FIRE FOLLOWING EARTHQUAKE

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1.0 SCOPE

This data sheet provides recommendations for protection against fires following earthquakes. It applies to locations in FM 50-year through 500-year earthquake zones as defined in Data Sheet 1-2, *Earthquakes.*

Recommendations in this document address prevention of ignition sources following an earthquake, as well as protection for piping and equipment containing flammable gas and ignitable liquid, and are generally applicable to most occupancies. However, a few fire following earthquake recommendations in other data sheets that modify or expand on the recommendations in this data sheet for some specific occupancies or situations are noted.

This data sheet does not cover recommendations for oxygen systems or other oxidizers that could contribute to a possible fire following an earthquake.

This data sheet does not contain recommendations related to earthquake protection of fire protection systems or water supplies; see Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems,* and Data Sheet 3-2, *Water Tanks for Fire Protection.*

1.1 Hazards

Improperly protected piping and equipment can move violently and with extreme force during an earthquake, causing breaks in piping and connections as well as sudden movement and toppling of equipment, even when structures are not damaged by the earthquake. This can result in leakage of flammable gas and spills of ignitable liquid contained in piping, tanks, and other reservoirs, as well as in the creation of unexpected ignition scenarios. Such accidents could potentially lead to fires and explosions following an earthquake, and present a concern even in well-protected facilities because an earthquake may also cause impairments to water supplies and automatic sprinkler systems. 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

April 2025. Interim revision. Minor editorial changes were made.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The recommendations in this data sheet are applicable to FM 50-year through 500-year earthquake zones as shown in Data Sheet 1-2, *Earthquakes,* and are intended to prevent and control accidental releases of flammable gas and ignitable liquid, and the creation of possible ignition sources following damaging ground shaking.

Seismic protection should be systematically provided. Equipment containing flammable gas or ignitable liquid, or presenting potential ignition sources should be braced and anchored for the expected seismic loads; piping carrying flammable gas or ignitable liquid should be designed and braced for the expected seismic loads and provided with adequate clearances, flexibility, and with means for automatic fuel shutoff in the event of strong ground shaking.

Several recommendations are aimed at restraining nonstructural components to the building structure. This may result in additional seismic loads to certain structural members and systems. When it is not obvious they are adequate, prior to attachment verify that such structural members and systems, as well as the actual points of attachment, have been determined to be capable of carrying the additional anticipated seismic loads by a qualified structural engineer.

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 Ignition Source Control

2.2.1 Provide anchorage for stationary equipment where toppling or movement as a result of an earthquake could result in potential ignition sources inside structures or create possible exposure fires. These would usually include electrical equipment, such as power transformers, bus bars, electrical switchgear, electrical panels, motor control centers and other similar equipment; equipment with hot surfaces, open flames or containing molten material; or, process equipment where hazardous chemical interactions could result in potential fire. See Data Sheet 1-2 (particularly the design requirements in Section 2.2 and the discussion regarding equipment anchorage design in Appendix C) for further information.

2.3 Equipment and Processes

2.3.1 Equipment Restraint and Anchorage

2.3.1.1 Provide seismic restraint of equipment utilizing ignitable liquid and flammable gas, including small units and units that are considered non-critical to operation. In general, equipment should either be anchored to the floor or braced from the overhead structure (see Figure 2.3.1.1), but not both due to the potential for differential motion. Provide anchorage or bracing to resist lateral translation or sliding, uplift or overturning, and rotation or swaying. Use means of restraint that provide for positive attachment (e.g., a through-bolted connection) and that do not rely on friction effects alone.

Fig. 2.3.1.1. Example of restraint for suspended space heaters

2.3.1.2 Design equipment anchorage and restraint to resist the anticipated seismic loads for the installed location of the equipment within the structure. Determine horizontal seismic forces in accordance with the requirements of the local building code, for the code's seismic zone involved, but not less than a horizontal force equal to 50% of the weight of the equipment acting on the equipment's center of gravity. See Data Sheet 1-2 (particularly the design requirements in Section 2.2 and the discussion regarding equipment anchorage design in Appendix C) for further information.

2.3.1.3 Provide anchorage of base-supported (floor mounted) equipment with anchor bolts through mounting holes provided in (or hardware attached to) the base of the equipment (or frame). (See typical examples in Figure 2.3.1.3, Details A and B.) Where anchors are not installed symmetrically, design anchors to resist the resulting expected torsional forces. Where vibration isolation is needed, provide independent seismic restraint in the form of stops and guides (snubbers) or use vibration isolation assemblies designed to resist seismic forces. Install snubbers with an air gap to allow vibratory oscillation of the equipment until seismic forces cause temporary contact with restraint and limit overall displacement. Secure snubbers with anchor bolts (see typical examples in Figure 2.3.1.3., Details C and D).

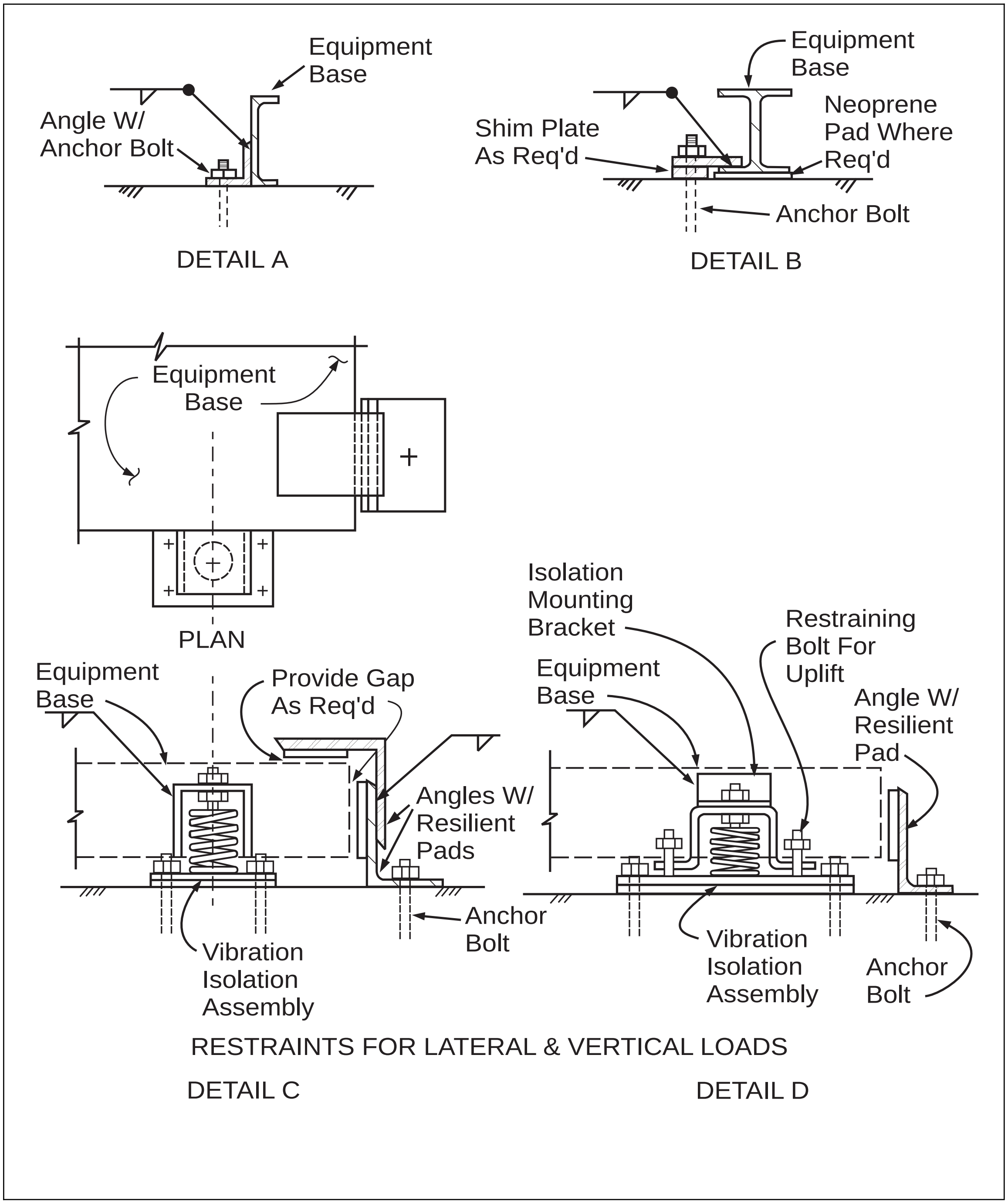

Fig. 2.3.1.3. Example of seismic restraint system for base-supported equipment (Source: ARMY TM 5-809-10)

2.3.1.4 Provide overturning restraint for equipment where it cannot be ensured that base anchorage alone can resist overturning. Low profile equipment (height to least-width ratio equal to 1 or less) will have less tendency to overturn than high profile equipment. Very tall equipment with narrow bases and without lateral braces require very high capacity base anchorage to resist overturning. High and low lateral braces are very effective in preventing overturning even without base anchorage. For an example of high profile equipment with two levels of restraint see the water heater tank in Figure 2.3.1.4.

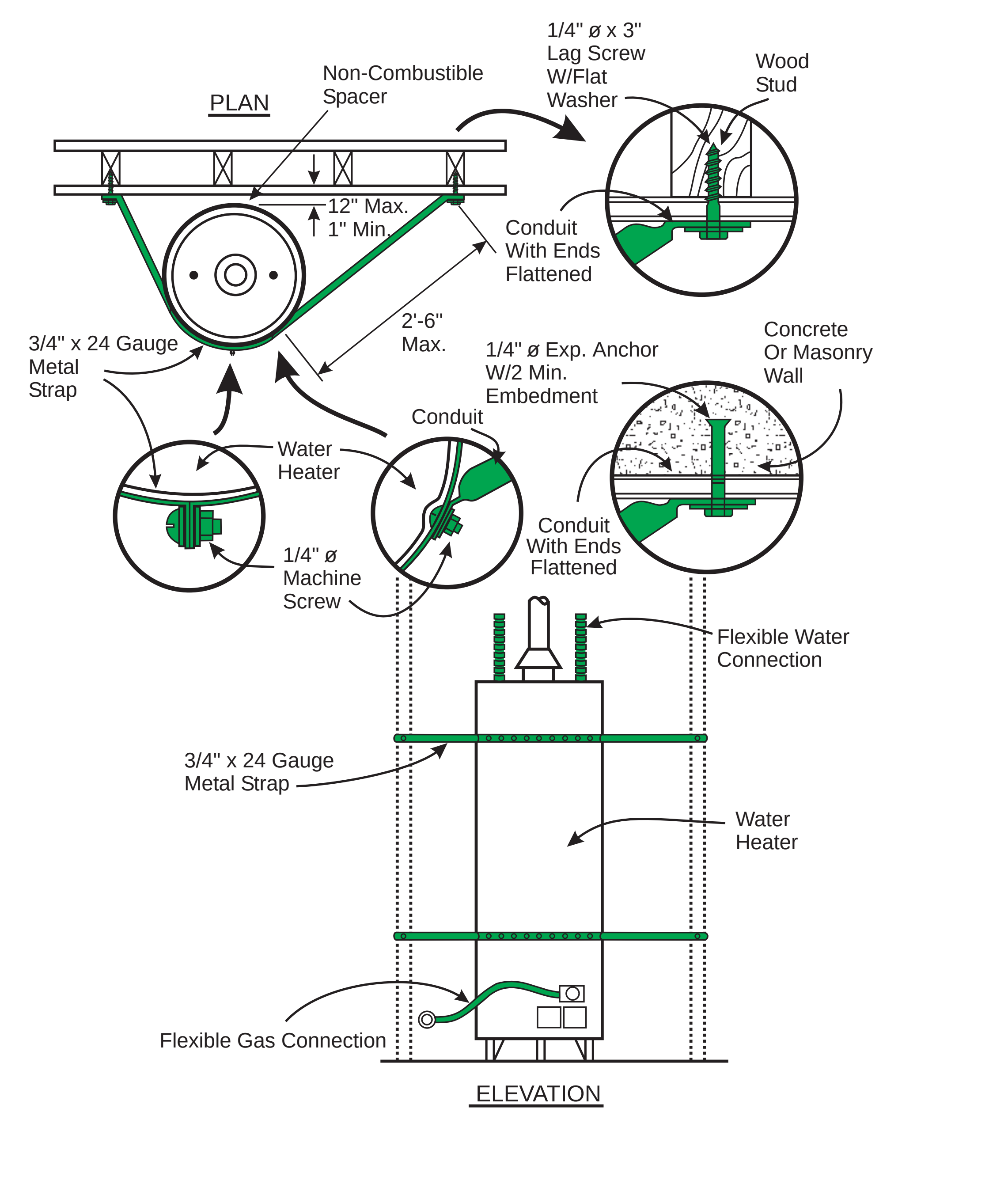

Fig. 2.3.1.4. Example of a 50 gal (200 liter) water heater restraint (source: FEMA 74)

2.3.1.5 For equipment suspended from the overhead structure, provide restraint to resist the expected seismic forces in all lateral directions. An example of such restraint is the installation of cross or diagonal bracing on each side of the equipment as shown in Figure 2.3.1.5. Where the equipment is mounted on a frame, restrain the equipment to the frame and restrain the frame to the building structure. Design the frame to resist the seismic forces. Cross and diagonal bracing on all sides is frequently used to strengthen equipment frames. See examples in Figure 2.3.1.1 and Figure 2.3.1.5.

