DAMAGE-LIMITING CONSTRUCTION

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1.0 SCOPE

This data sheet provides guidelines for the design and construction of building components for rooms or buildings where a combustion explosion (deflagration) hazard exists. This data sheet does not cover explosion suppression systems or protection against a detonation (see Section 3.2.1). Space separation or blast resistance of structures exposed to vapor cloud explosions (VCEs); boiling liquid, expanding vapor explosions (BLEVEs); reactor excursions or other large overpressure events are also beyond the scope of this data sheet (see Data Sheet 7-43/17-2, *Loss Prevention in Chemical Plants;* Data Sheet 7-44/17-3, *Spacing of Facilities in Outdoor Chemical Plants;* and Data Sheet 7-45, *Instrumentation and Control in Safety Applications,* for additional details). For protection against detonations, refer to Data Sheet 7-16, *Barricades.*

Recommended combinations of vent area and design pressures for pressure-resistant construction are addressed for gas/air deflagrations. The criteria varies depending on the degree of hazard of the fuel(s) involved. For criteria on combustible dusts, refer to Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires.*

1.1 Changes

May 2002. Editorial changes were made to section 3.1 Illustrative Losses.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Construction and Location

2.1.1 The location of rooms or buildings needing damage-limiting construction should agree with Section 3.2.3. Table 1 should be used to determine which table (2 through 5) to refer to for the design criteria (vent area [A_v], vent release pressure [P_v] design pressure for resistant walls [P_r]) for damage-limiting construction. If there is more than one fuel present in sufficient quantities to cause a room explosion, the design should be based on the worst case (the fuel with the highest table number.)

FOR AMMONIA USE TABLE 2

2.1.2 The minimum criteria in Table 2 should be met when the fuel involved is ammonia. The ratio of enclosure surface area (A_s) to vent area A_v should not exceed 24.5. Preferably, the vent panel weight should be limited to about 4 lb/ft^2 (19.5 kg/m^2).

2.1.3 The design of damage-limiting construction should meet the minimum criteria outlined in Table 3, if so directed by Table 1. The ratio of enclosure A_s to A_v should not exceed 23. Preferably, the vent panel weight should be limited to about 4 lb/ft^2 (19.5 kg/m^2).

2.1.4 The minimum criteria in Table 4 should be met, if so directed by Table 1. The vent panel weight should be limited to about 4 lb/ft^2 (19.5 kg/m^2). The ratio of A_s to A_v should not exceed 12.5.

2.1.5 The design criteria for damage-limiting construction should comply with Figure 10, when so directed by Table 1. A vent ratio of 1 ft^2 of venting for every 15 ft^3 (1 m^2/4.6 m^3) of room volume should be provided. However, in no case should the ratio of enclosure A_s to A_v exceed 7.25. The vent area need not exceed that available with all four exterior walls venting. The minimum design pressure for the resistant construction should be 100 psf (4.8 kPa); however, it should not be less than called for in Table 5. The maximum vent panel weight should be 3 lb/ft^2 (14.6 kg/m^2).

2.1.6 Venting only one end of an elongated enclosure should be avoided. If this is necessary, then the guidelines in Section 3.2.9 should be followed.

2.1.7 Manufacturer's recommendations should be followed during the installation of Factory Mutual Research Approved (see Appendix A for definition) explosion venting fasteners or systems.

2.1.8 The anticipated deflection of the explosion venting wall panels resulting from design wind loads should be limited to 1/240 of the span.

Table 1. Design Reference for Damage-Limiting Construction

Use Table 2	*Use Table 3*	*Use Table 4*	*Refer to Figure 10, Rec. No. 2.1.5 and Table 5*
Ammonia	*n-butyl-Benzene* *trans-Decalin (decahydronapthlene)* *Ethyl Acetate* *Gasoline (up to 100 octane)* *Isopropylamine* *Jet fuel (JP-1, JP-4)* *Methane* *diphenyl-Methane* *Methyl Chloride* *Tetralin (Tetrahydro-naphthalene)*	*Acetaldehyde* *Acetone* *Acrylic Acid* *Acrylonitrile* *Amyl Alcohol* *Benzene* *tert.-butyl-Benzene* *1,2-dimethyl-Benzene* *1,2,4-tri-methyl-Benzene* *2,3-dimethyl-1,3-Butadiene* *2-methyl-1,3-Butadiene* *n-Butane* *2-cyclopropyl-n-Butane* *2,2-dimethyl-n-Butane* *2,3-dimethyl-n-Butane* *2-methyl-n-Butane* *2,2,3-tri-methyl-n-Butane* *Butanol* *Butanone* *1-Butene* *2-cyclopropyl-1-Butene* *2,3-dimethyl-2-Butene-1-Butene* *2,3-dimethyl-1-Butene* *2-ethyl-1-Butene* *2-methyl-1-Butene* *3-methyl-1-Butene* *Butyl Acetate* *3,3-dimethyl-1-Butyne* *Carbon Disulfide* *Carbon Monoxide* *Cyclohexane* *Cyclopentadiene* *Cyclopentane* *Cyclopentene* *Cyclopropane* *methyl-Cyclohexane* *methyl-Cyclopentane* *ethyl-Cyclobutane* *isopropyl-Cyclobutane* *methyl-Cyclobutane* *cis-1,2-dimethyl-Cyclopropane* *trans-1,2-dimethyl-Cyclopropane* *ethyl-Cyclopropane* *methyl-Cyclopropane* *1,1,2-trimethyl-Cyclopropane* *n-Decane* *1-Decene* *Dichlorobenzene* *Diethyl Ether* *Dimethyl Either* *Ethane* *Ethanol* *Ethylenimine*	*Acetylene* *Acrolein* *Allene (propadiene)* *1,2-Butadiene (methylallene)* *1,3-Butadiene* *2-Buten-1-yne (Vinylacetylene)* *1-Butyne* *2-Butyne* *Cyclobutane* *methylene-Cyclobutane* *Ethene (ethylene)* *Ethylene Oxide* *Hydrogen* *1,2 Pentadienne (Ethylallene)* *1-Pentyne* *2-Pentyne* *Propylene Oxide (1,2-epoxypropane)* *1-Propyne* *Spiropentane* *Styrene* *Vinyl Chloride*

Table 1. Design Reference for Damage-Limiting Construction (continued)

Use Table 2	*Use Table 3*	*Use Table 4*	*Refer to Figure 10, Rec. No. 2.1.5 and Table 5*
		n-Heptane *1,5-Hexadiene* *Hexadecane* *n-Hexane* *1-Hexene* *1-Hexyne* *3-Hexyne* *Hydrocarbon Mists (all)* *Isopropyl Alcohol* *Methacrylic Acid* *Methyl Acetate* *Methyl Alcohol (methanol)* *Methyl Ethyl Ketone (MEK)* *Methyl Methacrylate* *CIS-1,3-Pentadiene* *trans-1,3 Pentadiene (piperylene)* *2 methyl-(CIS or trans) -1,3 Pentadiene* *1,4-Pentadiene* *2,3-Pentadiene* *1,4-Pentadiene* *2,3-Pentadiene* *n-Pentane* *2,2-dimethyl-n-Pentane* *2,3-dimethyl-n-Pentane* *2,4-dimethyl-n-Pentane* *2-methyl-n-Pentane* *3-methyl-n-Pentane* *2,2,4-trimethyl-n-Pentane* *1-Pentene* *Propane* *Propanol* *Propene (Propylene)* *Propionaldehyde* *2-methyl-Propene* *CIS-2-Pentene* *2-methyl-1-Pentene* *4-methyl-1-Pentene* *4-methyl-1-Pentyne* *4-methyl-2-Pentyne* *2-cyclopropyl-Propene* *2-cyclopropyl-Propane* *1-deutero-Propane* *1-deutero-2-methyl-Propane* *2-deutero-2-methyl-Propane* *2,2-dimethyl-Propane* *2-methyl-Propane* *Tetrahydropyran* *Tetrahydrofuran* *Toluene (methylbenzene)*	

2.1.9 Roof perimeter flashing at the junction of the roof and explosion venting wall panels should not restrict vent panel movement. The roof flashing should be secured near its lower edge and the top of the venting wall panel section should be terminated just below the roof flashing.

2.1.10 Relieving wall panels should terminate below rain gutters and respective bracing.

2.1.11 There should be no obstructions in the path of the relieving panels. This includes pipes, ducts and conduit that may run along an outside wall, yard storage, and adjacent equipment and structures. In addition, pipes, conduit, ducts, etc., located on the interior side of the relieving wall panels should not be connected to the relieving wall panels and should be limited so as not to significantly reduce the effective vent area.

2.1.12 The weight of relieving panels should be kept to a minimum. For additional guidelines refer to Section 3.2.5.

2.1.13 The roof vent area should not be relied on to achieve the minimum recommended vent area in cases where snow accumulations, ponded water, dust, debris or panel weight might hamper venting. If these conditions are unavoidable, refer to Section 3.2.4. A maximum weight of 3 lb/ft^2 (14.6 kg/m^2) is generally recommended for venting roof panels.

2.1.14 The following recommendations apply to the installation of Approved explosion relieving fasteners/devices:

a) When Approved, collapsing washers are used, a ½ in. (13 mm) diameter oversized hole should be drilled in the wall panel and a slightly smaller diameter centering washer or sleeve should be installed. It is imperative that the pilot hole for the screw/bolt be centered with respect to the centering washer. Only a specifically Approved No. 14 (¼ in., 6 mm in diameter) screw/bolt should be used with this washer (see Fig. 1).

