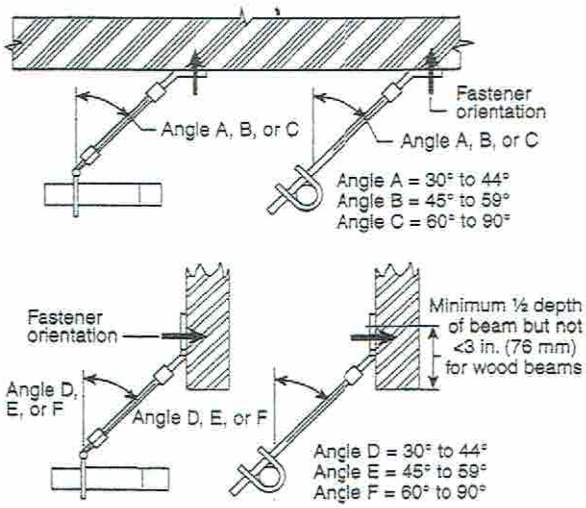


A 1-inch schedule 40 steel pipe is to be used as a longitudinal brace connecting an 8-inch main to a nominal 6 x 12 wood beam with a single ⅝-inch through bolt. Assume the sway brace attachment is listed for a load of 800 lbs.

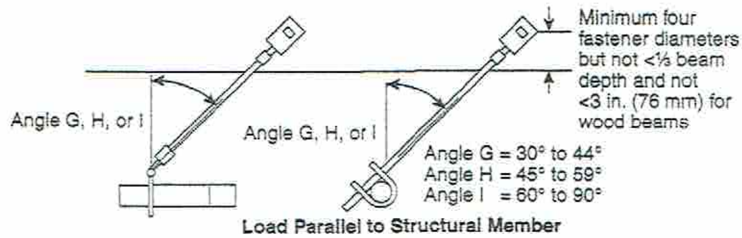
What is the maximum allowable load capacity of:

1. The brace ____________________
2. The attachment ________________
3. The (through bolt) fastener __________

What is the minimum distance of the bolt from the bottom of the beam? ________________



Load Perpendicular to Structural Member



Load Parallel to Structural Member

Wedge Anchors in 3000 psi Lightweight Concrete-Filled Metal Decking										
Diameter (in.)	Embedment (in.)	A	B	C	D	E	F	G	H	I
⅜	2	116	216	420	—	—	—	—	—	—
½	3¼	215	406	826	—	—	—	—	—	—
⅝	4	369	673	1282	—	—	—	—	—	—

Wedge Anchors in 3000 psi Norma Weight Cracked Concrete										
Diameter (in.)	Embedment (in.)	A	B	C	D	E	F	G	H	I
⅜	2	173	308	557	321	308	301	458	591	678
½	3¼	391	713	1358	784	713	678	1215	1537	1741
⅝	4	553	1021	2008	1159	1021	956	1904	2378	2671
¾	4¾	717	1332	2638	1523	1332	1243	2536	3155	3537

Undercut Anchors in 3000 psi Normal Weight Concrete										
Diameter (in.)	Embedment (in.)	A	B	C	D	E	F	G	H	I
⅜	4	685	1106	1714	989	1106	1187	1171	1571	1849
½	5	855	1479	2552	1473	1479	1483	1975	2582	2988
⅝	7½	1153	2041	3675	2121	2041	1997	3022	3902	4478

Wedge Anchors in 3000 psi Lightweight Cracked Concrete										
Diameter (in.)	Embedment (in.)	A	B	C	D	E	F	G	H	I
⅜	2	110	206	410	236	206	191	396	492	551
½	3¼	245	467	970	559	467	426	1021	1239	1368
⅝	4	344	661	1406	811	661	597	1569	1876	2055
¾	4¾	446	859	1639	1061	859	774	2078	2476	2706