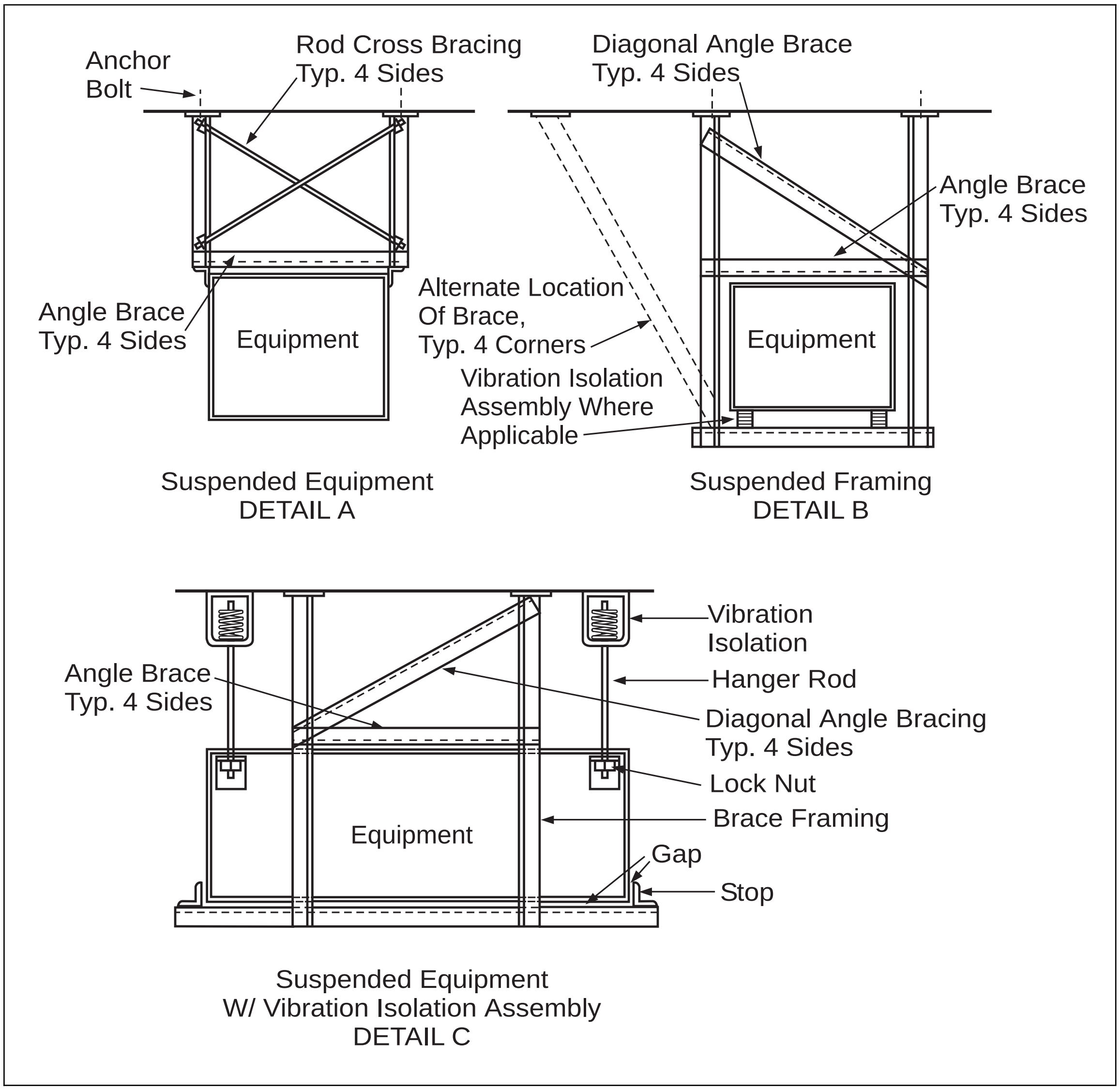

Fig. 2.3.1.5 Example of seismic restraint for suspended equipment, such as a suspendedspace heater (source: ARMY TM 5-800-10)

2.3.1.6 The members making up the equipment supporting framework, horizontal, vertical, diagonal and cross bracing should have a maximum slenderness ratio (i.e., l/r or length/least radius of gyration) of 200 unless they are designed for tension only. Examples of members that could possibly be designed for tension only are the vertical members of a suspended framework and both cross bracing members of any framework. The preferred l/r limit for tension members is 300 because it reduces vibration tendencies. Tables 2.3.1.6A through 2.3.1.6F give the maximum lengths of various shapes of brace members for different l/r values.

Notes for Tables 2.3.1.6A through 2.3.1.6F:

Note 1: The slenderness ratio, l/r, is defined as a brace length/least radius of gyration. The least radius of gyration, r, can be determine for various brace shapes as follows:

Pipe: $r = [\sqrt{(r_o^2 - r_i^2)}]/2$

where

r_o = radius of outside pipe wall

r_i = radius of inside pipe

Rods: r = (radius of rod/2)

Flats: r = 0.29h

where h = smaller dimension of two sides.

(Angles require a much more detailed calculation.)

Note 2: The steel yield stress (F_y) value used to generate the tables was taken as the yield stress for commonly used steel.

Table 2.3.1.6A. Maximum Horizontal Loads (lb) for Steel Sway Brace Members in Compression (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 2.3.1.6B. Maximum Horizontal Loads (N) for Steel Sway Brace Members in Compression (Metric) (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 2.3.1.6C. Maximum Horizontal Loads (lb) for Steel Sway Brace Members in Compression (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 2.3.1.6D. Maximum Horizontal Loads (N) for Steel Sway Brace Members in Compression (Metric) (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 2.3.1.6E. Maximum Horizontal Loads (lb) for Steel Sway Brace Members in Compression (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 2.3.1.6F. Maximum Horizontal Loads (N) for Steel Sway Brace Members in Compression (Metric) (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

2.3.1.7 Use fasteners that provide a positive form of attachment (i.e., don't rely on friction alone), and that have code-recognized (e.g., *International Building Code*) shear and tension capacity to resist the expected seismic loads. Such fasteners include anchors and embedded inserts that are cast-in-place in concrete, or through-bolts in steel or wood framework. Lag bolts are acceptable when properly installed and sized. Anchors relying on friction or proprietary anchors, such as post-drilled concrete expansion anchors, are only acceptable if FM Approved for the intended application. Because they have low capacity and often don't remain in place during the dynamic loading that occurs during an earthquake, do not use powder driven fasteners or C-clamps for equipment anchorage. See Data Sheet 1-2 for additional information regarding anchorage to concrete (post-installed anchors, in particular).

2.3.2 Flammable Gas Cylinders and Ignitable Liquid Cabinets, Drums, and Tanks

2.3.2.1 Tightly restrain the top and bottom of flammable gas cylinders and secure to a structure, such as shown in Figure 2.3.2.1A. Restraint can be accomplished using thin (e.g., 24 gauge [0.0239 in. or 0.61 mm] steel straps or nylon straps or steel chains of adequate strength to resist forces specified in Recommendation 2.3.2.2. For cylinder packs, provide a rack structure secured to the floor or to a structural member of the building, and restrain cylinders individually to the rack (see example in Figure 2.3.2.1B). For movable cylinder racks, provide tethering secured to the structure in order to limit uncontrolled movement during an earthquake and to avoid collisions that could damage cylinders or other nearby equipment.

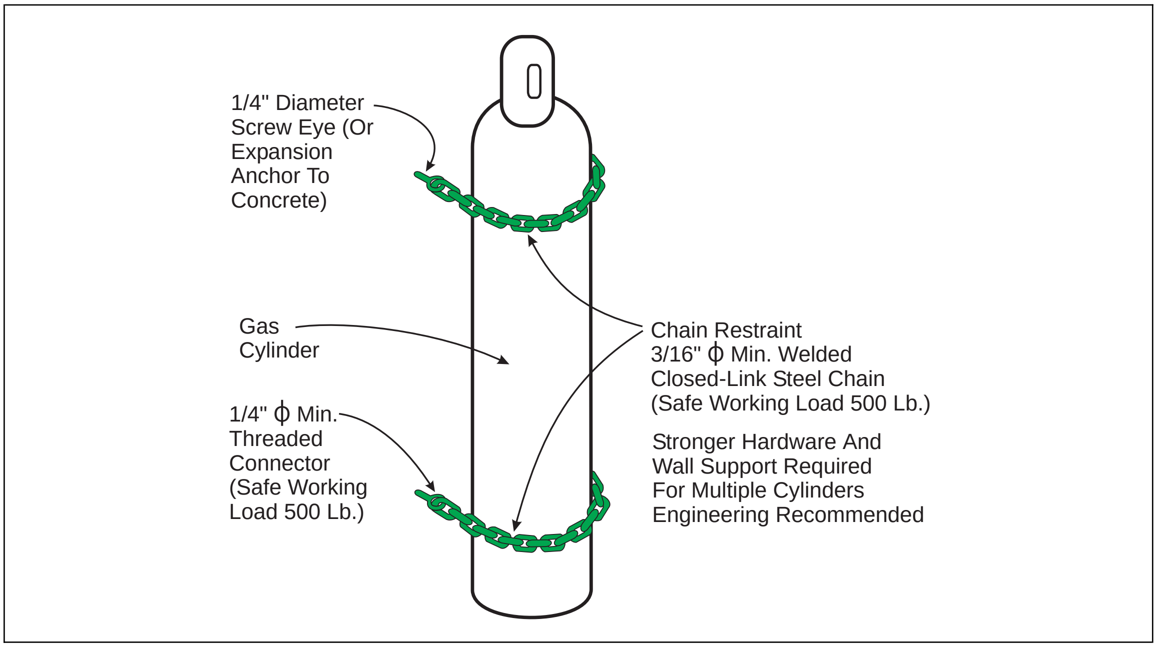

Fig. 2.3.2.1A. Example of individual cylinder restraint (source: FEMA 74)

Fig. 2.3.2.1B. Example of multiple cylinder restraint arrangement

2.3.2.2 For flammable gas cylinders inside gas cabinets, restrain individual cylinders to the cabinet and anchor the cabinet to the structure.

2.3.2.3 Where ignitable liquids are stored in FM Approved ignitable liquid cabinets, keep doors closed and latched. Restrain cabinets to the structure without altering their original configuration or interfering with the operation of vents and doors. In existing cabinets that are not provided with welded anchorage attachments by the manufacturer, toppling protection can be accomplished by installing thin steel bands (e.g., 24 gauge [0.0239 in. or 0.61 mm]), nylon straps or steel cables of adequate strength to resist forces specified in Recommendation 2.3.1.2 around the top header of the cabinet, securely anchored to the building structure. Sliding protection can be accomplished by floor-anchored stops (e.g., angle iron) installed tightly against all sides of the cabinet. See example in Figure 2.3.2.3.