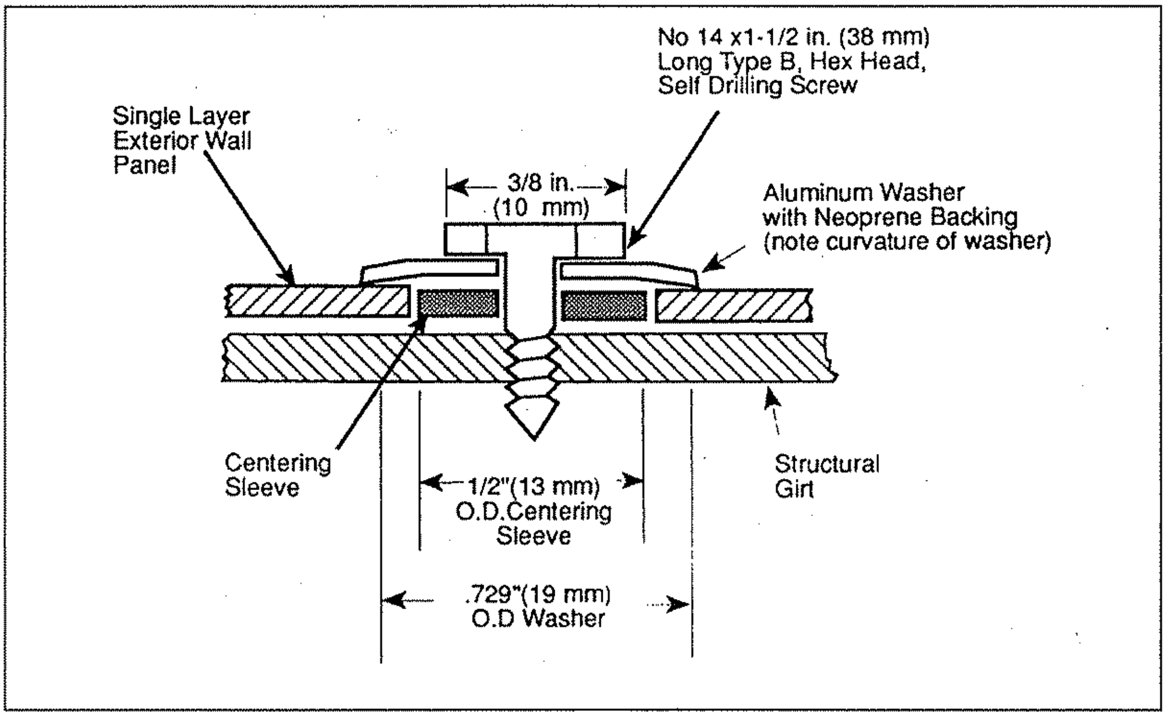


Fig. 1. Collapsing washer used with a single-layer panel.

b) When Approved reduced-shank machine bolts are used, the appropriate phenolic spacer and aluminum washer should be installed as well. These bolts can be installed to fail in tension (see Fig. 2). However, if installed to fail in shear it is imperative that the center of the reduced-shank area line up with the interface of the structural girt and the wall clip angle (see Fig. 3). When the occupancy is humid or corrosive, some protection should be provided to prevent rusting and bonding between the wall clip angle and the structural girt. Protection may be in the form of paint, a minimum 1/16 in. (1.6 mm) nylon pad or other suitable means. Since design values are higher for tension than for shear, it is important that the design values correspond to the actual installation. A locking fluid should be applied to prevent loosening of the nut. Beveled washers should be used when girt flanges are tapered.

c) Where Approved collapsing washers are used, the steel wall panel in contact with the fastener should be a minimum of 26 gauge (0.017 in. or 0.45 mm). This also applies to previously installed Z clips.

d) To prevent premature failure, explosion-relieving fasteners should not be torqued. A snug fit is recommended and caution should be exercised when using a wrench. Finger tightening is preferred whenever practical. Wrench tightening may lead to premature failure.

e) The static design of explosion-relieving fasteners/devices should be based on loads listed in the Factory Mutual Research Approval Report with no added factor of safety (safety factor of 1.0). The fasteners should resist lateral loads only and should not be arranged to resist vertical (dead) loads. The proposal

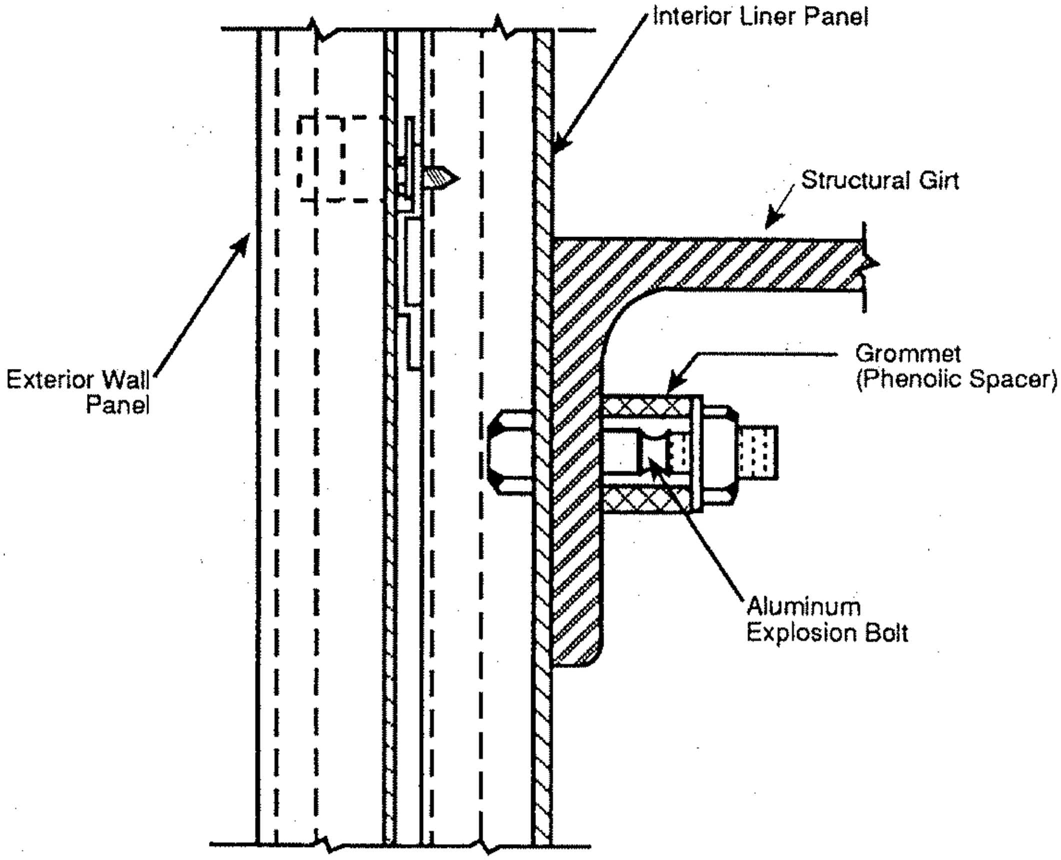


Fig. 2. Reduced-shank machine bolt installed to fail in tension.

should provide a lateral resistance that is as close as practical to the static design release pressure. Actual designs within 10% of the desired design value are acceptable. If the initial trial design results in pressures that deviate from the design values by more than 10%, changes are needed. This includes one or more of the following:

Fastener type/designation
Girt spacing
Fastener spacing along girts
Adding or deleting shims (for magnetic release only)
Vent area
Design pressure of pressure-resistant wall

For additional details relating to the last two items, refer to Tables 2 through 5 as applicable. Magnetic releases must be either shop or field calibrated to verify that they release within 10% of the design value (see Fig. 4).

2.1.15 Pressure-relieving wall panels should be designed to release at the lowest possible pressure that will provide adequate wind resistance. Generally, a static design pressure of 20 psf (0.96 kPa) is sufficient and is preferred. Conditions specific to the individual installation (such as the local design wind speed, wall height, ground roughness coefficient and pressure coefficient at corners - see Data Sheet 1-7, *Wind Forces on Buildings and Other Structures)* and governing building codes may necessitate a higher design pressure. In any case, the combination of vent area provided and design pressures for the pressure-resistant and pressure-relieving walls should at least meet guidelines in Section 3.2.5 and Tables 2, 3, 4 or 5 (as applicable). The design pressure for pressure-relieving walls should in no case exceed 40 psf (1.92 kPa).

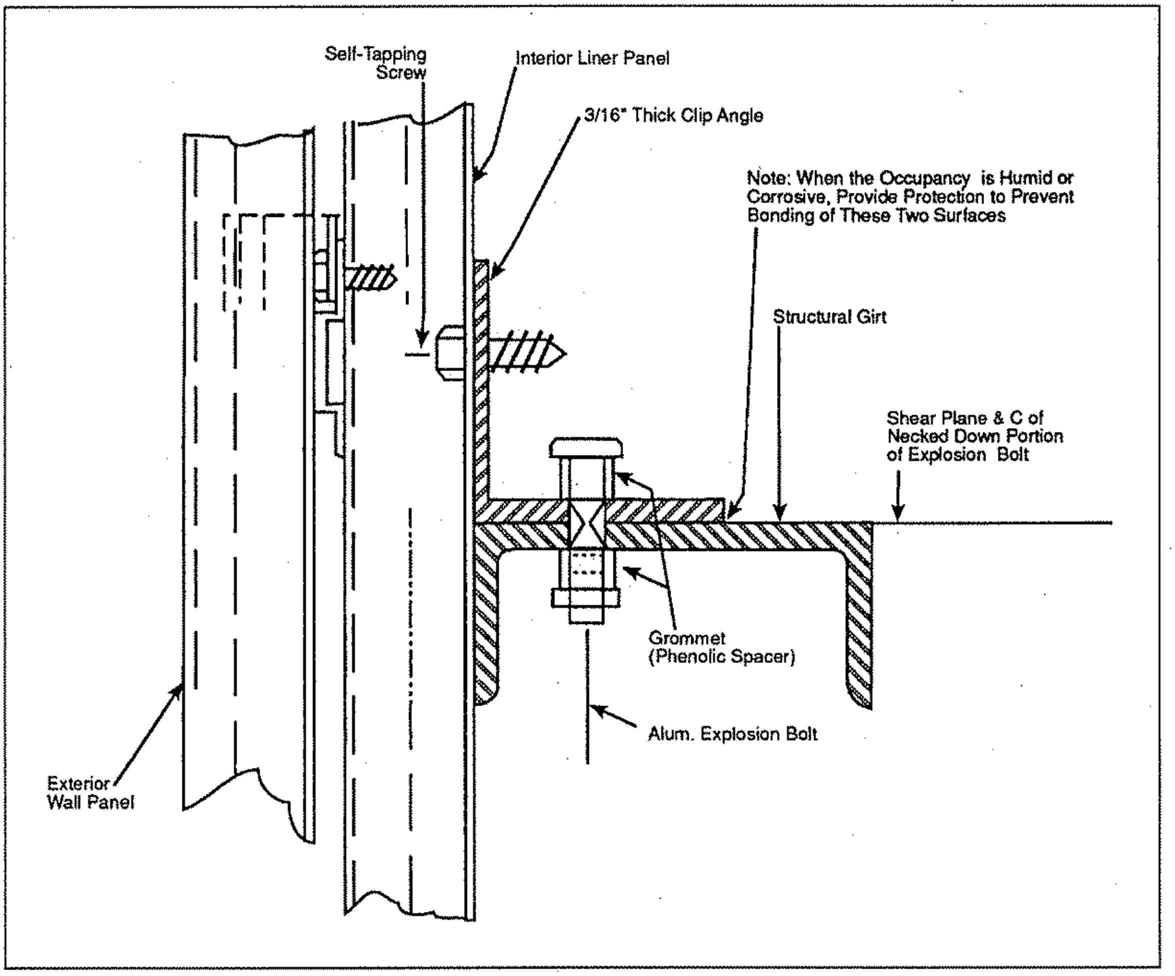


Fig. 3. Reduced-shank machine bolt installed to fail in shear.