Wedge Anchors in 4000 psi Normal Weight Cracked Concrete										
Diameter (in.)	Embedment (in.)	A	B	C	D	E	F	G	H	I
⅜	2	196	342	600	345	342	341	473	616	711
½	3¼	443	797	1477	852	797	769	1264	1616	1842
⅝	4	627	1147	2198	1268	1147	1088	1990	2513	2843
¾	4¾	816	1498	2891	1668	1498	1414	2653	3339	3770

Wedge Anchors in 6000 psi Normal Weight Cracked Concrete										
Diameter (in.)	Embedment (in.)	A	B	C	D	E	F	G	H	I
⅜	2	232	394	661	381	394	402	492	646	754
½	3¼	528	928	1649	951	928	916	1326	1720	1979
⅝	4	750	1344	2474	1428	1344	1300	2102	2694	3077
¾	4¾	976	1756	3261	1882	1756	1691	2807	3587	4089

Connections to Steel (Values Assume Bolt Perpendicular to Mounting Surface)																	
Diameter of Unfinished Steel Bolt (in.)																	
¼									⅜								
A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
400	500	600	300	500	650	325	458	565	900	1200	1400	800	1200	1550	735	1035	1278
Diameter of Unfinished Steel Bolt (in.)																	
½									⅝								
A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
1600	2050	2550	1450	2050	2850	1300	1830	2260	2500	3300	3950	2250	3300	4400	2045	2880	3557

Through-Bolts in Sawn Lumber or Glue-Laminated Timbers (Load Perpendicular to Grain)																												
		Bolt Diameter (in.)																										
		½									⅝									¾								
Length of Bolt in Timber (in.)		A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
	1½	115	165	200	135	230	395	130	215	310	135	190	235	155	270	460	155	255	380	155	220	270	180	310	530	170	300	450
	2½	140	200	240	160	280	480	165	275	410	160	225	280	185	320	550	190	320	495	180	255	310	205	360	615	215	365	575
	3½	175	250	305	200	350	600	200	330	485	200	285	345	230	400	685	235	405	635	220	310	380	255	440	755	260	455	730
	5½	—	—	—	—	—	—	—	—	—	280	395	485	325	560	960	315	515	735	310	440	535	360	620	1065	360	610	925

Lag Screws and Lag Bolts in Wood (Load Perpendicular to Grain — Holes Predrilled Using Good Practice)																												
		Lag Bolt Diameter (in.)																										
		⅜									½									⅝								
Length of Bolt in Timber (in.)		A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
	3½	165	190	200	170	220	310	80	120	170	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	4½	180	200	200	175	235	350	80	120	170	300	355	380	315	400	550	145	230	325	—	—	—	—	—	—	—	—	—
	5½	190	200	200	175	245	380	80	120	170	320	370	380	320	420	610	145	230	325	435	525	555	425	550	775	195	320	460
	6½	195	205	200	175	250	400	80	120	170	340	375	380	325	435	650	145	230	325	465	540	555	430	570	840	195	320	460

Note: Wood fastener maximum capacity values are based on 2001 National Design Specifications (NDS) for wood with a specific gravity of 0.35. Values for other types of wood can be obtained by multiplying the above values by the following factors:

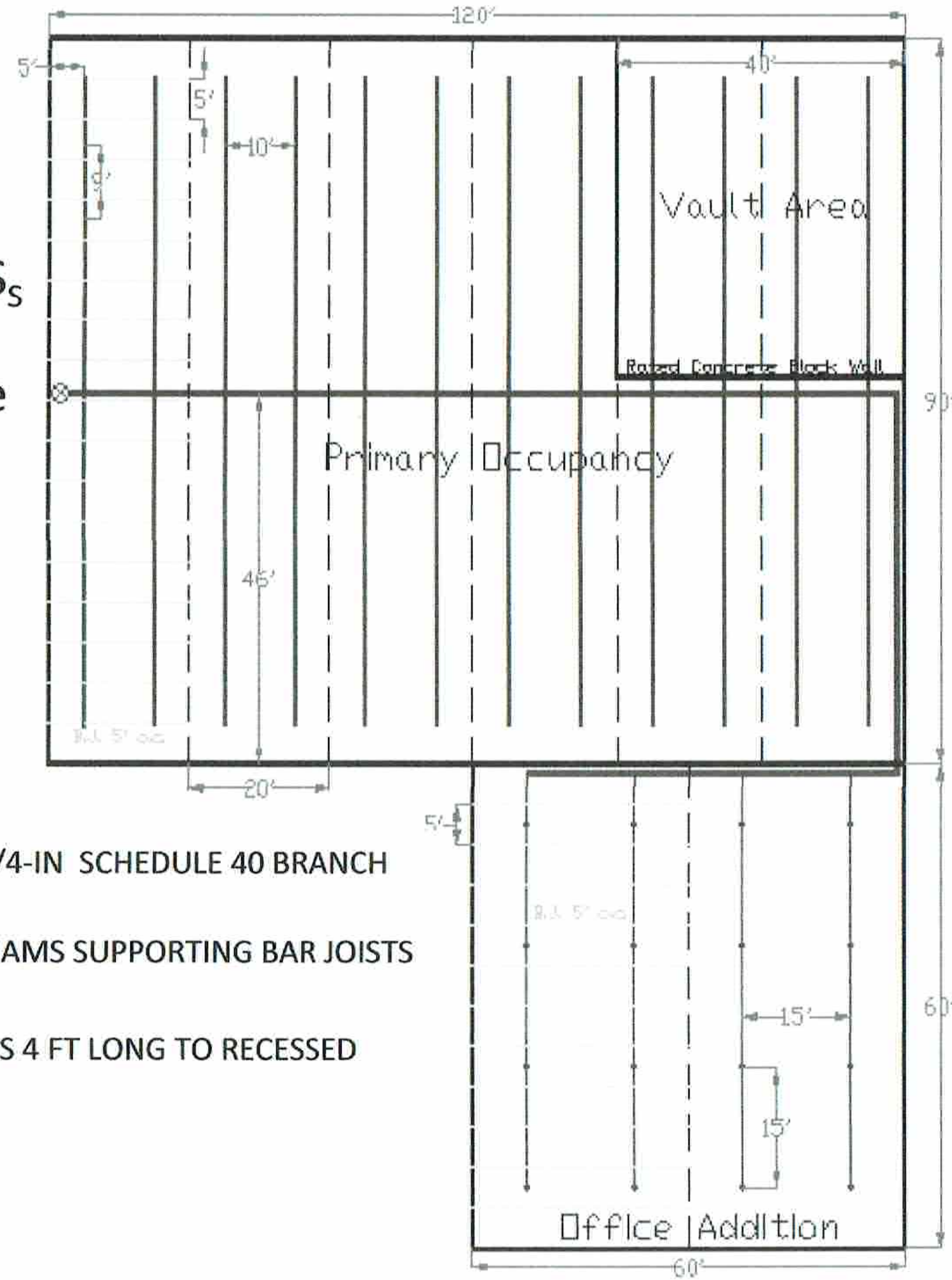
Specific Gravity of Wood	Multiplier
0.36 thru 0.49	1.17
0.50 thru 0.65	1.25
0.66 thru 0.73	1.50

For SI values, 1 in. = 25.4 mm.

FIGURE 9.3.5.12.1 Maximum Loads for Various Types of Structures and Maximum Loads for Various Types of Fasteners to Structures.

Exercise 3

Given this piping layout in a 1-story building in an area with S_S = 0.3, show the location for minimum required earthquake protection features such as braces ↔, flexible couplings F, clearances C, seismic separation assemblies > , and restraints &



MAIN BUILDING HAS UPRIGHT SPRINKLERS ON 1-1/4-IN SCHEDULE 40 BRANCH LINES 12 IN BELOW FLAT ROOF

BUILDING IS DIVIDED INTO BAYS BY 2-FT STEEL I-BEAMS SUPPORTING BAR JOISTS

ALL MAINS 4-IN SCHEDULE 10

NEW FREE-STANDING OFFICE ADDITION HAS DROPS 4 FT LONG TO RECESSED SPRINKLERS IN A RIGID METAL CEILING

ALL PIPING IS THREADED