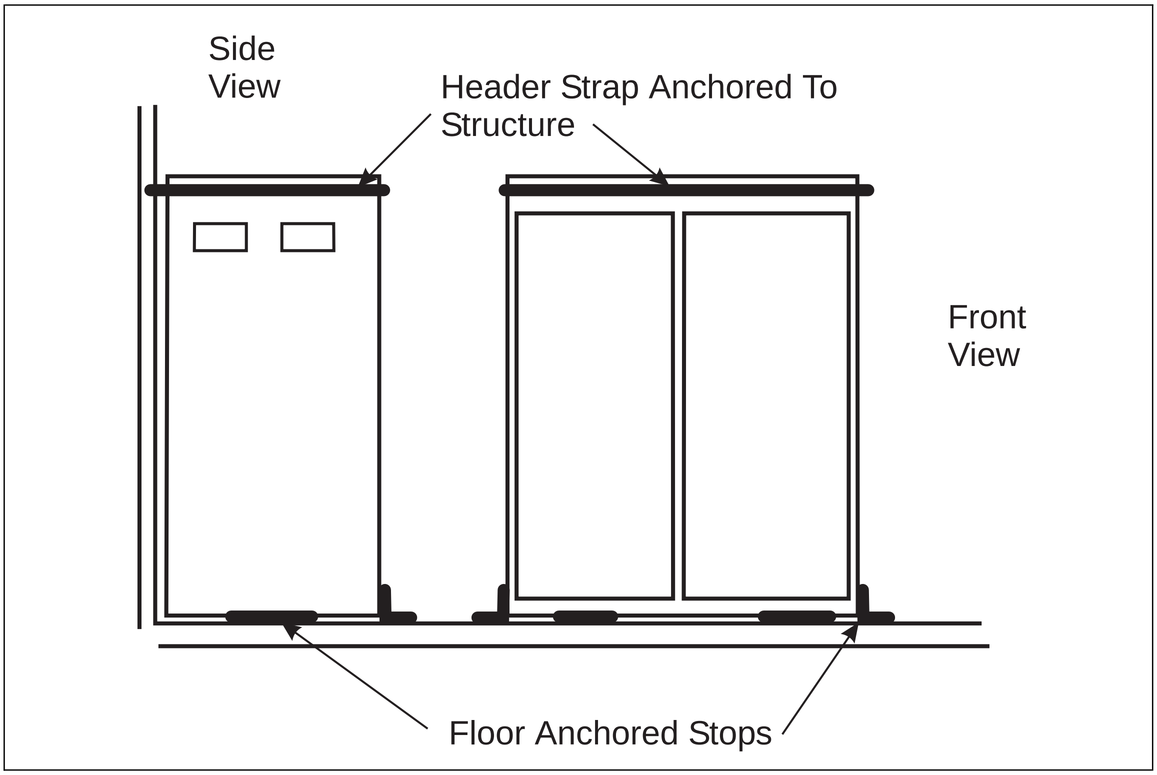

Fig. 2.3.2.3. Example of possible restraint for ignitable liquid cabinet

2.3.2.4 Use only FM Approved drum dispensing devices. Restrain horizontal dispensing drums to saddles and anchor saddles and/or dispensing racks to the structure. Restrain upright dispensing drums with chains, straps or cables to prevent sliding and toppling. Where upright dispensing drums rest on raised supports or platforms, restrain drums to the supporting platform and the platform to the building structure. Restraint should be adequate to resist forces specified in Recommendation 2.3.1.2.

2.3.2.5 Restrain tanks containing flammable gas (gas or liquefied state) or ignitable liquid. Where the tanks are relatively rigid, anchor to resist forces specified in Recommendation 2.3.1.2. For special tanks, such as large cylindrical ground-supported flat-bottom tanks having thin steel shells (similar to fire protection water suction tanks), use appropriate consensus design standards (e.g., American Petroleum Institute [API] Standard 650, *Welded Tanks for Oil Storage* or Data Sheet 3-2, *Water Tanks for Fire Protection*).

2.3.3 Connection Between Pipe and Equipment

2.3.3.1 Provide flexibility in the connection between rigid pipe carrying flammable material and point-of-use equipment, and between rigid pipe and internal and external supply tanks and reservoirs. Flexibility can be achieved using flexible pipe compatible with the application and rated for the required operating pressure, such as FM Approved corrugated stainless steel tubing (CSST) for fuel gas applications, or by FM Approved flexible hoses that meet all the criteria in Data Sheet 7-32, *Ignitable Liquid Operations,* for ignitable liquid applications. Provide slack of at least 6 in. (150 mm) in flexible connections to account for possible differential movement between piping and equipment. Alternatively, flexibility can be achieved by engineered systems using expansion loops with welded joints or by piping arrangements using two or more ball joints designed to accommodate expected deflections. Where support of equipment lead-in pipe stubs is needed downstream of the flexible connectors, provide such support in a manner not to interfere with, or defeat, the flexibility provided by the connection. See Figure 2.3.3.1 for an example of flexibility in connection to equipment. It should have been shown by testing that the expansion loops, corrugated metal tubing, or flexible hoses used in ignitable liquids systems do not fail when exposed to ignitable liquid fires.

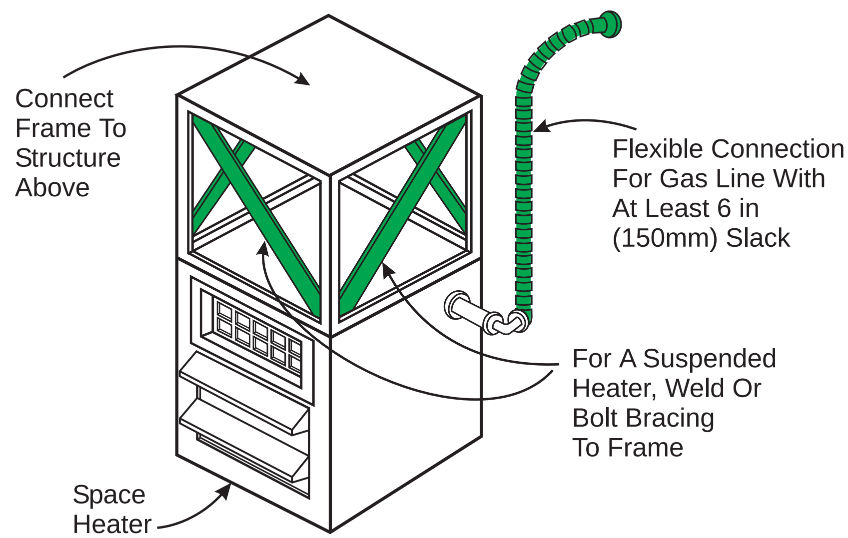

Fig. 2.3.1.1 Example of suspended space heater arrangement with flexible gas line connection (source: FEMA 74)

2.3.4 Piping Protection

Provide the following for flammable gas and ignitable liquid piping systems within buildings in active seismic areas (i.e., FM 50-year through 500-year earthquake zones as shown in Data Sheet 1-2).

Recommendations contained in this section apply to seismic protection of both flammable gas and ignitable liquid steel pipe schedule 40 or greater (or approximate SI unit equivalent, see Table 2.3.4.4B), installed within buildings. Additional considerations can be found in Data Sheet 7-54, *Natural Gas and Gas Piping* and in Data Sheet 7-32, *Ignitable Liquid Operations,* for ignitable liquid piping.

2.3.4.1 Provide separate ignitable liquid or metered gas supply mains for structurally independent adjacent buildings, or building sections separated by a seismic joint, where the buildings or sections can move independently in an earthquake.

Where piping must span the gap or joint, use FM Approved flexible hose (e.g., corrugated stainless steel tubing [CSST]), or provide seismic separation assemblies in piping crossing between structurally independent buildings or across seismic joints. Flexible couplings should not be used in the seismic separation assembly since they are susceptible to leakage. Determine the amount of flexibility needed assuming the horizontal seismic drift of each structure equals 1.5% of its height above the ground at the pipe location (i.e., 0.015 ft [m] horizontal movement per ft [m] of height). Since each structure can move independently, the total movement to be accommodated is the sum of the drift (i.e., 3% of the height at the pipe location).

2.3.4.2 Use welded steel piping designed in accordance with an internationally-recognized code (e.g., ASME B31.3, *Process Piping*) and local building code requirements for ignitable liquid and gas service. For fuel gas service, use of FM Approved corrugated stainless-steel tubing is acceptable where allowed by local authorities.

Threaded pipe should not be used unless unavoidable. Welded piping systems can withstand the cyclic, horizontal, vertical and rotational forces of an earthquake much better than threaded piping, which may fail after several cycles.

Cast iron should not be used for valves, fittings, or supports.

Flexible couplings should not be used since experience has shown that they are susceptible to leakage.

2.3.4.3 Pipe Hangers and Support

2.3.4.3.1 Provide pipe support in accordance with Data Sheet 7-54 and Data Sheet 7-32 and in accordance with the following guidelines:

A. Provide vertical restraint (such as a wraparound U-hook hanger in lieu of an open U-hook hanger) on horizontal piping at the last hanger at the free end and within 2 ft (0.6 m) of the end of an armover feeding a drop.

B. Keep piping at least 1 ft (0.3 m) away from unbraced pipe of equal or larger diameter. If unavoidable, provide bracing to the unbraced lines.

C. Keep piping at least 1 ft (0.3 m) away from unrestrained fixtures and equipment.

D. Provide U-bolts or other equivalent means of vertical and lateral restraint to pipes that are supported by simply resting on structural elements or on trapeze hangers. When used, U-bolts need to be tightly fastened against the structure.

E. Provide retaining straps for C-clamps used to attach hangers to the structural members. Avoid the use of C-clamps on Z and C purlin flanges, preferably attaching directly to the web; if used, install them so that they will not deform the stiffening lip of flanges, and use retaining straps with a positive means of attachment to the web.

F. Because of their inability to remain in place during the dynamic loading that occurs during an earthquake, do not use powder-driven fasteners to attach hangers to the building structure.

2.3.4.4 Seismic Sway Bracing

Flammable gas and ignitable liquid piping should be routed such that it is within a reasonable distance of building structural elements to allow earthquake bracing to be attached to the building. Routing of gas piping close to and along walls, or near floor or roof structural elements is favorable and should be preferred whenever possible.

2.3.4.4.1 Provide sway bracing for ignitable liquid and flammable gas piping systems of nominal pipe size (NPS) 1 inch (25 mm) or larger in accordance with local code requirements but not less than recommended below. Where the piping temperature varies widely (e.g., pipes containing heat transfer fluid) use sway braces with a snubber element that allows slow thermal expansion but restrains the more rapid movement that will occur during an earthquake.

2.3.4.4.2 Risers and Vertical Pipe Runs

A. Provide four-way bracing as recommended below. A four-way bracing (or through floor sleeves) on risers and other vertical pipes may also act as the initial lateral and longitudinal bracing for the adjacent, connected, horizontal main lines of the same size or smaller, if the bracing is installed within 24 in. (0.6 m) of the main.

1. Within 24 in. (0.6 m) of the top and bottom of risers and vertical pipes.

2. Within 24 in. (0.6 m), upstream or downstream, from valves, meters, pressure regulators and other concentrated mass piping elements.

3. At intermediate points not exceeding the allowable spacing for transverse (lateral) sway braces in Table 2.3.4.4A.

4. Although providing actual brace assemblies is preferred, for risers in multistory structures intermediate four-way bracing may be omitted where risers pass through a steel sleeve or a hole in a structural (usually concrete) floor that provides lateral restraint at the floor level. Provide additional intermediate four-way bracing between floors if needed such that the distance between each braced location does not exceed the allowable spacing for transverse (lateral) sway braces in Table 2.3.4.4A. Only those floor sleeves having clearance less than or equal to the value given in Table 2.3.4.5 can be considered to provide acceptable restraint against lateral movement.

Table 2.3.4.4A. Sway Bracing Spacing for Individual Straight Runs of Pipe (See Note 3)

Nominal Pipe Size (NPS)	Brace Requirements (See Notes 1 and 2)	Sway Brace Spacing	
		Transverse (Lateral) (T)	Longitudinal (L)
Up to NPS ¾ in. (20 mm)	Sway brace not needed	DNA	DNA
1 in. (25 mm) ≤ NPS ≤ 2.0 in. (50 mm)	Transverse sway bracing not needed for pipe supported by hanger rods less than 6 in. (150 mm)	30 ft (9.1 m)	80 ft (24.4 m)
NPS 2.5 in. (65 mm) ≤ NPS ≤ 4 in. (100 mm)	Transverse sway bracing not needed for pipe supported by hanger rods less than 6 in. (150 mm)	40 ft (12.2 m)	80 ft (24.4 m)
NPS 5 in. (125 mm) and larger	Sway bracing required for all pipe. (Note 2)	40 ft (12.2 m)	80 ft (24.4 m)

Note 1: Individual hanger rod length measured between the top of the horizontal pipe and the point of attachment to the structure.
Note 2: Transverse sway bracing on horizontal or vertical pipe can be considered to exist where pipe is held directly against the structure using firmly-attached, properly-sized U-bolts.
Note 3: An individual straight pipe run is considered to be a single straight section between any bends in the pipe. However, the pipe run can be treated as an individual straight pipe run where the offset at a single bend, or the sum of the offsets of multiple bends, between brace locations is less than 6 ft (1.8 m) for 2½ in. (65 mm) and larger piping or 3 ft (0.9 m) for 2 in. (50 mm) and smaller piping.