2.1.16 The area of explosion-relieving wall panels should be as large as practical. However, the overall design should at least meet criteria in Section 3.2.5 and Tables 2, 3, 4 or 5, as applicable.

2.1.17 Doors located within explosion venting walls should be arranged to open outward, but their area should not be considered as part of the design vent area. They need not be pressure-resistant.

2.1.18 If venting panels are tethered or hinged, they should be connected at the top or bottom only and never at more than one edge. If a flashing detail is provided at the top of the panel that could initiate panel rotation, the panel should be hinged or tethered from the top. Tethers should utilize sufficient slack cable to allow adequate panel movement. Hinges should be made of corrosion-resistant materials.

2.1.19 Vent panels should be as evenly distributed and centrally located as practical.

2.1.20 Vent panels may be single layer metal panels, glass fiber or paper honeycomb core metal sandwich panels or Approved panels meeting guidelines in Section 2.1.

2.1.21 Walls protecting adjacent occupancies from those with an explosion hazard should be designed to resist pressures as outlined in Tables 2, 3, 4 or 5, as applicable. In multistory locations, exposed floors above or below should be designed similarly. When a lean-to arrangement is utilized, pressure-resistant construction should be extended as outlined in Figure 5. Adequate reinforcement should be provided around door openings. Pressure-resistant walls, particularly those of masonry construction, should not be load-bearing.

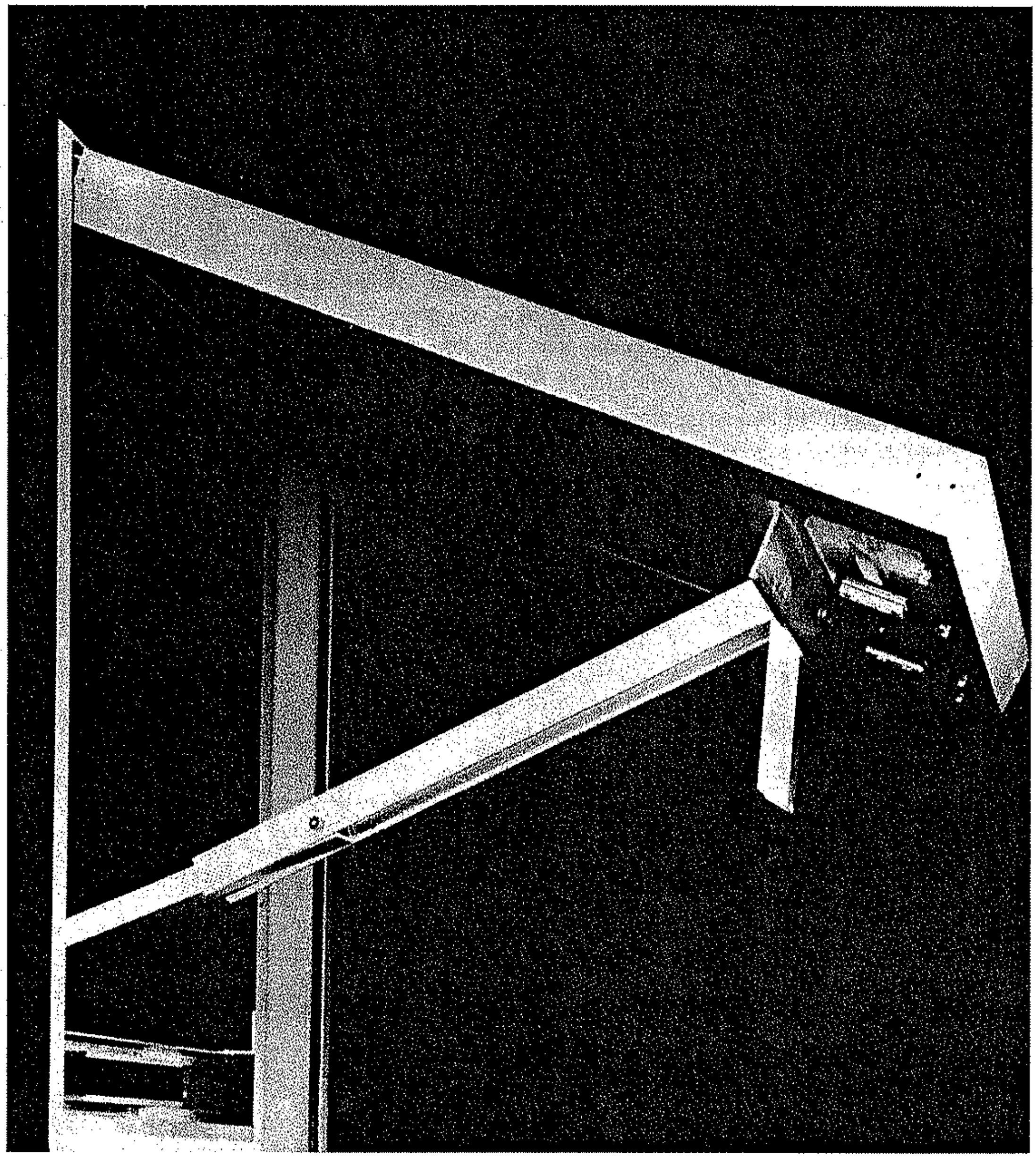


Fig. 4. Explosion-relieving panel with magnetic release. (Courtesy of Construction Specialties, Inc.)

2.1.22 Doors in pressure-resistant walls should be arranged as follows:

a) They should be normally closed and should close automatically. Personnel doors should be equipped with door closers or spring hinges. Vehicle doors should be equipped with power operators. Electrical power operators should be suitable for their environment (see Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations).* Vehicle doors should be equipped with tripwires or photo-eyes to allow automatic closure after vehicles have passed through the opening.

b) All doors should be capable of resisting the same overpressures as the wall. The door manufacturer should provide test data or calculations to substantiate the adequacy of the door. Permanent deformation under design loading is acceptable as long as the door stays in place to prevent the propagation of pressure, flames and projectiles.

c) Whenever possible, and not in disagreement with local codes, personnel doors on pressure-resistant walls should open inward so that initial force pushes the door against the bar stop. The latch throw should be minimum ¾ in. (19 mm) and the bar stop should be minimum ⅝ in. (16 mm) deep.

Egress doors (doors opening out of the room and equipped with panic bars) preferably should be installed at the ends of the exterior venting wall. Railings may be needed outside the door opening (see Fig. 6). Depending on the size and geometry of the room, one door at each end may meet code requirements for maximum travel distances to egress doors.

When egress doors are required by local code on pressure resistant walls, the door and latch should be designed to withstand the same pressure as the wall without disengaging. Three point latches are desirable and sometimes necessary in such a case. Precautions should be taken to prevent damage from pressure and flame propagation and projectiles resulting from the release of a panic bar (see Section 3.2.7).

d) If double personnel doors are used, they should latch into a mullion. Alternatively, the doors may latch together where they meet with a three point latch, and the inactive leaf should latch into the top of the frame and into the floor near the junction of the two doors (see Fig. 7).

e) Vehicle doors, if used, should be mounted on the hazard side of the pressure-resistant wall. Anchorage of the mounting hardware should be capable of resisting the design pressure over the door area.

Multilevel Buildings

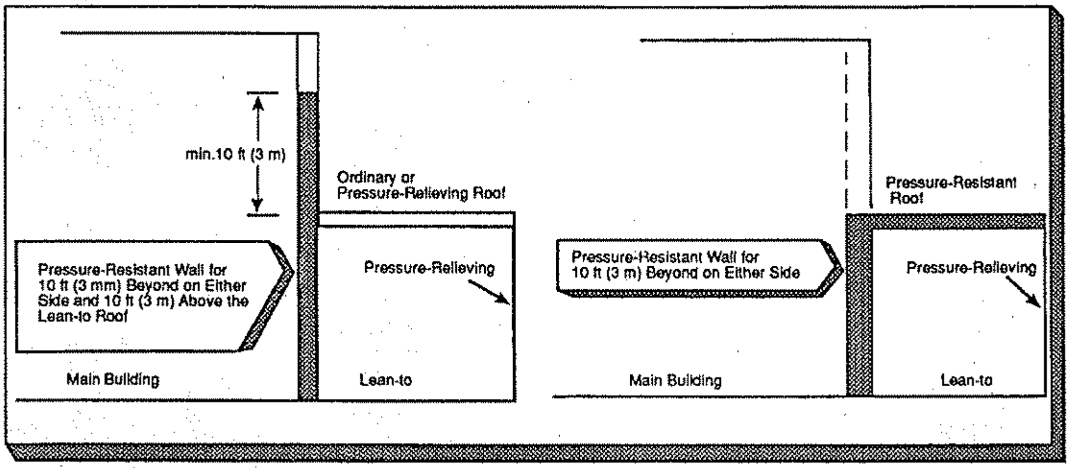


Fig. 5. Construction details for lean-to with damage-limiting construction.