2.3.4.4.3 Horizontal Pipe Runs

A. Provide transverse and longitudinal braces.

1. Install transverse sway braces as follows:

a. Within 6.0 ft (1.8 m) from the beginning and end of pipe runs (includes the free end, and the beginning or end of the rigid pipe adjacent to seismic separation assemblies, flexible pipe or flexible hose).

b. Within 24 in. (0.6 m) from changes in direction. At changes in direction, a transverse brace for one pipe section may also act as longitudinal brace for a pipe section of the same size or smaller, connected perpendicular to it, if the bracing is installed within 24 in. (0.6 m) of the elbow, tee or 90° bend (See Figure 2.3.4.4.3).

c. Within 24 in. (0.6 m) from vertical drops.

d. Within 24 in. (0.6 m), upstream or downstream, from valves, meters, pressure regulators and other concentrated mass piping elements.

e. Provide additional braces to satisfy the maximum spacing between braces given in Table 2.3.4.4A.

2. Install at least one longitudinal sway brace for each pipe run, a longitudinal brace within 40 ft (12.2 m) from the beginning and end of pipe runs (i.e., from the free end, or from seismic separation assemblies, flexible pipe or flexible hose), and additional longitudinal braces in accordance with the maximum spacing given in Table 2.3.4.4A (see Figure 2.3.4.4.3). A longitudinal brace for one pipe section may also act as transverse brace for a pipe section of the same size or smaller, connected perpendicular to it, if the bracing is installed within 24 in. (0.6 m) of the elbow, tee or 90° bend.

2.3.4.4.4 Vertical Drops

A. Provide flexible pipe or flexible hose in accordance with recommendation 2.3.3.1, where possible and allowed by local authorities having jurisdiction. When rigid pipe is used, restrain vertical drops against uncontrolled movement as follows:

1. Restrain drops 6 ft (1.8 m) to 20 ft (6.1 m) long at a location below the drop midpoint (e.g., 3/4 of the distance down from the connection to the overhead supply pipe). Restraint can be accomplished by attaching the pipe drop to the structure (e.g., building column or structural wall), or by bracing it to the overhead structure. Do not restrain drops to the equipment being supplied or to a structure (such as a mezzanine) that can move differentially from the main building structure; this could result in differential movement being imposed on the drop pipe.

2. Avoid drops in excess of 20 ft (6.1 m) unless specially engineered to provide adequate restraint without creating excessive stresses at the point of connection to the overhead supply pipe.

2.3.4.4.5 Connect braces directly to the pipe to be restrained. A longitudinal brace may also be placed on a connected pipe of the same or larger diameter within 2 ft (0.6 m) of an elbow or tee. Do not place braces on smaller size piping, such as branch lines, to restrain larger size piping (such as mains).

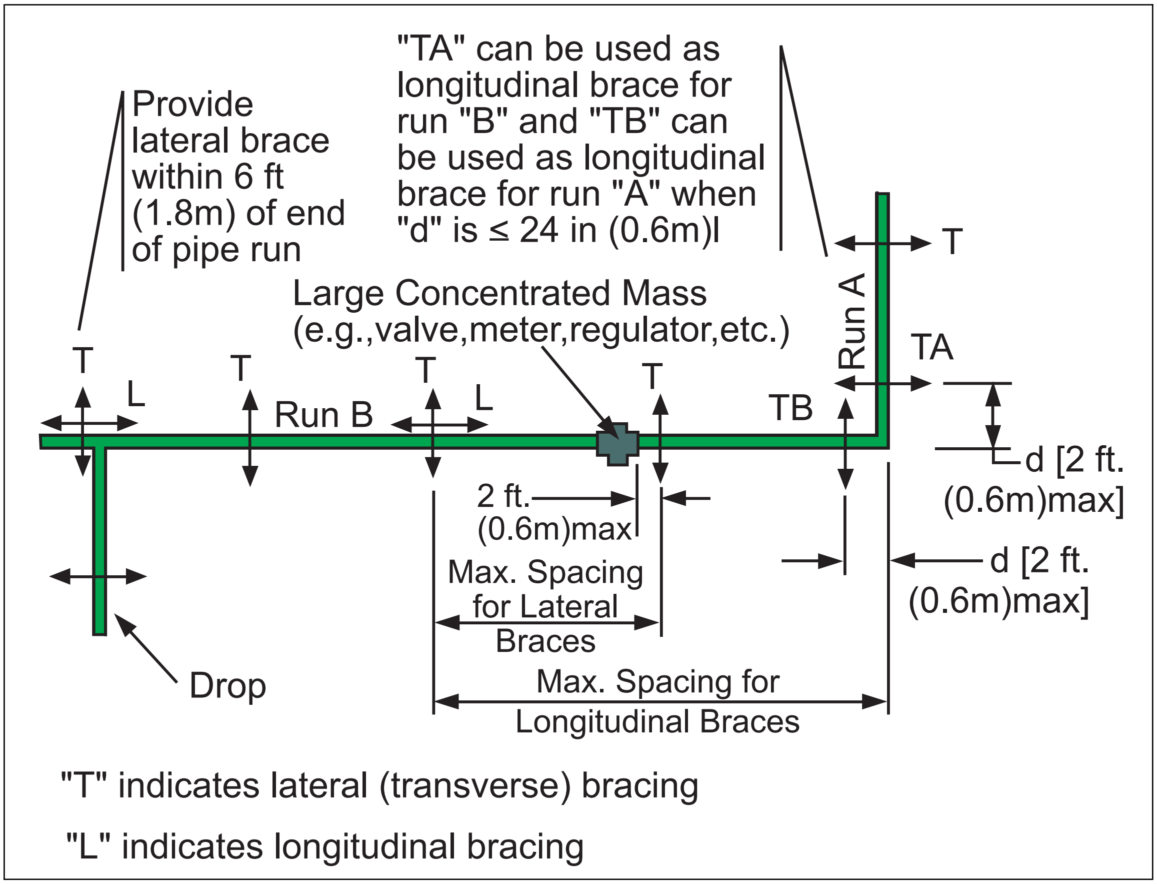

Fig. 2.3.4.4.3. Example of layout of sway bracing for piping

2.3.4.4.6 Provide bracing for pipes on trapeze hangers using the same requirements as single pipes on hangers. Locate braces to coincide with trapeze locations and properly restrain pipes to the trapeze. Determine the seismic load for trapeze hangers based on the weight of all the pipes on the trapeze, and place braces symmetrically to prevent twisting of the trapeze.

2.3.4.4.7 Use FM Approved sway brace components for attachment of the sway brace member to the pipe and building structure.

A. Calculate the seismic design load for each sway brace location in accordance with Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems,* Section 2.2.1.2, using the appropriate weight of pipe material, contents and fittings. The weight of schedule 40 steel pipe is given in Table 2.3.4.4B for gas pipe (schedule 40 gas pipe is common, but where different pipe is used [e.g., schedule 80] adjust the weight used for calculations).

Table 2.3.4.4B. Dimensions and Weights of Schedule 40 Steel Gas Piping

Schedule 40 Piping					
Nominal Pipe Diameter		Pipe Wall Thickness(1)		Weight of Pipe(2)	
in.	mm	in.	mm	lb/ft	N/m
3/4	20	0.113	2.87	1.1	16
1	25	0.133	3.38	1.7	25
1-1/4	32	0.14	3.56	2.3	33
1-1/2	40	0.145	3.68	2.7	40
2	50	0.154	3.91	3.7	53
2-1/2	65	0.203	5.16	5.8	85
3	80	0.216	5.49	7.6	111
3-1/2	90	0.226	5.74	9.1	133
4	100	0.237	6.02	10.8	158
5	125	0.258	6.55	14.6	214
6	150	0.28	7.11	19	277
8	200	0.322	8.18	28.6	417

1 The pipe outside diameter roughly equals the nominal diameter plus twice the wall thickness.
2 Weights in Table 2.3.4.4B should be increased by the weight of fittings, valves and other components. The weights of remote actuated valves (valves with extended topworks) or other in-line components should be obtained from the manufacturer. As a rule of thumb, values in Table 2.3.4.4B should be increased by 10% to account for the weight of the fittings. The weight of a hand operated valve can be assumed as 5 times the weight of the pipe for the length of the valve.

B. Select the proposed sway brace configuration in accordance with Data Sheet 2-8, Section 2.2.1.3.

C. Select the attachment method to the structure and to the piping in accordance with Data Sheet 2-8, Section 2.2.1.3. Because they have low capacity and often don't remain in place during the dynamic loading that occurs during an earthquake, do not use powder driven fasteners or c-clamps with or without retaining straps to attach sway braces to the building structure.

2.3.4.5 Piping Clearances

2.3.4.5.1 Where piping passes through walls or floors, provide minimum clearance per Table 2.3.4.5. Seal openings with mastic or a weak, frangible mortar if needed. If the pipe passes through a fire wall, fill the space with acceptable material such as mineral wool held in place with a pipe collar. When the wall material is frangible, such as gypsum board, and the wall is not required to have a fire rating, clearance is not needed. Where providing the recommended clearances is not possible, provide flexibility on both sides of the wall by installing flexible piping or ball joints.

Table 2.3.4.5. Recommended Minimum Piping Clearances

Nominal Pipe Size (NPS)	*Clearance*
NPS < 4 in. (100 mm)	1 in. (25 mm) all around pipe
NPS ≥ 4 in. (100 mm)	2 in. (50 mm) all around pipe
Valves	
Manually Operated	2 in. (50 mm)
Remote Operated	6 in. (150 mm)
Pipe Ends	
Distance from Walls	2 in. (50 mm)

2.3.4.5.2 Locate piping no closer than 2 in. (50 mm) from walls, unless it is rigidly braced away from the wall.

2.3.4.5.3 Provide a clearance of at least 2 in. (50 mm) to handwheels of manually operated valves and a clearance of at least 6 in. (150 mm) to the topworks of remotely operated valves.

2.3.5 Fuel Gas and Flammable Gas Seismic Shutoff Valves

2.3.5.1 Provide seismic gas shutoff valves (SGSV) as specified in this section. Ensure that the seismic gas shutoff valve (SGSV) is installed in the correct orientation for horizontal and vertical pipes. Arrange these earthquake-actuated devices for automatic operation and to safely shutdown the flow of fuel gas and other flammable gas in the event of strong ground motion. Incorporating a seismic sensor into a customary emergency shutoff system (e.g., the master fuel trip of a gas turbine) is an acceptable alternative to providing a separate system. Where a process safety review or guidance in other data sheets indicates that automatic shutdown in accordance with the following requirements would introduce unacceptable new hazards (e.g., Section 2.3.5.5), either modify the requirements as necessary to mitigate the new hazard or omit the automatic shutoffs if the new hazard cannot be mitigated.

2.3.5.2 Integrated SGSV should be certified by a nationally-recognized testing laboratory to meet the requirements of ASCE 25, *Earthquake-Actuated Automatic Gas Shutoff Devices,* 2006 edition or international equivalent. Seismic sensors of remotely-actuated SGSV that provide a signal to separate safety shutoff valves (SSOVs) should be certified to comply with the same actuation/non-actuation points found in ASCE 25 (see Section 3.2.2.1).

2.3.5.2.1 A seismic sensor may provide a signal directly to the SSOV it controls to trigger valve closure, or may be arranged to provide a signal to a control panel (see Figure 2.3.5.2.1), master fuel trip relay, etc. that then automatically initiates closure of the SSOV(s).

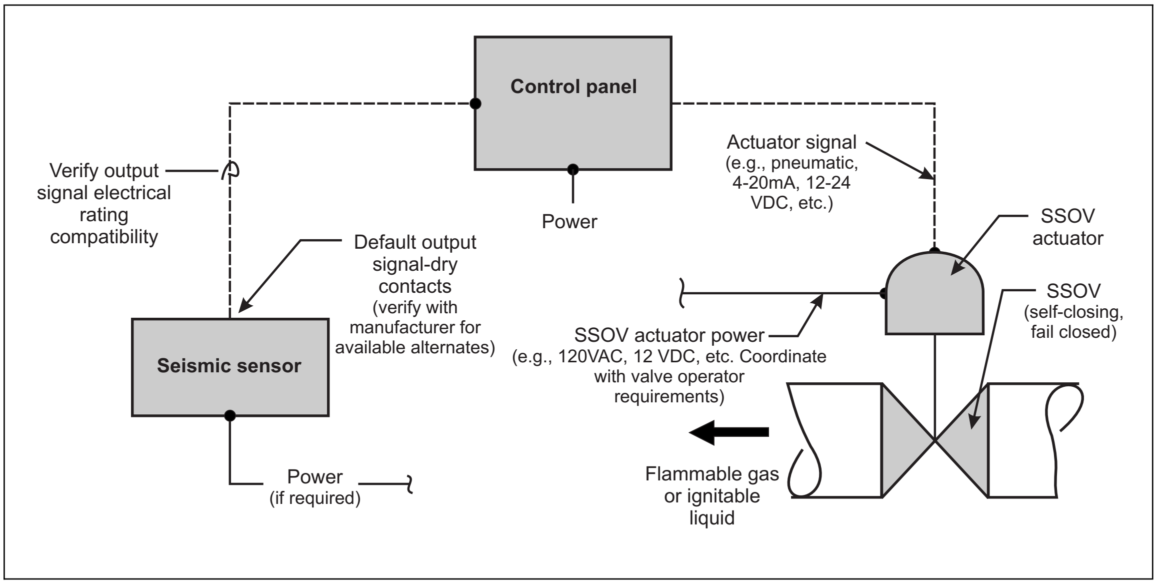

Fig. 2.3.5.2.1. Seismic shutoff using a seismic sensor that provides a signal to a control panel

2.3.5.2.2 SSOV actuated by seismic sensors should be fast closing type (closing within 5 seconds) and of a fail-safe design (i.e., normally closed, where in case of energy loss to the actuator, the armature closes automatically).

2.3.5.3 Mount the integrated SGSV (in the correct orientation for horizontal and vertical pipes) or the seismic sensor of the remotely-actuated SGSV in accordance with the manufacturer's instructions and in a manner that the seismic sensing device responds to earthquake ground motions and not to motions that may result from the dynamic response of structures, equipment or their accessories. Attach integrated SGSV or the seismic sensor of a remotely-actuated SGSV to rigid mountings only.

2.3.5.3.1 Integrated SGSV or the seismic sensor of a remotely-actuated SGSV attached to rigid mounts in pits below grade or to rigid building structural elements (such as slabs, columns, concrete or masonry walls and beams) no higher than 3 ft (0.9 m) above grade level are considered adequate.

2.3.5.4 Install an SGSV at the supply side to each individual building utilizing fuel gas in the right orientation as per manufacturer's specification.. Fuel gases include natural gas (methane), propane, butane and LPG in the vapor phase.

2.3.5.4.1 The SGSV can be either an integrated SGSV (see example in Figure 2.3.5.4.1) or a remotely-actuated SGSV. Integrated SGSV come in different pressure ratings (of 60 psi [414 kPa] or less) and must be listed for use with the specific fuel gas at the pressure supplied.

Fig. 2.3.5.4.1. Automatic integrated seismic gas shutoff valve (SGSV) installed in a fuel gas line downstream of pressure regulator

2.3.5.4.2 Install integrated SGSV or the SSOV of a remotely-actuated SGSV outside buildings on piping owned and controlled by the facility; downstream of the utility-owned piping and equipment such as pressure regulators, meters, and bypass connection; and in a clearly marked and accessible location. The seismic sensor of a remotely-actuated SGSV can be located separate from the SSOV in a marked, accessible location inside a building as long as it is mounted in accordance with 2.3.5.3.

2.3.5.4.3 Size valves in accordance with applicable local gas plumbing code or the International Fuel Gas Code to the maximum gas demand and allowable pressure drops in the system, so that the supply pressure at any equipment is greater than the minimum required for proper equipment operation

2.3.5.5 Install remotely-actuated SGSV for flammable gas other than fuel gas, fed from tanks, cylinder packs, manifold or dispensing rack systems, gas cabinets, etc. The SSOV of the remotely-actuated SGSV should ideally be located outside the building. Where this is not possible, pay particular attention to earthquake protection (i.e., anchorage, bracing, etc.) of all piping and equipment upstream of the SSOV such that a break will not occur upstream of the SSOV.

This recommendation is not intended to be applied to closed systems using flammable gas, such as refrigeration. However, equipment and piping earthquake protection (e.g., anchorage and bracing) recommendations should be applied for these systems.

Per Data Sheet 7-79, *Fire Protection for Gas Turbines and Electric Generators* and Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators,* do not install seismic shutoffs on the hydrogen supply covered by these data sheets.

2.3.6 Ignitable Liquid Shutoff Valves

2.3.6.1 Integrated in-line (i.e., flow-through) seismic shutoff valves are not currently available for ignitable liquids. Therefore, shutting off the flow must be accomplished by safety shutoff valves (SSOV) outside the building actuated by a seismic sensor (i.e., a remotely-actuated seismic shutoff).

2.3.6.2 Provide FM Approved SSOV, arranged to close automatically in the event of strong ground motion, on the supply pipe of all ignitable liquid piping systems having flash point below 100°F (38°C), and on the supply side of liquids heated to their flash point. This can be accomplished by installing seismic sensors that provide a signal to normally closed SSOV (i.e., in case of energy loss to the actuator, the armature closes automatically). Seismic sensors should have actuation/non-actuation points as recommended in 2.3.5.2, provide signals as recommended in 2.3.5.2.1, and be mounted as recommended in 2.3.5.3 and 2.3.5.3.1. The SSOV should be as recommended in 2.3.5.2.2.

Similar to fuel and flammable gas systems (see 2.3.5.1), incorporating a seismic sensor into a customary emergency shutoff system is an acceptable alternative to providing a separate seismic shutoff system. Where a process safety review (e.g., see Data Sheet 7-32, *Ignitable Liquid Operations*) or guidance in other data sheets indicates that automatic shutdown in accordance with Data Sheet 1-11 requirements would introduce unacceptable new hazards, either modify the requirements as necessary to mitigate the new hazard or omit the automatic shutoffs if the new hazard cannot be mitigated. Per Data Sheet 7-79, *Fire Protection for Gas Turbines and Electric Generators* and Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators,* do not install seismic shutoffs on lube-oil systems covered by these data sheets.

See Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems,* and Data Sheet 7-88, *Ignitable Liquid Storage Tanks,* for requirements to shut down ignitable liquid systems beyond those designated above during a seismic event.

2.4 Human Element

2.4.1 Inspection, Testing, and Maintenance

2.4.1.1 Inspect seismic protection systems (e.g., valves, braces, anchors, signal paths, power paths and sources) yearly for conditions that could impair operation, including corrosion, damage, deterioration, unauthorized modifications, etc. Inspect normal and emergency power systems to verify availability of required levels (e.g., psi, volts, amps, battery levels, etc.).

2.4.1.2 Test seismic protection systems at intervals of approximately 5-7 years.

2.4.1.2.1 Test integrated seismic valves per the manufacturer's recommendations.

2.4.1.2.2 Test remotely-actuated seismic SSOVs by doing the following:

A. Functional test the entire system as a whole by simulating a signal from the seismic sensor and verifying all intended actions occur (e.g., SSOVs close, pumps stop, alarms annunciate, etc.). Provide this test both on normal power and emergency power.

B. Test the response of the seismic switch per the manufacturer's recommendations, and by subjecting the sensor to movement per ASCE 25 for both actuation and non-actuation (e.g., seismic shake table).

2.4.1.3 Maintain systems to provide proper functioning, and per manufacturer's recommendations. Repair or replace components as required as identified by inspection or testing.

2.4.1.4 Document all inspection, testing, and maintenance programs.

2.4.2 Establish an earthquake emergency response team within the overall facility emergency response team; and a comprehensive earthquake emergency plan to provide guidelines for control of hazards, fire safety, repairs, and salvage. See Data Sheet 10-1, *Pre-Incident Planning* for specific guidance.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Historic Losses

3.1.1 Fires and Gas Leaks Following Earthquakes

Historically, the major secondary effect of earthquakes has been fire. The San Francisco earthquake of 1906, the Tokyo-Kanto earthquake of 1923, and the Kobe earthquake of 1995 are renowned as much for their fire damage as for their earthquake effects. The conflagrations from these earthquakes were mostly due to wind, high density wood construction, and water system disruption.

The risk of major fire loss after earthquakes is still high today. There were 86 reported fires following the 1987 Whittier Narrows earthquake, 115 fires following the 1971 Sylmar earthquake, and 110 fires following the 1994 Northridge earthquake. Mexico City experienced 200 fires in 1985 following an earthquake, even though the epicenter was 250 miles (400 km) away from the city. The 1995 Kobe earthquake in Japan had 240 fires directly attributed to the earthquake. After the 2011 Tohoku earthquake in Japan, there were at least 293 fires. Of 269 fires reviewed, 124 were tsunami-induced in coastal regions and 145 were earthquake shaking-induced (36 in coastal regions and 109 in inland areas); if the tsunami had not occurred there would have undoubtedly been many more earthquake shaking-induced fires in coastal regions.

More telling than the incidence of fire is the frequency of fuel gas leaks following an earthquake. In the 1994 Northridge earthquake, Los Angeles-area fire services responded to over 1,000 reported gas leaks and at least 50 gas-related structural fires. Additionally, the utility gas company reported over 14,000 leaks on customers' lines, including 162 leaks in the 841 buildings where an SGSV properly closed (see Section 4.2). The Northridge earthquake occurred at approximately 4:30 a.m. and had a 6.7 magnitude, with strong ground shaking lasting for only about 15 seconds. Had the earthquake been stronger, occurred during normal business hours, or the power not been lost, the number of gas-related fires and explosions would likely have been larger.

3.1.2 Performance of Water Supply Systems Following Earthquakes

In addition to the high risk of fire following earthquakes, public water supply systems, particularly in areas of poor soil conditions, have typically performed poorly during earthquakes. Breaks in public water systems can result in increased water demands and loss of water supply for fire protection. Table 3.1.2 summarizes the performance of water supply systems in some of the historic earthquakes per Ballantyne and Crouse (see Section 4.2).

Similar to the Ballantyne findings, a report by Eidinger (see Section 4.2) indicates that after the 2010 earthquake in Chile there were major disruptions to water supplies in Concepción and the adjacent community of Talcahuano, as well as in many rural communities. In Concepción, only about 10% of customers had water immediately after the earthquake, 30% had water three days after the earthquake, and 80% had water 17 days after the earthquake. In Talcahuano, essentially all customers were without water for the first three days, only 10% had water after 14 days, and about 50% had water after 17 days.

The water supply to these cities was disrupted mainly due to damaged steel transmission piping resulting from liquefaction of the supporting soils. Cast iron and asbestos cement distribution piping was also damaged. There was extensive damage at the water treatment plant, which was off-line for about 45 minutes until the emergency generator was activated; it later remained in service at a reduced capacity. In rural areas, water was typically supplied by an elevated tank filled by a pump (with no emergency generator back-up) that draws water from an underground aquifer. Of 420 tank locations in the strong earthquake shaking area, at least 73 tanks were verified by the Eidinger to have collapsed and there were reports of the collapse of many more.

Table 3.1.2. Performance of Public Water Supply System in Historic Earthquakes

Disaster Event	*Year*	*Failure Consequences*		
		See Note 1	*See Note 2*	*See Note 3*
		Fire Suppression/ Lacked Water Supply	*Fire*	*Use of Alternative Water Supplies*
San Francisco	1906	5	5	5
Kanto (Japan)	1923	5	5	5
Whittier (CA)	1987	3	1	3
Loma Prieta (CA) (EBMUD only)	1989	4	4	1
Landers/Big Bear (CA)	1992	5	1	NA
Petrolia (CA)	1992	5	3	1
Northridge (CA)	1994	5	4	5
Kobe (Japan)	1995	5	5	3

Note 1: This column indicates whether there was disruption of the water supply during the event which resulted in lack of water for fire suppression. A rating of 5 indicates complete, wide spread water system disruption; a rating of 3 indicates limited water system disruption in limited areas.
Note 2: This column identifies whether there was a fire following the earthquake and how significant the fire was. A rating of 5 indicates major fire conflagrations; a rating of 4 indicates several significant fires; and a rating of 3 indicates single structural fires.
Note 3: This column rates the use of alternate supplies. A rating of 1 indicates aggressive, successful use of alternate supplies. A rating of 3 indicates use of alternate supply with moderate success. A rating of 5 indicates unsuccessful use of alternate supplies.