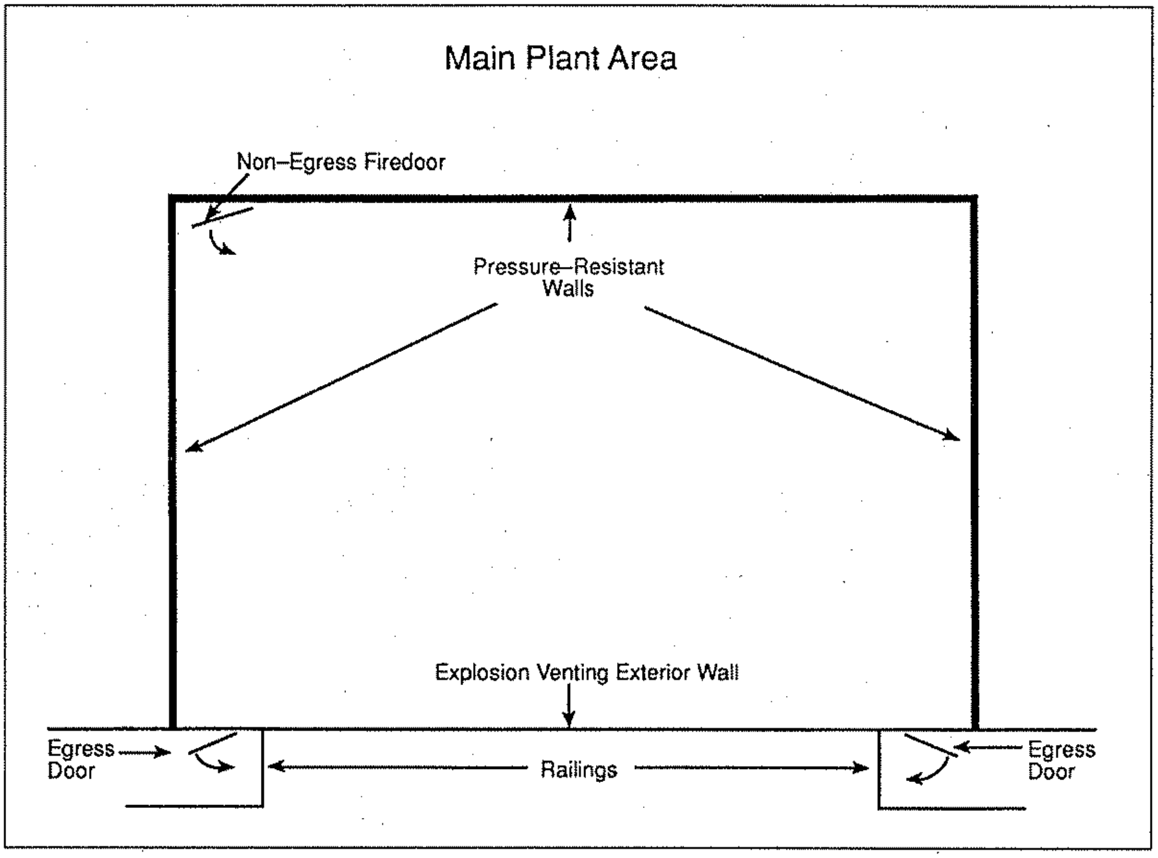


Fig. 6. Preferred locations of egress doors.

* *Table 2. P_r (psf) English Units* AMMONIA

P_v	A_s/A_v																					
(psf)	14*	14-½	15	15-½	16	16-½	17	17-½	18	18-½	19	19-½	20	20-½	21	21-½	22	22-½	23	23-½	24	24-½
20*	70	76	81	87	92	98	104	110	117	123	130	137	144	151	158	166	174	182	190	199	207	216
25	75	76	81	87	92	98	104	110	117	123	130	137	144	151	158	166	174	182	190	199	207	216
30	80	80	81	87	92	98	104	110	117	123	130	137	144	151	158	166	174	182	190	199	207	216
35	85	85	85	87	92	98	104	110	117	123	130	137	144	151	158	166	174	182	190	199	207	216
40	90	90	90	90	92	98	104	110	117	123	130	137	144	151	158	166	174	182	190	199	207	216

* Or less

Calculation based on: $P_r = C^2 \left(\frac{A_s}{A_v}\right)^2 \times 144 \left(\frac{psf}{psi}\right)$

Where: $C = 0.05\ (psi)^{1/2}$ for ammonia
No extrapolation beyond these ranges should be made.
Linear interpolation will provide a reasonable level of accuracy.
Min. $P_r = P_v + 50$ psf

Table 2. P_r (kPa) SI Units

P_v	A_s/A_v																				
(kPa)	14*	14-½	15	15-½	16	16-½	17	17-½	18	18-½	19	19-½	20	20-½	21	21-½	22	22-½	23	23-½	24	24-½
.96*	3.36	3.65	3.89	4.18	4.42	4.70	4.99	5.28	5.62	5.90	6.24	6.58	6.91	7.25	7.58	7.97	8.35	8.74	9.12	9.55	9.94	10.37
1.20	3.60	3.65	3.89	4.18	4.42	4.70	4.99	5.28	5.62	5.90	6.24	6.58	6.91	7.25	7.58	7.97	8.35	8.74	9.12	9.55	9.94	10.37
1.44	3.84	3.84	3.89	4.18	4.42	4.70	4.99	5.28	5.62	5.90	6.24	6.58	6.91	7.25	7.58	7.97	8.35	8.74	9.12	9.55	9.94	10.37
1.68	4.08	4.08	4.08	4.18	4.42	4.70	4.99	5.28	5.62	5.90	6.24	6.58	6.91	7.25	7.58	7.97	8.35	8.74	9.12	9.55	9.94	10.37
1.92	4.32	4.32	4.32	4.32	4.42	4.70	4.99	5.28	5.62	5.90	6.24	6.58	6.91	7.25	7.58	7.97	8.35	8.74	9.12	9.55	9.94	10.37

* Or less
Min. $P_r = P_v$+2.4 kPa
No extrapolation beyond these ranges should be made.
Linear interpolation will provide a reasonable level of accuracy.

Table 3. P_r (psf) English Units

P_v	A_s/A_v																				
(psf)	3*	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
20*	70	74	80	87	93	100	106	113	119	125	131	138	145	151	158	164	170	176	183	190	196
25	75	75	80	87	93	100	106	113	119	125	131	138	145	151	158	164	170	176	183	190	196
30	80	80	80	87	93	100	106	113	119	125	131	138	145	151	158	164	170	176	183	190	196
35	85	85	85	87	93	100	106	113	119	125	131	138	145	151	158	164	170	176	183	190	196
40	90	90	90	90	93	100	106	113	119	125	131	138	145	151	158	164	170	176	183	190	196

* Or less
Linear interpolation is acceptable.
No extrapolation should be made beyond table limits.
Min. $P_r = P_v$+50 psf

Table 3. P_r (kPa) SI Units

P_v	A_s/A_v																				
kPa	3*	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0.96*	3.36	3.55	3.84	4.18	4.46	4.80	5.09	5.42	5.71	6.00	6.29	6.62	6.96	7.25	7.58	7.87	8.16	8.45	8.78	9.12	9.41
1.20	3.60	3.60	3.84	4.18	4.46	4.80	5.09	5.42	5.71	6.00	6.29	6.62	6.96	7.25	7.58	7.87	8.16	8.45	8.78	9.12	9.41
1.44	3.84	3.84	3.84	4.18	4.46	4.80	5.09	5.42	5.71	6.00	6.29	6.62	6.96	7.25	7.58	7.87	8.16	8.45	8.78	9.12	9.41
1.68	4.08	4.08	4.08	4.18	4.46	4.80	5.09	5.42	5.71	6.00	6.29	6.62	6.96	7.25	7.58	7.87	8.16	8.45	8.78	9.12	9.41
1.92	4.32	4.32	4.32	4.32	4.46	4.80	5.09	5.42	5.71	6.00	6.29	6.62	6.96	7.25	7.58	7.87	8.16	8.45	8.78	9.12	9.41

* Or less
Linear interpolation is acceptable.
No extrapolation beyond table limits should be made.
Min. $P_r = P_v$+2.4 kPa

Table 4. P_r (psf) English Units

P_v	A_s/A_v																		
(psf)	3*	3-½	4	4-½	5	5-½	6	6-½	7	7-½	8	8-½	9	9-½	10	10-½	11	11-½	12
20*	70	75	84	92	100	109	117	125	134	142	150	158	166	173	181	190	199	207	215
25	75	75	84	92	100	109	117	125	134	142	150	158	166	173	181	190	199	207	215
30	80	80	84	92	100	109	117	125	134	142	150	158	166	173	181	190	199	207	215
35	85	85	85	92	100	109	117	125	134	142	150	158	166	173	181	190	199	207	215
40	90	90	90	92	100	109	117	125	134	142	150	158	166	173	181	190	199	207	215

* Or less
Linear interpolation is acceptable.
No extrapolation beyond table limits should be made.
Min. $P_r = P_v$+50 psf

Table 4. P_r (kPa) SI Units

P_v	A_s/A_v																	
(kPa)	3*	3-½	4	4-½	5	5-½	6	6-½	7	7-½	8	8-½	9	9-½	10	10-½	11	11-½	12
0.96*	3.36	3.60	4.03	4.42	4.80	5.23	5.62	6.00	6.43	6.82	7.20	7.58	7.97	8.30	8.69	9.12	9.55	9.94	10.32
1.20	3.60	3.60	4.03	4.42	4.80	5.23	5.62	6.00	6.43	6.82	7.20	7.58	7.97	8.30	8.69	9.12	9.55	9.94	10.32
1.44	3.84	3.84	4.03	4.42	4.80	5.23	5.62	6.00	6.43	6.82	7.20	7.58	7.97	8.30	8.69	9.12	9.55	9.94	10.32
1.68	4.08	4.08	4.08	4.42	4.80	5.23	5.62	6.00	6.43	6.82	7.20	7.58	7.97	8.30	8.69	9.12	9.55	9.94	10.32
1.92	4.32	4.32	4.32	4.42	4.80	5.23	5.62	6.00	6.43	6.82	7.20	7.58	7.97	8.30	8.69	9.12	9.55	9.94	10.32

* Or less
Linear interpolation is acceptable.
No extrapolation beyond table limits should be made.
Min. $P_r = P_v + 2.4$ kPa

Table 5. P_r (psf) English Units

P_v	A_s/A_v													
(psf)				4.75*	5	5.25	5.5	5.75	6	6.25	6.5	6.75	7	7.25
20*				100	104	115	126	136	150	163	176	190	204	216
25				100	104	115	126	136	150	163	176	190	204	216
30				100	104	115	126	136	150	163	176	190	204	216
35				100	104	115	126	136	150	163	176	190	204	216
40				100	104	115	126	136	150	163	176	190	204	216

* Or less

Calculation based on: $P_r = C^2 \left(\frac{A_s}{A_v}\right)^2 \times 144 \left(\frac{psf}{psi}\right)$

Where: $C = .17\ (psi)^{1/2}$
Min. $P_r = P_v + 50$ psf
No extrapolation beyond these ranges should be made.
Linear interpolation will provide a reasonable level of accuracy.