3.2 Earthquake Effects and Mitigation for Nonstructural Components

3.2.1 Earthquake Effects on Nonstructural Components

During an earthquake, strains will be imparted to nonstructural components, such as equipment and piping systems, throughout the building. A location that presents any appreciable degree of fire and explosion hazard can be at an increased risk, with respect to these perils, following moderate to severe earthquakes. This is because of the increased probability of the spread and ignition of leaking flammable gas and ignitable liquid, along with the impairment of fire protection systems. Therefore, it is imperative that the escape of flammable gas and ignitable liquid be mitigated.

Historically, earthquake damage to various piping systems occurs when excessive pipe movements and differential deflections are not prevented between main and branch lines or between piping systems and connected equipment. Failures have typically occurred at fittings and joints. Fittings in welded steel pipe and soldered or brazed copper lines have generally survived past earthquakes with very little damage. Threaded fittings are more susceptible to damage because of potential fatigue at the threads from cyclic deflections. Differential movement can be accommodated through a systematic application of sway bracing, piping flexibility, clearances and equipment anchorage where needed.

The recommendations provided are intended to minimize the potential for breakage or leakage of the flammable gas or ignitable liquid piping. Seismic considerations also include provisions for prompt and safe shutdown of flow during strong earthquakes, and control of possible ignition sources. Note that advantageously locating equipment and piping is another low- or no-cost way to reduce the potential for, or severity of, fire following earthquake.

3.2.2 Mitigation of Earthquake Effects on Nonstructural Components

3.2.2.1 Seismic Shutoff Valves

Seismically-actuated shutoff valves are installed to stop the flow of flammable gas or ignitable liquid in the event of an earthquake. This limits the supply of flammable gas or ignitable liquid that can be released in the event of line break to the inventory present in the piping system. When seismic shutoffs are installed and are combined with restraint of piping and equipment, and appropriate flexibility of the pipe (e.g., where it connects to equipment or spans between buildings), both the probability and severity of fires are significantly reduced.

Most integrated SGSV, such as the one shown in Figure 2.3.5.4.1, are passive sensors having a mechanical trigger (a pin or other securing mechanism to release a gate, a ball to drop into the gas flow, etc.) that actuates when the amplitude and frequency content of shaking are indicative of an earthquake.

Some remotely-actuated seismic shutoffs use similar passive mechanical seismic sensors. Other remote seismic sensors are more sophisticated to reduce the probability of false trips. These systems may sense duration as well as amplitude and frequency of shaking, or may have programmable trigger settings tailored to individual sites based on typical background sources of vibration that are present, or may combine accelerometers in multiple locations across a site to allow “voting” logic (e.g., two of three accelerometers need to sense an earthquake before a valve is shut). These more sophisticated systems have a higher capital cost and must be maintained in order to be effective. Thus, the simple passive mechanical sensors can be a more attractive option as they are essentially maintenance free once installed.

Earthquake shaking varies in amplitude and frequency content. The intensity or amplitude of motion can be measured in terms of displacement, velocity, or acceleration. Acceleration as a fraction of gravity (g), where one “g” equals 32.2 ft/s^2 (9.8 m/s^2 or 980 cm/s^2), is a commonly-used parameter for setting seismic shutoff actuation. Shaking strength can be measured versus the frequency in cycles per second (Hertz or Hz), or period (seconds). The period is the inverse of frequency (i.e., period in seconds = 1/Hz). The frequency content of dominant earthquake shaking (see the example in Figure 3.2.2.1A) is typically 0.1 to 10 Hz (periods of 10 to 0.1 seconds) although the range can be slightly larger for some earthquakes. As the magnitude of an earthquake increases the lower range of frequencies becomes prevalent. The frequency and amplitude of shaking vary with time.

One of the best-known standards for seismic gas shutoff valves (SGSVs) is ASCE 25, Earthquake-Actuated Automatic Gas Shutoff Devices. Some international standards use criteria very similar to those found in ASCE 25. The ASCE 25-06 actuation/non-actuation requirements for SGSV are listed below and shown graphically in Figure 3.2.2.1B.

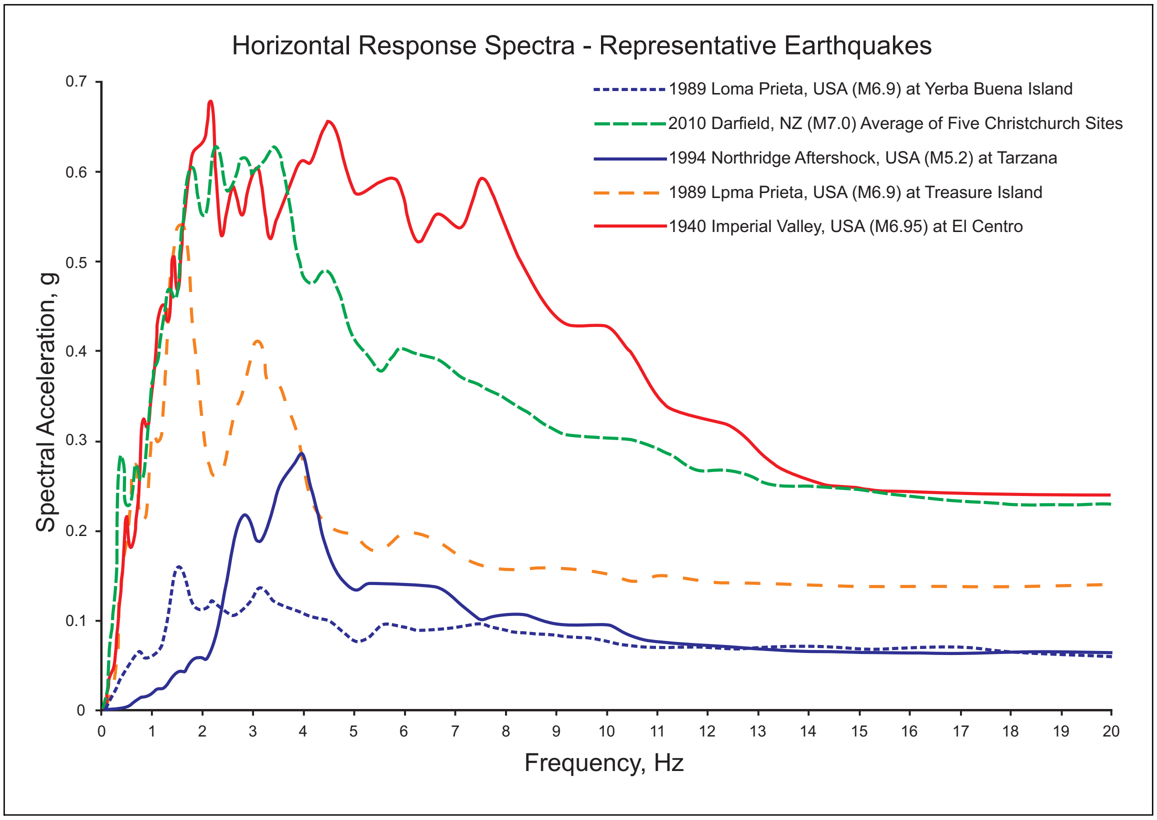

Fig. 3.2.2.1A. Average horizontal response spectra of representative earthquakes showing the make-up of energy (acceleration vs. frequency) based on rotated median values with 5% damping from the Pacific Earthquake Engineering Research Center (PEER)ground motion database.

A. **Non-Actuation Required.** Actuation should not occur at or below the following horizontal or vertical acceleration threshold levels:

1. Peak acceleration of 0.40 g (3.92 m/s_2) at a period of 0.1 second (10 Hz. frequency).
2. Peak acceleration of 0.20 g (1.97 m/s_2) at a period of 0.2 second (5 Hz. frequency).
3. Peak acceleration of 0.15 g (1.47 m/s_2) at a period of 0.4 second (2.5 Hz. frequency).
4. Peak acceleration of 0.10 g (0.98 m/s2) at a period of 1.0 second (1 Hz. frequency).

B. **Actuation Required.** Actuation should occur within 5 seconds of horizontal sinusoidal oscillation, at any point between the threshold acceleration levels given in “A” above and the following:

1. Peak acceleration of 0.70 g (6.87 m/s^2) at a period of 0.13 second (7.7 Hz. frequency).
2. Peak acceleration of 0.40 g (3.92 m/s^2) at a period of 0.2 second (5 Hz. frequency).
3. Peak acceleration of 0.30 g (2.94 m/s^2) at a period of 0.4 second (2.5 Hz. frequency).
4. Peak acceleration of 0.25 g (2.45 m/s2) at a period of 1.0 second (1 Hz. frequency).

Seismic shutoffs compliant with the ASCE 25 criteria (or equivalent international codes) and that are properly installed will sense and actuate in response to damaging earthquake ground shaking (Modified Mercalli Intensity [MMI] of approximately VII or higher - see Data Sheet 1-2, *Earthquakes* for more information regarding MMI). The possibility of nuisance trips from minor earthquakes or common non-seismic vibrations (such as those from explosions or vehicle traffic) is minimal for properly-installed seismic shutoffs meeting the ASCE 25 criteria.

Because of the differences in their shaking profiles relative to earthquake shaking, a properly installed ASCE 25-compliant seismic sensor typically will not actuate in response to distant explosions or nearby heavy

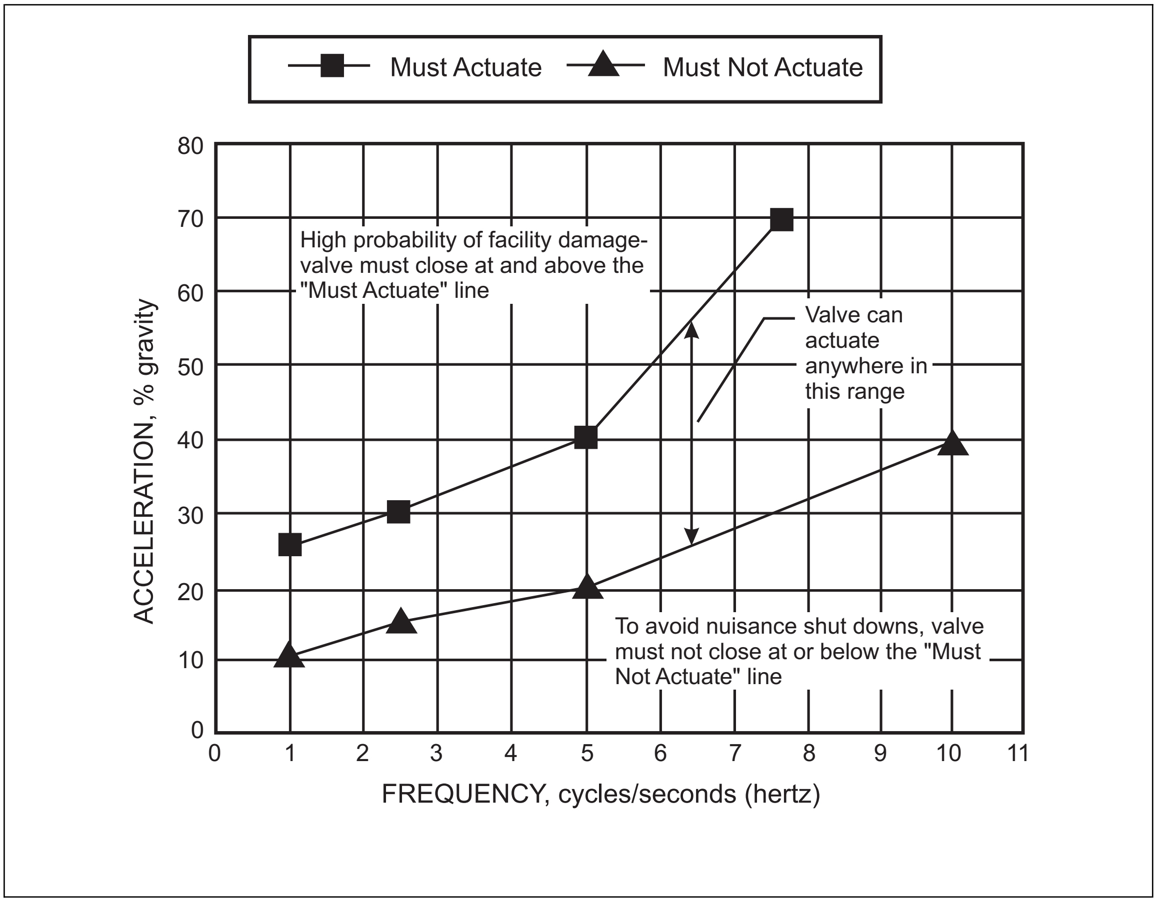

Fig. 3.2.2.1B. SGSV actuation and non-actuation requirements from ASCE 25-06

vehicle traffic. As can be seen in Figure 3.2.2.1A, the dominant frequency of earthquake ground motion is usually less than 10 Hz (and can be below 5 Hz for some earthquakes). By contrast, the dominant frequency of traffic-induced and explosion-induced ground motion is usually higher (commonly at least 10-20 Hz and sometimes significantly greater). As shown in Figure 3.2.2.1B, accelerations needed to trip ASCE 25-compliant seismic shutoffs increase with frequency of shaking, making traffic or explosion-induced false trips less likely.

In addition to frequency dissimilarities, other differences in traffic and explosion-induced shaking relative to earthquake shaking make false tripping of ASCE 25-compliant seismic shutoffs unlikely. For example, although continuous traffic vibrations have a much longer duration than earthquake shaking, ground accelerations from nearby car and truck traffic (i.e., 1 to 20 m [3 to 65 ft] away) are usually low (commonly 0.02g or less). Also, an underground explosion typically lasts a fraction of a second, releases energy orders of magnitude smaller than for earthquakes, and radiates only a small fraction of this energy as seismic waves. Thus, the duration of shaking from a single underground explosion will be very short by comparison to an earthquake, and ground accelerations will only be high if the explosion is relatively large and near a site. As an example, experiments conducted in 1977 in Tajikistan to determine the nature of ground motions from explosions show that an underground (10 m [33 ft] below grade) explosion equivalent to 128 kg (282 lb) of TNT caused ground motions 40 m (131 ft) away having accelerations near the threshold of those that could cause a seismic shutoff to trip, but these motions lasted less than one second.

In some cases, as vibrations pass through the ground they can be affected by changes in soil conditions, which can potentially shift the dominant frequencies. Additionally, if located incorrectly (e.g., at an upper floor of a building or attached to a flexible support near grade) the structure to which a seismic sensor is attached can amplify or otherwise affect the nature of the shaking experienced by the sensor (e.g., a support in resonance with traffic vibrations near it). To prevent shaking from minor earthquakes or from non-earthquake sources being modified by the soil or structure to a point where the sensor sees them as earthquakes, seismic sensors must be installed such that they experience the actual ground motion (e.g., by solidly attaching them to a substantial rigid concrete wall very close to the base of a building).

Although ASCE 25-compliant seismic shutoffs should typically not actuate in response to non-earthquake shaking, where there are many sources of vibration, such as near roadways with high traffic or near quarries, the chance of a false trip can be further reduced by employing a remote sensing system placed in area with low background vibrations.

3.2.2.2 Piping Protection

A summary of the Section 2 piping protection requirements is presented in Table 3.2.2.2. The information in Table 3.2.2.2 is not comprehensive and should only be used in conjunction with the details in the Section 2 recommendations.

3.2.2.2.1 Pipe Bracing

Seismic forces from an earthquake can occur in any horizontal or vertical direction. Sway bracing is referred to as two-way or four-way. A two-way brace can resist tension or compression and can be either transverse (lateral) or longitudinal, depending on its orientation with the axis of the pipe. A transverse brace resists differential movement perpendicular to the axis of the pipe, while a longitudinal brace resists differential movement parallel to the axis of the pipe. An appropriate distribution of transverse and longitudinal sway braces within a piping system can effectively provide resistance to seismic loads in any horizontal direction. A four-way sway brace acts like two lateral braces resisting movement in perpendicular directions. Four-way sway bracing is typically provided on risers to resist differential movement in all horizontal directions.

3.2.2.2.2 Piping Flexibility

Bracing is used on piping to minimize differential seismic motions between the piping system and building structure and equipment. At the same time, differential motion may occur between the structure and internal equipment or between different structures. Piping flexibility is needed at strategic locations to help absorb the differential motions between attachment points of the piping. Anchorage and restraint of equipment minimizes differential movement between equipment and structures.

Branch supply lines generally drop from the main header to the equipment. The header, connected to the overhead structure, may be subjected to different motion than the equipment anchored to the floor. Flexibility should be provided where pipes connect to equipment. The equipment may be directly anchored, suspended and braced, or mounted on vibration isolators.

3.2.2.2.3 Piping Clearances

Clearance around piping minimizes the potential for detrimental impact between piping and the structure or equipment as a result of differential movement. Piping impact can be especially damaging to valves, causing breaks to handwheels and actuators and rendering the valve inoperable. Even when no flammable material escapes as a direct result of the impact, an inoperable valve can have critical consequences to emergency flow control.

3.2.2.3 Restraint of Equipment, Tanks, Cylinders, and Drums

Restraint of equipment, tanks, cylinders, and drums is an often overlooked item. When anchorage requirements are specified at the time these items are ordered and installed, it is typically a low- or no-cost item. However, it can be costly to install retrofit restraint later.

When equipment, tank, cylinder, or drum movement in strong ground shaking could result in flammable gas or ignitable liquid release, or could create ignition sources, these items should be restrained to reduce the risk of a fire following the earthquake. All connections should be positive direct connections for good seismic performance. Friction resulting from gravity loads should not be considered to provide resistance to seismic forces except at the foundation-to-soil interface as allowed by the geotechnical engineer.

Requirements for equipment restraint are provided in this data sheet. Extensive additional information regarding design of equipment restraint, post-installed concrete anchor considerations, United States Federal Emergency Management Agency (FEMA) resources showing generic anchorage schemes, etc. are contained in Data Sheet 1-2, *Earthquakes,* Section 2 and Appendix C.

Table 3.2.2.2. Summary of Data Sheet 1-11 Flammable Gas (FG) and Ignitable Liquid (IL) Piping Protection Recommendations - Schedule 40 (or Equivalent) or Stronger Steel Pipe

PIPE BRACING RECOMMENDATIONS **(Brace piping ≥1 in. [25 mm] diameter)**	**Section(s)**
Risers & Vertical Pipe Runs	2.3.4.4.1
<u>Provide 4-way bracing</u> • At top and bottom (within 2 ft [0.6 m]) • At concentrated mass elements (e.g., valves, meters) within 2 ft (0.6 m) • On straight runs of pipe: - At 30 ft (9.1 m) on center maximum for diameter ≤ 2 in. (50 mm) - At 40 ft (12.2 m) on center maximum for diameter > 2 in. (50 mm) <u>Miscellaneous</u> • A 4-way brace can be considered to exist where a riser or vertical pipe in a multistory structure passes through a steel sleeve or a hole in a structural (usually concrete) floor and pipe clearance is not more than indicated in the clearance section below • 4-way bracing not needed on vertical pipe sections less than: - 3 ft (0.9 m) long for diameter < 2½ in. (65 mm) - 6 ft (1.8 m) long for diameter ≥ 2½ in. (65 mm)	2.3.4.4.2
Horizontal Pipe Runs	2.3.4.4.1
<u>For straight runs, provide:</u> • Transverse/lateral bracing: - At concentrated mass elements (e.g., valves, meters) - within 2 ft (0.6 m) - At 30 ft (9.1 m) on center maximum for diameter ≤ 2 in. (50 mm) - At 40 ft (12.2 m) on center maximum for diameter > 2 in. (50 mm) • Longitudinal bracing at 80 ft (24.4 m) on center maximum (at least one brace in each pipe run) <u>At changes in direction:</u> • Transverse/lateral bracing within 2 ft (0.6 m) from vertical drops • Transverse/lateral bracing within 2 ft (0.6 m) of the change in direction where pipe length adjacent to change in direction is greater than: - 3 ft (0.9 m) long for diameter < 2½ in. (65 mm) - 6 ft (1.8 m) long for diameter ≥ 2½ in. (65 mm) <u>At beginning/ends (free ends & adjacent to flexible pipe or seismic separation assemblies) provide:</u> • Transverse/lateral bracing within 6 ft (1.8 m) • Longitudinal bracing within 40 ft (12.2 m) <u>Miscellaneous</u> • An individual straight pipe run is a single straight section between any bends in the pipe. Exception: the pipe run can be treated as an individual straight pipe run where the offset of a single bend, or the sum of offsets of multiple bends, between brace locations is less than 6 ft (1.8 m) for piping ≥ 2½ in. (65 mm) diameter or 3 ft (0.9 m) for piping ≤ 2 in. (50 mm) diameter. • Transverse/lateral sway bracing is not needed for pipe ≤ 4 in. (100 mm) supported by hanger rods less than 6 in. (150 mm) long measured between the top of the pipe and the point of attachment to the structure.	2.3.4.4.3

Table 3.2.2.2. Summary of Data Sheet 1-11 Flammable Gas (FG) and Ignitable Liquid (IL) Piping Protection Recommendations - Schedule 40 (or Equivalent) or Stronger Steel Pipe (continued)

<table>
<tr><th>PIPE BRACING RECOMMENDATIONS (continued)
(Brace piping ≥ 1 in. [25 mm] diameter)</th><th>Section(s)</th></tr>
<tr><td>Drops</td><td></td></tr>
<tr><td>• When rigid pipe is used for vertical drops 6 ft (1.8 m) to 20 ft (6.1 m) long, restrain it (e.g., by attaching it to a building column or structural wall, or bracing it to the overhead structure) at a location below the midpoint of the drop length measured from the connection to the overhead supply pipe
• Drops in excess of 20 ft (6.1 m) should be specially engineered to provide adequate restraint without creating excessive stresses at the point of connection to the overhead supply pipe
• Do not restrain drops to the equipment being supplied or to a structure (such as a mezzanine) that can move differentially from the main building structure</td><td>2.3.4.4.4</td></tr>
<tr><td>Common Bracing Recommendations</td><td></td></tr>
<tr><td>• Do not attach bracing to smaller diameter piping to brace connected larger diameter piping
• A transverse/lateral brace may act as a longitudinal brace, and vice versa, for a perpendicular pipe of equal or lesser diameter if the brace is installed within 2 ft (0.6 m) of the elbow, tee or 90° bend
• A 4-way brace on a riser or vertical pipe may act as the initial transverse/lateral brace and longitudinal brace for an attached horizontal pipe or main of the same or smaller diameter that is within 2 ft (0.6 m) of the 4-way brace
• 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 transverse/lateral brace or a four-way brace
• For trapeze-supported pipe, properly restrain (i.e., U-bolt) pipes to the trapeze, and brace each trapeze to avoid twisting and for the weight of all pipe supported on it
• Where piping temperature can vary widely, use braces (e.g., snubbers) that allow slow thermal expansion but restrain rapid earthquake movements
• Braces for horizontal pipe should be oriented at least 30° from vertical
• Compression braces should have a slenderness ratio (l/r) of 200 or less
• Tension braces should have l/r of 300 or less (cable bracing should not be used)
• Braces should not be fastened to the structure using C-clamps (with or without retaining straps) or powder-driven fasteners
• Make brace connections to the pipe and structure with positive, mechanical attachments or FM Approved connectors
• Take the Allowable Stress Design horizontal design force (H) as a “G” factor multiplied by the weight of pipe in the zone of influence (W_p). Use “G” = 0.75 in FM 50-year zones, 0.5 in FM 100-year zones, and 0.4 in FM 250- and 500-year zones unless a higher “G” is required by the local building code.
• Transverse/lateral or longitudinal brace uplift force should be resisted by a vertical brace or second diagonal brace if it exceeds ½ of W_p</td><td>2.3.4.3
2.3.4.4.1
2.3.4.4.2
2.3.4.4.3
2.3.4.4.5
2.3.4.4.6

2.3.4.4.7 and the referenced Data Sheet 2-8 sections</td></tr>
<tr><th>PIPE FLEXIBILITY RECOMMENDATIONS
(Apply regardless of diameter)</th><th></th></tr>
<tr><td>Drops</td><td></td></tr>
<tr><td>Provide FM Approved flexible pipe or flexible hose, or other engineered piping arrangements, to accommodate expected deflections (at least 6 in. [150 mm]) at connections to equipment or tanks</td><td>2.3.3.1
2.3.4.4.4</td></tr>
</table>

Table 3.2.2.2. Summary of Data Sheet 1-11 Flammable Gas (FG) and Ignitable Liquid (IL) Piping Protection Recommendations - Schedule 40 (or Equivalent) or Stronger Steel Pipe (continued)