Table 5. P_r (kPa) SI Units

P_v	A_s/A_v													
(kPa)				4.75*	5	5.25	5.5	5.75	6	6.25	6.5	6.75	7	7.25
0.96*				4.80	4.99	5.52	6.05	6.53	7.20	7.82	8.45	9.12	9.79	10.37
1.20				4.80	4.99	5.52	6.05	6.53	7.20	7.82	8.45	9.12	9.79	10.37
1.44				4.80	4.99	5.52	6.05	6.53	7.20	7.82	8.45	9.12	9.79	10.37
1.68				4.80	4.99	5.52	6.05	6.53	7.20	7.82	8.45	9.12	9.79	10.37
1.92				4.80	4.99	5.52	6.05	6.53	7.20	7.82	8.45	9.12	9.79	10.37

* Or less
Min. $P_r = P_v + 2.4$ kPa
No extrapolation beyond these ranges should be made.
Linear interpolation will provide a reasonable level of accuracy.

2.1.23 Windows and duct penetrations in pressure-resistant walls should be avoided. When necessary, windows, frames and anchorage should be designed to withstand the same pressure as the wall. Also, ductwork should be designed to prevent buckling at its juncture with the wall (see Section 3.2.7).

2.1.24 When designing steel wall panels or framing for pressure-resistant construction, guidelines in Section 3.2.11 should be followed.

2.1.25 When designing reinforced concrete pressure-resistant walls, a minimum safety factor of 1.2 should be used with Ultimate Strength Design (see Section 3.2.12).

2.1.26 Metal lath and plaster walls used for pressure-resistant construction should comply with Section 3.2.13.

2.1.27 Reinforced masonry pressure-resistant design should comply with Sections 3.2.14 and 3.2.15. Unreinforced masonry is not recommended.

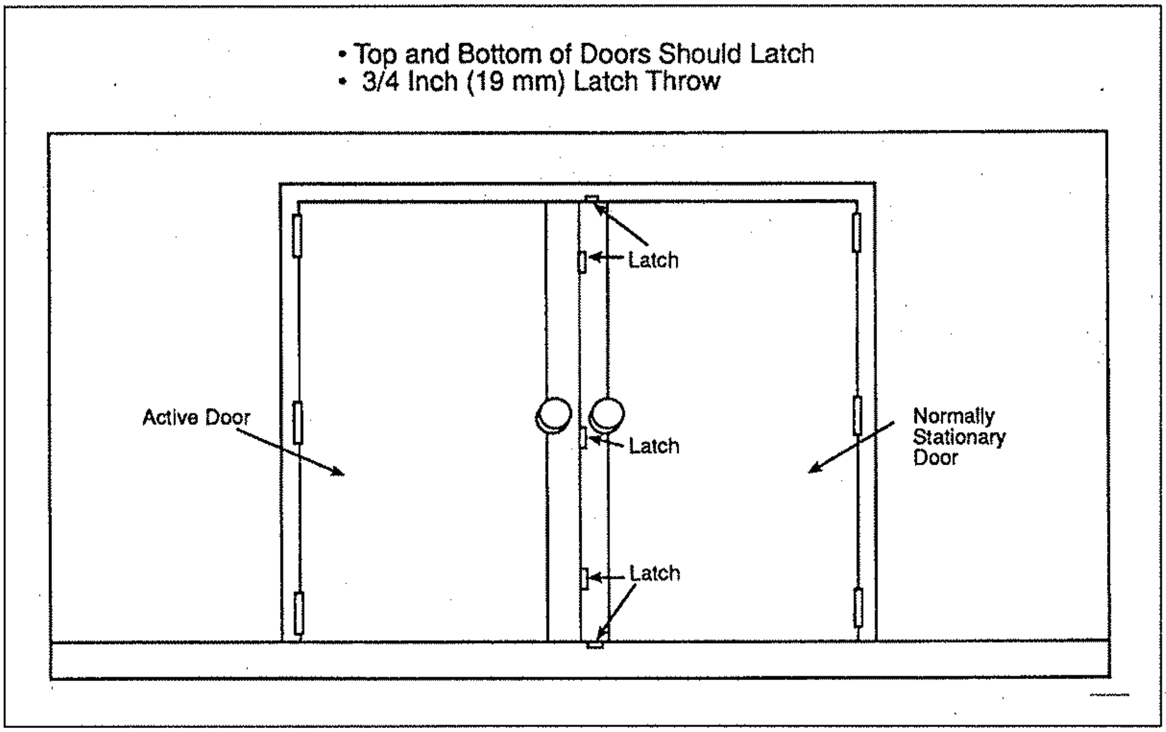


Fig. 7. Details for double doors in pressure-resistant walls.

2.2 Protection

All of the following recommendations apply to protection of piping, valves and fittings against damage from explosions. All apply to sprinkler piping and, where noted, some apply to other piping:

2.2.1 Sprinkler risers should be located in areas cut off by pressure-resistant walls or shielded by structural columns. Waterflow alarms should be provided.

2.2.2 Sprinkler feed and cross mains should be located away from reactors or pressure vessels whenever practical (e.g., in the aisles or off to the sides of reactors or pressure vessels but never directly above this equipment).

2.2.3 Generally, *all* water supply mains to hazardous process areas should be buried, looped and equipped with divisional valves so that any breaks due to explosion damage can be isolated. Domestic/process water lines for small rooms may be fed from adjacent areas as long as a readily accessible, remote manual shutoff valve is available.

2.2.4 All piping over 2 in. (51 mm) should be welded or have welded flanged fittings. Welding should conform to the American National Standards Institute (ANSI) B 31.1.0, *Power Piping.* Welded flanged fittings should conform to ANSI B 16.9— *Wrought Steel Buttwelding Fittings*, or B 16.25— *Buttwelding Ends.* Welding should be prohibited in an occupied structure, however, welded subassemblies may be prepared outside the area and assembled (flanged) within the area. Piping 2 in. (51 mm) or smaller may be welded. Alternatively, malleable iron or steel fittings of 150 psi (1034 kPa) steam rating (300 psi [2068 kPa]) W.O.G. (water, oil, or gas) rating conforming to ANSI B 16.3— *Malleable Iron Screwed Fittings,* or B 16.5— *Steel Pipe Flanges and Flanged Fittings,* should be used. Flexible couplings should *not* be used.

2.2.5 *All* piping should be supported by the building or structural framework; however, outdoor piping may be attached to self-supporting process equipment.

2.2.6 For processing structures located indoors or outdoors, a readily accessible manual shutoff valve should be provided for each sprinkler system and for flammable liquid and gas piping. These valves should be located at least 50 ft (15.2 m) from the building or structures.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Illustrative Losses

3.1.1 Acetylene Manufacturing Facility Destroyed by Explosion

This acetylene manufacturing facility was 38×62×30 ft (11.6×18.9×9.1 m) high and was constructed of lightweight exterior metal wall and roof panels (with ordinary fastening) on steel framing. The 23x31 ft (7.0×9.4 m) acetylene generator was separated from adjacent areas (including the acetylene fill area) by ordinary unreinforced concrete block walls.

A leak from the acetylene generator became ignited and resulted in an explosion. Most of the concrete block separation walls collapsed. All exterior metal wall and roof panels in the immediate area were blown off; however, all the steel framing was permanently deformed. Some damage also occurred to exterior wall panels and steel framing on the opposite side of the separation walls. Only about 500 of 1000 acetylene cylinders located in the acetylene fill area were salvageable. Sprinkler branch lines and feed mains were cracked. Debris was scattered for several hundred feet. Piping, electrical and heating equipment and the boiler were damaged. The manufacturing equipment was salvaged; however, despite the large vent area, the entire building had to be demolished because of the negative factors noted below.

This loss illustrates several points:

1. The relative severity of an acetylene explosion and why it is in the most stringent design category.

2. The adverse effects of not using Approved explosion relieving fasteners on exterior wall panels. The ordinary fastening most likely resulted in static release pressures of at least two to three times that normally recommended. That load was transferred to the building frame, causing complete damage to it.

3. The very limited pressure-resistance of an ordinary, unreinforced concrete block wall.

3.2 General Comments

3.2.1 Overview of Explosion Hazards

The bursting of buildings or containers due to development of internal pressure are examples of structural failures caused by explosions. An explosion can be caused by rapid combustion of dusts or flammable gas-air mixtures. This combustion process results in the rapid release of energy, the expansion of gases and the development of overpressures within the enclosure. A gas-air mixture must be within the flammable limits for the particular material involved to ignite and propagate a flame. This flammable range is listed by percent volume and is bounded by the lower explosive limit (LEL) and the upper explosive limit (UEL). Sufficient energy, usually in the form of an open flame or a mechanical or electrical spark, is needed to initiate the combustion reaction. Construction features referred to as damage-limiting construction are utilized to minimize overpressures and damage caused by this combustion process.

In addition to normally provided safeguards, damage-limiting construction is used to enclose hazardous occupancies that have an explosion potential. Typical occupancies may be involved with the handling of flammable liquids and gases or the performance of operations involving combustible dust and materials subject to explosive decomposition or reactions. For more specific details, see Data Sheet 7-32, *Flammable Liquid Operations,* and Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires.* Overpressures can result from either deflagrations or detonations. A deflagration is the propagation of a combustion zone at a velocity less than the speed of sound in the unreacted medium. A detonation is the propagation of a combustion zone at a velocity greater than the velocity of sound in the unreacted medium. In a deflagration, the pressure front reaches the venting panels causing their release before the flame front reaches that point. The maximum pressure developed in a properly vented deflagration is usually no more than 1 or 2 psi (6.9 to 13.8 kPa).

If the initial deflagration is completely contained (no venting), peak pressures of approximately 100 psi (690 kPa) or more can result. In a detonation, the flame front reaches the perimeter of the enclosure at the same time that the pressure front does, thus releasing all available energy before vents can release. Consequently, explosion venting is only effective for deflagrations and not detonations. Comments and recommendations contained in this data sheet should be applied to deflagrations only.

There are various non-construction factors present at ignition that could affect the overpressure developed in an explosion. These include the burning velocity of the material, the exact gas-air concentration, the portion of the enclosure that is in the explosive range and the degree of turbulence. Turbulence can result from normal building airflow at the time of the explosion, the escape of flammable gases under high pressure or gas-air movement around equipment or other obstacles in the enclosure during the combustion reaction.

Damage-limiting construction may be provided as a separate building, an enclosure adjoining a building or within the building along an exterior wall. It is intended to limit the extent of damage and to provide protection for adjoining portions of a plant. These same principles apply to locations where the hazard occupies the entire building or room, and to enclosures in which equipment occupies a significant portion of the area (see Data Sheet 7-32) and has the potential for an explosion.

3.2.2 Design Considerations

The design of damage-limiting construction does not anticipate its effectiveness for the worst possible situation. It is intended to be effective for the more likely condition where the explosive mixture develops in only a portion of the enclosure prior to ignition, or where the mixture is somewhat rich or lean. Consequently, it is preferable to make maximum use of exterior walls as pressure-relieving walls (as well as the roof where practical) rather than to provide the minimum recommended. Open structures are preferable. They provide the most effective damage limitation.

For enclosures adjoining a building or within a building along an exterior wall, a pressure-resistant wall should be placed between the hazardous and protected areas (Fig. 8). Generally, where both pressure-resistant and pressure-relieving walls are used, the pressure-resistant wall should be capable of resisting loads that are considerably higher than those that the relieving wall will take. With such a design, the resistant walls are expected to absorb the explosion shock developed while the relieving walls release and help to minimize the pressure.

In addition to considering the design of the enclosure, it should be verified that nearby elements of the building, including utility and sprinkler piping, will not be affected by explosive action from within the enclosure. Where necessary, these elements should be reinforced to resist the expected forces.

Damage-limiting construction, including pressure-resistant and relieving elements, should be designed by a registered structural or civil engineer.

3.2.3 Location

Occupancies needing damage-limiting construction preferably should be located in detached buildings at a substantial distance from main plant buildings (see Fig. 8, Area I or II).

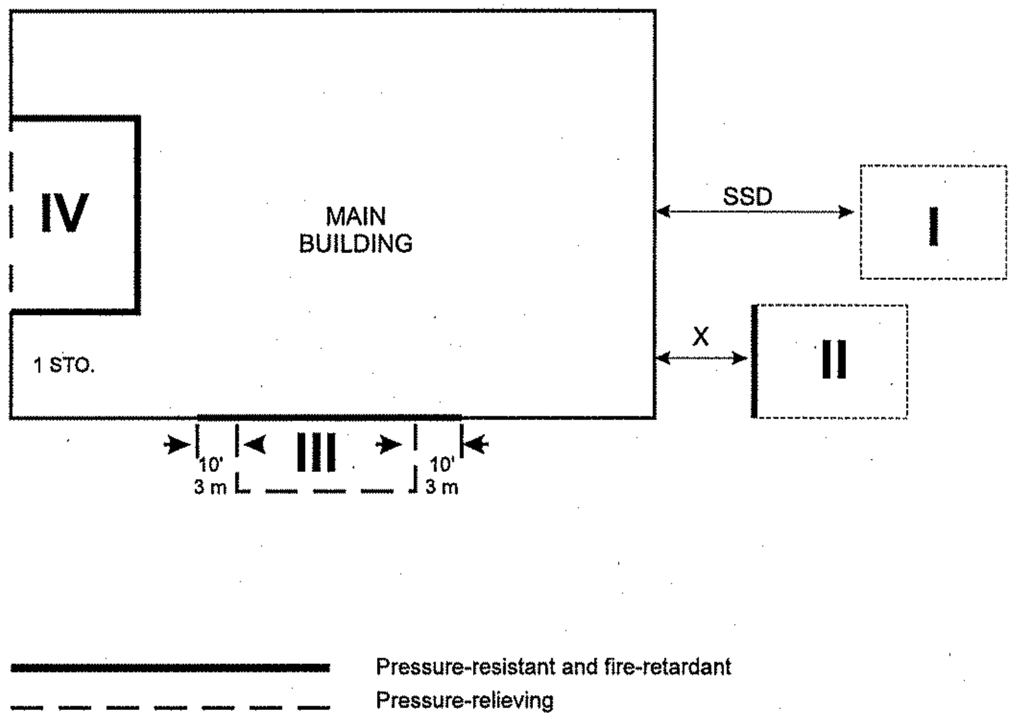
Where this is not practical, alternate arrangements for single story buildings, in order of decreasing desirability, are lean-to construction along exterior walls of main buildings (see Fig. 8, Area III) or a first floor (immediately above grade) enclosure within the main building along an exterior wall (see Fig. 8, Area IV).

In multistory situations, detached buildings or lean-tos are still preferable. Where they are not practical, either a penthouse or a first floor enclosure adjacent to an exterior wall should be used in preference to intermediate or basement floor locations at an exterior wall. The choice of penthouse or first floor enclosure will depend on building construction, height, material and quantity or operation enclosed, and costs. The penthouse permits greater venting but creates fire fighting problems and requires careful design to make drainage facilities and flooring explosion-resistant. The first floor enclosure has few fire fighting and drainage problems but may have less area available for venting if partially below grade. All exposed floors (other than slabs on grade) should be designed to resist the explosion overpressure in addition to the normal design loads.

Enclosures at interior locations within single and multistory buildings, and in basements, are undesirable and should be avoided or eliminated.

Recommended locations for areas having a deflagration potential are noted in order of preference in Figure 8 and are defined below:

Location I —Detached Building with a minimum Safe Separation Distance from nearby buildings as noted in Figure 8. Steel frame, no walls or pressure-relieving walls.



Location 1 - Detached building w/min. safe separation distance

Occupancy with Explosion Hazard	Min. Safe Separation Distance (SSD) - ft (m)	Refer to Data Sheet
Compressed Gas Cylinders	50 (15)	7-50
Flammable Liquid Mixing	75 (23)	7-32
Flammable Liquid & Gas Processing	100 (30)	7-14

Location II - Deteched building without min. safe distance separation distance.

Use this criteria when:

10 ft (3.0) < X < SSD (as noted in Location I)
If x , 10 ft (3.0) - Follow guidelines in section 3.2.3 for Location III.

For additional information see Section 3.2.3

Fig. 8. Locations for damage-limiting construction, in order of preference.

Location II — Detached Building without the minimum Safe Separation Distance from nearby buildings as noted in Figure 8. Steel frame, no walls or pressure-relieving walls on up to three sides. Fire and pressure-resistant wall on side(s) exposing nearby buildings.

Location III — Lean-to. Steel frame, pressure-relieving exterior walls and roof, pressure-resistant common wall extended 10 ft (3.0 m) beyond lean-to in each direction horizontally and above lean-to roof (if the roof is not pressure-resistant). This is necessary because construction immediately adjacent to the venting panels will be subjected to the overpressure. The wall above the lean-to need not be pressure-resistant if the lean-to roof is pressure-resistant (see Fig. 5).

Location IV— Enclosure within building on exterior wall. Pressure-resistant interior walls, pressure-relieving exterior wall(s). Enclosure can be located at the building corner to increase available vent area.

3.2.4 Construction—General

For detached locations and penthouses, the building should have a structural steel frame and either no walls or lightweight noncombustible pressure-relieving walls. The roof also should be of lightweight noncombustible material and, optionally, may be secured with explosion venting fasteners as well. An explosion will blow off the exterior panels leaving the structural frame in place. Afterward, the building can be quickly resheathed and readied for continued use.

The recommendations for detached buildings also apply to buildings where the hazard occupies most or all of the building. When these buildings have several stories, the interior of the building should be as free of partitions as possible. Where practical, the use of open grid-type floors is preferable, and solid floors should be used only for those areas where needed for operator comfort, drainage control and trucking. Solid floors are recommended where there are significant quantities of flammable liquids above ground level. This will reduce the severity of subsequent spill fires. Solid floors may also be needed to satisfy code requirements for area separation or fire resistance.

Where lean-to construction is used, the lean-to should have a structural-steel frame. The three exterior walls should be of the lightweight pressure-relieving type. The common wall between the lean-to and the main building should be of the fire and pressure-resistant type. To provide exposure protection for the main building, the common wall should extend approximately 10 ft (3 m) horizontally beyond each lean-to side wall and vertically above the lean-to roof. The common wall above the lean-to roof need not be made pressure-resistant if the roof of the lean-to is pressure-resistant.

For interior enclosures along exterior walls, the interior walls should be of the fire and pressure-resistant type and the exterior walls of the pressure-relieving type.

Although undesirable, occasionally there are occupancies at interior locations that need damage-limiting construction. Where these conditions exist and cannot be readily moved, all enclosure walls should be of a fire and pressure-resistant type with provision made for explosion-venting through the roof. Enclosures of this type may be vented using roof sections sheathed with lightweight (no heavier than 3 lb/ft^2 [14.6 kg/m^2]) single-layer, venting panels installed as described below. Consideration should be given to normal snow accumulations, snow drifts, ponded water and dust or debris accumulations that may hamper venting. In areas subject to snow accumulation, the vent panels may be installed across steeply sloped (minimum 60°) sections of the raised roof or on the upper wall sections (above the top of anticipated snow drifts) of a monitor. In either case, sufficient freeboard should be provided on the walls of the raised roof section to compensate for potential snow accumulations (see Data Sheet 1-54, *Roof Loads for New Construction).* The additional surface area of the raised section should be added in determining design pressures for resistant construction. The A_v used in Tables 2 through 5 should be the lesser of the horizontal projected area of the roof (the room length times width) or the area of the vent panels in the raised roof section. Steeply sloped roof sections may be practical for narrow rooms, whereas monitors may be more practical for wide rooms.

Experience has shown that load-bearing masonry walls or precast roof units are not desirable components of damage-limiting construction and should be avoided. The load-bearing walls are likely to collapse when subjected to an explosion, dropping everything they support into the debris, and requiring complete reconstruction of the enclosure or building. This would also impair sprinkler protection and potentially lead to an uncontrolled fire. During an explosion, precast roof units of lightweight or conventional concrete or gypsum or cementitious wood fiber may yield flying fragments or spalled sections which can collapse onto sprinkler piping. Units remaining after the explosion become a safety hazard during early phases of cleanup. Loss experience has been favorable with poured-in-place decks, metal panel and insulated steel deck roofs.

3.2.5 Pressure-Relieving Construction

When subjected to an explosive force, pressure-relieving walls are intended to vent the force quickly and safely before it causes excessive damage. These walls should vent an area appropriate for the pressure-resistant construction as outlined in Tables 2, 3, 4 or 5, as applicable.