PIPE FLEXIBILITY RECOMMENDATIONS (continued) (Apply regardless of diameter)	**Section(s)**
Piping	
Provide a seismic separation assembly (no flexible couplings) or FM Approved flexible hose in pipe that: • Crosses a building seismic joint • Spans between buildings	2.3.4.1
PIPE CLEARANCE, SUPPORT, AND MISCELLANEOUS RECOMMENDATIONS (Apply regardless of diameter)	
Risers & Vertical Pipe Runs	
See the “Common Clearance, Support, and Miscellaneous Recommendations” below	
Horizontal Pipe Runs	
In addition to the “Common Clearance, Support, and Miscellaneous Recommendations” below Provide hangers that can also resist vertical uplift: • At the last hanger on dead end pipe	2.3.4.3
Drops	
In addition to the “Common Clearance, Support, and Miscellaneous Recommendations” below Provide hangers that can also resist vertical uplift: • On armovers within 2 ft (0.6 m) of the drop	2.3.4.3
Common Clearance, Support, and Miscellaneous Recommendations	
Provide a hole or sleeve through non-frangible or fire-rated walls/floors/roofs with clearance of: • 1 in. (25 mm) larger, all around the pipe for pipes < 4 in. (100 mm) nominal diameter • 2 in. (50 mm) larger, all around the pipe for pipes ≥ 4 in. (100 mm) nominal diameter Other considerations: - Allow pipe to move in openings that need to be sealed (e.g., by using mastic or a weak, frangible mortar) or fire protected (e.g., by using mineral wool) - When the wall material is frangible, such as gypsum board, and the wall is not required to have a fire rating, clearance is not needed - Where providing the recommended clearances is not possible, provide flexibility on both sides of the wall by installing flexible piping or ball joints Provide clearance: • ≥ 2 in. (50 mm) from walls unless rigidly braced from the wall • ≥ 2 in. (50 mm) to handwheels of manually operated valves • ≥ 6 in. (150 mm) to the topworks of remotely operated valves • ≥ 1 ft (0.3 m) from unrestrained fixtures, equipment and pipe of equal or greater diameter Hanger attachments to structure: • For Z and C metal purlins, attach to the webs instead of to the flange • Provide retaining straps on all C-clamp hanger attachments • Do not use powder-driven fasteners Miscellaneous: • Preferably use welded steel pipe or FM Approved flexible pipe/hose • Do not use flexible couplings • Avoid using threaded connections if possible • Do not use cast iron for valves, fittings or supports	2.3.4.2 2.3.4.3 2.3.4.5

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*
Data Sheet 3-2, *Water Tanks for Fire Protection*
Data Sheet 5-23, *Design and Protection for Emergency and Standby Power Systems*
Data Sheet 7-7/7-12, *Semiconductor Fabrication Facilities*
Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-79, *Fire Protection for Gas Turbines and Electric Generators*
Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
Data Sheet 7-99, *Heat Transfer by Organic and Synthetic Fluids*
Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*
Data Sheet 7-108, *Silane*
Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*

Approval Guide, an online resource of FM Approvals.

FM Approvals Standard Class 1950, *Approval Standard for Seismic Sway Braces for Pipe, Tubing and Conduit.*

FM Approvals Standard Class 6036, *Flexible Hose Assemblies for Flammable Gases and/or Ignitable Liquids.*

FM Approvals Standard Class 7400, *Approval Standard for Liquid and Gas Safety Shutoff Valves.*

4.2 Others

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APPENDIX A GLOSSARY OF TERMS

Accessible: Having access to but which first may require the removal of a panel, door, or similar covering of the item described.

Accessible, readily: Having direct access without the need to remove or move any panel, door, or similar covering of the item described.

Anchor: The device used to fix or connect the equipment to the building, foundation or ground.

Anchored/Anchoring: See Anchor.

Axial brace: Synonymous with longitudinal brace.

Branch supply line: Piping that conveys gas from a main (supply) line to the equipment (appliance).

Building control joint: Usually a bituminous fiber strip used to separate concrete units to prevent cracking from thermal expansion.

Building seismic joint: A physical separation between immediately adjacent building structures or sections of a single building that allows independent differential motion between the structures or sections.

Design load: The assessed maximum load due to earthquake and other effects used to proportion and size component parts of equipment.

Differential motion: The relative motion of two different objects moving in different directions in response to a seismic event.

Distribution header: The main pipe routed throughout a structure to supply gas from the meter to the equipment.

Equipment (appliance): Any device that utilizes gas as a fuel or raw material to produce light, heat, power, refrigeration, or air conditioning.

Equipment displacement: The estimated maximum relative movement between items of equipment or between equipment and the building elements under condition of earthquake loading.

Flexibly mounted equipment: Equipment constructed or fixed on mounts with a period of vibration greater than or equal to 0.10 s or as defined under the relevant clauses.

FM Approved: Products and 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.

Fuel gas: Includes natural gas (methane), butane, propane and liquefied petroleum (LP) gas in the vapor phase only.

Gas utilization equipment: Any device that utilizes gas as a fuel and/or raw material.

Ignitable liquid: Any liquid or liquid mixture that is capable of fueling a fire, including flammable liquids, combustible liquids, inflammable liquids, and any other term for a liquid that will burn. An ignitable liquid is one that has a fire point.

Integrated seismic gas shutoff valve (SGSV): A Seismic Gas Shutoff Valve (SGSV), typically only appropriate for use on low to moderate pressure (60 psi [414 kPa] or less) fuel gas lines, consisting of a valve and a seismic sensor integrated into one single unit and installed directly in the fuel gas line.

Inter-story displacement: The design relative movement between successive floors measured parallel to the lower floor.

Lateral bracing: Bracing oriented to resist pipe motion perpendicular to the axis of the pipe.

Longitudinal bracing: Bracing oriented to resist pipe motion parallel to the axis of the pipe.

Master Fuel Trip Relay: An electrical relay or group of relays whose purpose is to isolate power to critical boiler end devices, such as the fuel shutoff valves, pilot gas valves and spark igniters.

Modified Mercalli Intensity (MMI): One of 12 levels (I to XII, from least to most severe) identifying earthquake shaking intensity at a given location, usually via qualitative observations of human reactions, and likely damage to certain building types and objects. Rough correlations between MMI and quantitative ground shaking measures (e.g., peak ground accelerations) have also been made. See Data Sheet 1-2 for more information.

Normally Closed Safety Shutoff Valve (SSOV): A self-closing SSOV where, in case of energy loss to the actuator, the armature closes automatically.

Pipe brace: Hardware or structure designed to resist pipe motion in horizontal or vertical directions.

Pipe restraint: Synonymous with pipe brace.

Pipe hanger and support: Hardware or structure primarily designed to support the deadweight of the piping.

Piping configuration: The layout of the piping system, including pipe routing, supports, bracing, and attachments to equipment.

Piping system: All piping, valves, and fittings from the point of delivery from the supplier to the outlets of the equipment shutoff valves.

Positive anchoring: An anchoring in which components are held in place in such a manner that permanent relative movement cannot take place without exceeding the yield of one or more parts. Bearing of bolts against a hole or welding are examples of positive anchorage; friction alone is not (unless, for example, slippage would cause bolts to transfer loads via bearing).

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.

Remotely-actuated seismic gas shutoff valve (SGSV): A seismic gas shutoff valve (SGSV) that can be used on any fuel gas or flammable gas line of any pressure, consisting of a safety shutoff valve (SSOV) installed in the fuel gas or other flammable gas line that is actuated by a separate remotely-located seismic sensor.

Remotely-actuated seismic shutoff valve: A safety shutoff valve (SSOV) installed in a flammable gas or an ignitable liquid line that is actuated by a separate remotely-located seismic sensor, automatically interrupting the flow of flammable gas or ignitable liquid in case of earthquake ground shaking above a threshold level.

Resilient mount: A mount designed to support equipment but isolate the transmission of vibration to or from the structure.

Response spectrum: A graphical plot of the maximum acceleration, velocity, or displacement that an object (e.g., a structure or piece of equipment) with specific characteristics (e.g., its natural period of vibration and damping) will experience when subjected to a specific input motion (e.g., of an earthquake).

Rigidly mounted equipment: Equipment constructed or fixed in such a manner that the first mode period is less than 0.05 s.

Safety shutoff device: A device that will shut off the gas supply to the controlled burner(s) in the event the source of ignition fails. This device may interrupt the flow of gas to main burner(s) only, or to pilot(s) and main burner(s) under its supervision.

Safety shutoff valve (SSOV): A valve installed (e.g., in the fuel train of a burner or in an ignitable liquid line) to interrupt the flow of flammable gas or ignitable liquid, and typically actuated by a remote sensor that senses abnormal conditions. Valve is held open by electric energy or pressure (e.g., pneumatic) and is self-closing upon loss of the holding medium (electric or pressure). The SSOV must be appropriate for the flammable gas or ignitable liquid flowing through it. SSOVs can be found listed in the FM Approval Guide.

Seismic gas shutoff valve (SGSV): A seismically-actuated valve that automatically interrupts the flow of fuel gas or other flammable gas in case of earthquake ground shaking above a threshold level. See also definitions for integrated SGSV and remotely-actuated SGSV.

Seismic loading: The design load on the building or equipment due to earthquake effects.

Seismic shutoff valve: Any valve that is actuated by an integrated or separate seismic sensor that automatically interrupts the flow of gas or liquid in case of earthquake ground shaking above a threshold level.

Shutoff: See Valve.

Snubber: Resilient and strong anchored blocks placed next to equipment to prevent earthquake forces from moving it laterally. In piping, a snubber is an element within a brace that allows slow movement (e.g., from thermal expansion) but restrains rapid movement (e.g., from earthquake shaking).

Sources of ignition: Devices or equipment that, because of their intended modes of use or operation, are capable of providing sufficient thermal energy to ignite flammable gas-air mixtures.

Transverse bracing: Synonymous with lateral bracing.

Valve: A device used in piping to control the gas or liquid supply to any section of a system of piping or to equipment (appliance).

- *Automatic gas shutoff:* A valve used to shut off the gas supply to a fuel-gas burning water heating system. It may be constructed integrally with the gas shutoff device or be a separate assembly.
- *Automatic seismic gas shutoff:* A seismically actuated valve to shut off the gas to an entire piping system or individual supply lines.
- *Equipment shutoff:* A valve located in the piping system, used to shut off individual equipment.
- *Manual main gas-control:* A manually operated valve in the gas line for the purpose of completely turning on or shutting off the gas supply to the appliance, except to pilot or pilots that are provided with independent shutoff devices.
- *Service shutoff:* A valve, installed by the supplier, between the service meter or source of supply and the customer piping system, to shut off the entire piping system.

Vertical loading: The vertical component of the earthquake-induced loading.

Zone of influence: The piping to be included in the load distribution calculation for a given sway brace location.

APPENDIX B DOCUMENT REVISION HISTORY

April 2025. Interim revision. Minor editorial changes were made.

July 2016. This data sheet has been completely revised. The following changes were made:

A. Clarified Section 1.0, Scope.

B. Added Section 1.1, Hazards.

C. Clarified Sections 2.1 and 2.2.

D. Renamed and revised Section 2.3. Clarified text and added references to other data sheets. Made several technical revisions, the most significant of which are the following:

1. Requirements for tank anchorage (2.3.2.5)

2. Requirements for drift at seismic joints (2.3.4.1)

3. Limitations on piping materials and couplings (2.3.4.2)

4. Modifications to pipe support (2.3.4.3) and seismic sway bracing (2.3.4.4) requirements

5. Extensive revision and clarification of seismic shutoff requirements and configurations for flammable gas (2.3.5) and ignitable liquid (2.3.6)

E. Revised the inspection, testing, and maintenance requirements in Section 2.4. Deleted the guidance for earthquake emergency response, which will be moved to Data Sheet 10-2, *Emergency Response.*

F. Updated Section 3.1, Historic Losses.

G. Updated Section 3.2.2.1 with an extensive explanation of seismic shutoff valve operation and requirements.

H. Added Table 3.2.2.2 to summarize the Section 2.3 earthquake protection of piping requirements.

I. Added Section 3.2.2.3 regarding restraint of equipment, tanks, cylinders, and drums.

J. Updated the references in Section 4.0.

K. Revised the definitions in Appendix A.

L. Revised figure and table numbers throughout the data sheet.

May 2010. The following changes were made:

- Revised brace capacity Tables 1 through 6 and Section 2.3.4.4 to be consistent with the latest edition of Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*.
- Made minor editorail changes throughout the document.

January 2008. Minor editorial changes were made.

September 2004. References to FM Global earthquake zones have been modified for consistancy with Data Sheet 1-2, *Earthquakes.*

January 2004. The following changes were made:

1. Made editorial revisions to Figures 2, 4, 7, and 9; to Sections 2.3.1, 2.3.5.1, 2.3.5.2, and 2.3.5.3; and to Appendix B. Changed numbering of Sections 2.3.4.3 to 2.3.4.5 (formerly 2.3.4.3 to 2.3.4.13).

January 2002. First issued.