When explosion venting wall or roof panels are needed, such panels should be relatively light. It is recommended that the panel weight not exceed 3 lb/ft^2 (14.6 kg/m^2). This may be most critical when the occupancy contains gases with a relatively high fundamental burning velocity or subject to flame instabilities such as those covered by Table 5. In those cases, all else being equal, the pressure will rise faster in a deflagration, taking longer to move the panel far enough to allow effective venting. Panels weighing no more than 3 lb/ft^2 (14.6 kg/m^2) are believed to provide minimal resistance. The type and weight of exterior panels used in industrial buildings varies, however, metal panels are commonly used. Lightweight corrugated-steel or aluminum sheets are the most desirable materials for this purpose. Single-layer metal panels generally weigh approximately 2 lb/ft^2 (9.8 kg/m^2). However, for energy conservation, insulated metal sandwich wall panels weighing about 3 to 4 lb/ft^2 (14.6 to 19.5 kg/m^2) are often used. This is acceptable for wall panels (but not recommended for roofs) for fuels listed for use with Tables 2, 3 or 4.

When insulation is needed but the weight of a sandwich panel is excessive for the type of fuel involved, a single-layer metal panel may be used with glass fiber batt insulation (Class 1) between the panel and structural girt. In some cases it may be necessary to use ordinary fasteners to draw up the panel and compress the batt insulation between the panel and girt. Then all the fasteners must be backed out and replaced with explosion-venting fasteners one at a time. This will help prevent premature failure of the explosion-venting fasteners.

In some instances where alternative locations are not available, a fire-rated venting wall panel may be needed to resist external fire exposure. This venting panel may use one or more layers of gypsum board within a metal sandwich panel. (See Data Sheet 1-21, *Fire Resistance of Building Assemblies,* for additional details and hourly ratings). This will add about 4 lb/ft^2 (19.5 kg/m^2) for every inch (25 mm) of gypsum board thickness resulting in a total weight of about 8 lb/ft^2 (39 kg/m^2) for a one-hour fire-rated panel. This panel weight is greater than preferred but can be tolerated for those fuels governed by Table 2 or 3. In no case should the panel weight exceed 8.3 lb/ft^2 (40 kg/m^2).

To minimize damage to nearby buildings from pressure and flying debris, there should be a minimum of 50 ft (15.2 m) clear space (see Fig. 8) opposite the pressure-relieving walls. Where such space is not available, pressure-resistant construction can be provided on either the exposed or the exposing building.

Snow, water, dust or debris accumulations on roof explosion vents could increase the pressure developed in the enclosure to beyond that anticipated.

It is desirable, from an explosion venting standpoint, to arrange exterior wall panels to relieve at the lowest pressure possible. However, the panels must withstand design wind loads. These wind loads vary depending on geographical location, height above grade and ground roughness (the effect of terrain on wind velocity). Design wind pressures of 20 to 40 psf (0.96 to 1.92 kPa) are most commonly encountered and failure of the fasteners (and not the panel) due to wind suction on the leeward side should be considered. Inadequate design or construction of explosion-relieving fasteners could result in blow-off during a windstorm of minor magnitude should the actual release pressure be less than recommended. On the other extreme, design or construction that resulted in higher release pressures than recommended could yield higher overpressures in an explosion than anticipated. Pressure-relieving walls preferably should be designed for a static release pressure of 20 psf (0.96 kPa). That design pressure provides just enough resistance to wind forces in most cases. When greater lateral resistance to wind is needed, a larger vent area or higher design pressure for the pressure-resistant construction may be needed. Acceptable combinations are outlined in Tables 2 through 5, as applicable.

It is desirable to provide as large an area of vent panels as practical in design as the vent area is very significant in limiting deflagration overpressures. Locating a room with a potential explosion hazard in the corner of a building optimizes the vent area; however, applying the proper wind pressure coefficient in that area would result in a need to increase the wind design load for some distance (the lesser of 0.4 times the building eave height or 0.1 times the building width) from the corner. Particularly in the case of existing buildings, available vent area may be less than desired and the pressure-resistant construction must be designed to resist higher overpressures.

Particular attention must be given to the design and selection of the fasteners used with venting panels so they will release at the designed pressure. Fasteners normally used with ordinary wall panels are too strong for explosion-venting purposes. Only fasteners that are Approved for this specific purpose should be used.

When sizing Approved fasteners the following reaction formulas (See Fig. 9) should be utilized:

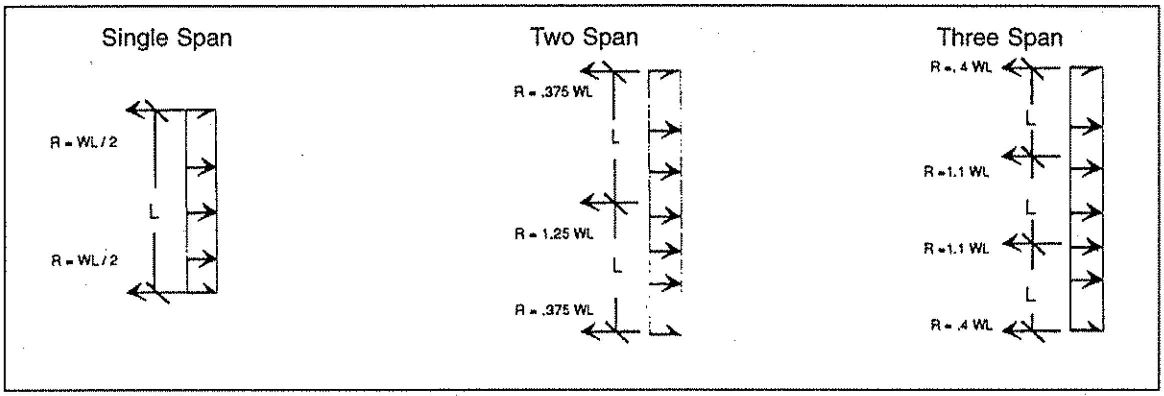


Fig. 9. Reaction formulas.

Where: W = uniform design load – lb/ft (N/m)
L = span between supports – ft (m)

One Approved fastener consists of aluminum bolts with a necked-down cross section. These are strength rated depending upon their net cross section and used as necessary to meet the design release value. Other Approved arrangements involve oversized holes in the venting panels combined with thin gauge collapsing aluminum washers. Each type of fastener comes in a variety of sizes to allow for flexibility in the design. Differentiation between sizes is provided by stamping or color coding as noted in the *Factory Mutual Research Approval Guide.*

One Approved explosion release system utilizes lightweight panels with a corrosion-resistant hinge at one end and a heavy magnet and strike plate at the other. Each magnetic release is shop or field calibrated by static means to within ±10% tolerance of the design release force. Each vent panel bears a nameplate noting the static design pressure as well as the associated latch release forces.

Venting will not be effective if the resulting open area is obstructed. Large equipment or facilities such as process vessels or control panels within the enclosure should be located well away from the opening so they will offer minimum obstruction to it.

For safety purposes it is fairly common practice to tether explosion-venting wall panels. Successful tests have been conducted by Factory Mutual Research using venting panels that were tethered near their top edges. Two ¼ in. (6.4 mm) diameter steel cables were used for each 3 ft (0.9 m) wide by 15 ft (4.6 m) high panel section. Cables were secured to structural steel with ½ in. (13 mm) diameter eye bolts and to the vent panels with ½ in. (13 mm) diameter eye bolts and 2.5 in. (64 mm) OD×⅛ in. (3 mm) thick washers. Two cable clamps were used at each connection. Panels were tethered at the top to simulate a more severe case. Sufficient "slack cable" (about 2 ft or 0.6 m) was provided to allow the panels to move away from the girts before complete pivoting, and to allow complete horizontal extension of the panels. Longer lengths of "slack cable" may be needed in some cases depending on the location of their points of connection to the frame and the wall panels. Other designs could be used. An alternative method is contained in NFPA 68, *Venting of Deflagrations.*

3.2.6 Pressure-Resistant Construction

Despite the provision of explosion venting wall panels, the maximum overpressure in a deflagration can be considerably higher than the static release pressure of the venting panels. In a typical deflagration in a small enclosure, vent panels may start to release within a fraction of a second after ignition; however, it may take several times that time period for the peak pressures to occur. The pressure rise generally stalls or drops significantly after vent panels start to open; however, the pressure may then continue to rise until the flame has fully propagated through the unburned medium and the vent panel has moved sufficiently to provide effective venting. The pressure front that initiates panel release moves at the speed of sound while the flame front in a deflagration moves through the unburned medium at a speed considerably lower than the speed of sound in that medium. Consequently, more energy can be released after the vent panels start to open. Also, due to the dynamic loading conditions, the pressure at which the panel releases (dynamic release pressure) may be considerably higher than the static design pressure (in some cases 2.0 to 2.5 times as high).

Pressure-resistant walls are intended to absorb and resist the initial explosion force until it is vented by the pressure-relieving walls. The pressure-resistant walls and their supports should be capable of resisting explosion forces according to Table 2, 3, 4 or 5 (as applicable), which takes into consideration the geometry of the enclosure, and the vent area and release pressure.

Walls that have a degree of elasticity are most desirable. Types of wall construction in this category include reinforced-concrete, metal lath and plaster on steel studs and insulated-metal panels with gypsum-board core on steel framing. Steel plate or corrugated sheet walls should be used only where there is no potential for a significant fire ensuing.

Masonry walls such as minimum 12 in. (305 mm) brick or concrete block reinforced with vertical steel reinforcing bars are alternatives. The use of unreinforced masonry or any structural clay tile walls is not recommended. These walls have little lateral resistance and when subjected to explosive forces may collapse and/or fragment and create many small projectiles likely to cause damage in the adjoining protected area.

3.2.7 Openings in Pressure-Resistant Walls

Openings in the wall of any type should be avoided, but when necessary should be protected by mechanical means capable of resisting the same force as the wall. The allowable steel stresses noted in Section 3.2.11 and comparable values for wood (wood insulated, metal clad fire doors) may be used in the design of these doors.

All windows should be installed in a steel frame with a gasket that will cushion the glass from the frame and prevent the passage of hot gases. The thickness should be such that the window will resist the same explosion pressure as the wall.

The fire rating of the glazing should be at least three-quarters that of the wall. For example, ¼ in. (6 mm) thick wired glass is acceptable from a fire standpoint in a wall with up to a one-hour fire resistance rating. Small panes (about 100 in^2, 645 cm^2) of ¼ in. (6 mm) wired glass, such as found in fire doors, may resist pressures on the order of 100 psf (4.8 kPa). Larger panes, however, must be backed up by pressure-resistant glazing such as acrylic or glass laminates or polycarbonates.

Any ductwork passing through the wall should be of minimum 18 gauge (0.045 in., 1.1 mm) steel and provided with a collar at the wall. The collar should be constructed of angle steel fastened to the wall and to the sides of the duct at the point of penetration. This will prevent buckling of the duct at that point which might allow the passage of pressure, flame and projectiles.

Doors in pressure-resistant walls must be normally closed in order to prevent the propagation of pressure, flame, projectiles and hot gases through the opening. Otherwise, the pressure-resistant wall may be largely defeated and adjoining areas could be damaged by pressure and projectiles. Open doors could also allow a fire to spread to the opposite side of the wall. Vehicle doors and ordinary personnel doors should be mounted on the hazard side of the wall or door frame. The wall should be reinforced around the opening. Vehicle doors should be securely anchored to the wall to resist rebound effects and should close automatically via photo-eye or trip wire as soon as the opening is cleared. Personnel doors should be made self-closing by the provision of a door closer at the top of the door or spring hinges. Fusible devices to allow door closure are not effective in this situation. Some permanent deformation is tolerable as long as the door remains intact and blocks the opening.

Double personnel doors should be equipped with latches at the head and sill of the inactive leaf where the doors meet. A three-point latch should secure the active leaf to the inactive leaf (see Fig. 7). Personnel doors should be equipped with a door closer and should have no device to hold them open.

When egress doors are required by local code on a pressure-resistant wall, it is a major concern that the door might be blown open during an explosion and allow pressure and flame propagation and projectiles through the opening. Providing proper latching as previously recommended will help to reduce the probability of this happening. The vulnerability of the panic bar is also a key factor. The area of most conventional panic bars is large enough, and code required release forces are low enough (15 lb, 73N) so that a pressure considerably lower than that of the pressure-resistant wall may cause the panic bar to operate. The probability of such an occurrence can be considerably reduced (without requiring excessive force for personnel egress) if the area of the bar is reduced. This reduces the total force applied to the bar by the deflagration overpressure (force per unit area). Panic bars that have large areas and are enclosed in a frame fastened directly to the door (pushbar design) are most likely to open in a deflagration. These should be utilized on egress doors on *pressure-relieving* walls, but not on pressure-resistant walls.

A typical crossbar type design consists of a 1 in. (25 mm) diameter hollow metal bar and is recommended in lieu of the pushbar type when exit hardware is required on doors in pressure-resistant walls. Codes generally require that this crossbar extend across at least half the width of the door but not necessarily the entire width. Installing a bar that extends as close as practical to one-half the door width reduces the area the overpressure can act on, thus helping to prevent release of the crossbar and opening of the door. It is estimated that 1 in. (25 mm) diameter crossbars of 36 in. (914 mm), 30 in. (762 mm) and 24 in. (610 m) lengths may be effective (prevent release) for pressure-resistant designs of up to 100 psf (4.8 kPa), 120 psf (5.7 kPa) and 150 psf (7.2 kPa), respectively. Reducing the diameter of the crossbars to below 1 in. (25 mm) would also reduce the bar area susceptible to pressure. However, such designs are not readily available and may permanently deform under actual or test loads, thus negating their acceptability as panic hardware. An alternative would be to provide a pressure-resistant vestibule or partition wall to help maintain the integrity of the pressure-resistant wall.

3.2.8 Guidelines for Using Tables 1 through 5.

1. Use Table 1 to determine which one of Tables 2 through 5 applies for the fuel(s) involved. If there is more than one fuel in sufficient quantities to cause a room explosion, the design should be based on the worst case (the fuel listed with the highest table number).

2. Select the table that is appropriate for that fuel (in the case of Table 5, also refer to Recommendation No. 2.1.5 and Fig. 10).

3. Calculate the internal surface area (A_s) of the enclosure in which an explosive mixture can occur (see below). Do not subtract the vent area (A_v) from A_s.

4. Calculate the A_v provided. **Note:** the A_v available preferably should be the maximum amount that is practical to provide. If venting only one end of an elongated enclosure, refer to Section 3.2.9.

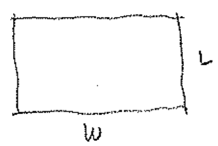
5. Divide A_s by A_v. If the value of A_s/A_v is higher than the table limits, a larger vent area is needed.

6. Determine the static vent release pressure (P_v).

7. Find the respective value of P_v on the left side and A_s/A_v across the top. At the intersection of those columns select the recommended design value for pressure-resistant construction (P_r).

P_v = static vent opening pressure (psf or kPa)
A_v = vent area (ft^2 or m^2)
A_s = interior surface area of the enclosure in the explosive range (ft^2 or m^2)

A_s = 2 (LxW)+2(LxH)+2(WxH) (for a rectangular enclosure)



Where:

L = length (ft or m)
W = width (ft or m)
H = height (ft or m)

When surfaces are sloped or curved, use the actual surface area and not the projected area when determining A_s.

P_r = resistant design pressure (psf or kPa)

The value of P_r must be at least equal to the vent release pressure (P_v) plus 50 psf (0.35 psi, 2.4 kPa). For relatively low values of A_s/A_v this condition governs.

Limits of Tables:

- Panel weight as outlined in Section 3.2.5
- Static vent opening pressure (P_v) 20 psf (0.96 kPa) up to ≤40 psf (1.92 kPa)

Tables 2, 3, 4 and 5 are intended to apply only to "low strength" enclosures that are defined as P_r not exceeding 1.5 psi or 216 psf (10.3 kPa). These tables reflect the relative severity of the various fuels in order of increasing hazard. A relatively high value of A_s/A_v may result in a disproportionately high P_r. Extrapolation of any of these tables beyond their limits may result in unconservative values for P_r.

The fundamental burning velocity (S_u) is established under quiescent laboratory conditions. The actual flame speed in a deflagration may be considerably higher due to turbulence, the geometry of equipment within the enclosure and flame instabilities. The effect of flame instabilities is a function of the fuel involved. Testing has indicated a significant effect with fuels like propane. The fundamental burning velocity for propane (1.51 ft/sec, 46 cm/sec) is relatively close to that of methane (1.31 ft/sec, 40 cm/sec). However, a deflagration involving propane could result in significantly higher overpressures than a deflagration involving methane, all else being equal. Consequently, while the fundamental burning velocity is used in part to reflect the relative ranking of fuels and to some degree reflects their severity, it is not the only relevant factor.

3.2.9 Venting Elongated Enclosures

When venting only one end of an elongated enclosure, the following criteria must be met:

$L_3 \leq 12A_E/P$

Where: L_3 = largest enclosure dimension, ft (m)
A_E = cross sectional area of the elongated enclosure, ft^2 (m^2)
P = perimeter of the elongated cross-section, ft (m)

3.2.10 Pressure-Resistant Construction Details

Pressure-resistant walls can be designed as statically loaded vertical slabs using the allowable stresses that follow.

The supports for the walls should be capable of resisting the forces transferred to them so the walls will remain in place. Where the wall is tied into a portion of the structural steel or reinforced concrete frame of a large building designed to resist wind loads of 30 psf (1.44 kPa) or greater, the building framing can be considered strong enough to transfer the loads from a typical pressure- resistant wall (designed for 100 psf [4.8 kPa] or less) to the foundations.

The wall can be designed as a one-way slab spanning vertically or horizontally; or as a two-way slab spanning in both directions as long as the design and arrangement of slab and supports are consistent with the assumptions made and the material of the wall is suitable.

Where hazardous operations are located at penthouse level or along the exterior walls of multistory buildings, pressure-resistant floors are also needed to protect the building areas above and below.

Various building code requirements and specifications have been referenced. For locations outside the United States, comparable local codes and specifications may be used.

For walls of brittle materials, such as brick and concrete block, the bending moment should be computed using simple spans with no allowance for continuity across supports.

3.2.11 Steel Walls and Framing

Steel is one of the best materials for use in pressure-resistant walls. It has a relatively large elastic range and can take large deflections that absorb much energy.

It can be used as panel material in the form of insulated panels, as metal lath for plaster, as concrete or masonry reinforcing, and as structural shapes, forming the framing system that holds the various panels in place. In special cases of small enclosures for explosives processes where an explosion is not likely to be followed by a fire, steel plates can be used as wall panels.

Due to the high ductility of carbon steels, tension members and beams with the compression flange restrained can be designed using allowable stresses close to the yield point. This procedure may allow some permanent distortion of the structural steel as the wall absorbs the explosive force. It also assumes the wall will retain sufficient integrity to prevent passage of fire that may occur after the explosion.

Where steel framing backs up brick or concrete block walls, use standard American Institute of Steel Construction (AISC) allowable stresses or satisfy normal deflection criteria to minimize cracking of the walls that might occur with large deflections of the steel framing.

Where the failure mode will be determined by the Modulus of Elasticity (columns and beams without sufficient lateral restraint at the compression flange), standard design formulas should be used with no increase in allowable design stresses. Except where full lateral support is not provided or as otherwise noted, the normal allowable stresses may be increased by one-third for Allowable Stress Design (ASD) and a safety factor of 1.2 may be used for Load and Resistance Factor Design (LRFD). This is considerably lower than the normally used safety factor and reflects the short duration and long recurrence interval of such an event.

Connections should be designed using normal stress limits in all cases. Also, stress increases should not be applied to the yield stress of steel reinforcing bars used in Ultimate Strength Design of reinforced concrete.

If horizontal girts are used to reduce the span of the wall, both the girts and the columns supporting the girts should be designed to take the loads transferred to them. If the wall spans clear from floor to roof/floor, the beams at roof level immediately supporting it may need additional bracing to prevent lateral buckling and allow successful transfer of loads to remaining building framework.

3.2.12 Reinforced Concrete Walls

Reinforced concrete for pressure-resistant walls takes the form of vertical slabs tied into and deriving their support from a reinforced concrete or steel structural frame, or precast slabs buttressed by a steel or reinforced-concrete structural frame.

If the area of steel in a reinforced concrete slab or beam is held within appropriate limits, the member will fail by yielding in the steel rather than crushing of the concrete. Such members can be considered ductile and the safety factor lowered as in the case of steel. A safety factor of 1.2 applied to the overpressure liveload may be used in Ultimate Strength Design. Otherwise, the design should comply with American Concrete Institute (ACI) Standards. In addition, appropriate dead and live loads should be used for floor slabs.

To prevent shrinkage cracks, diagonal reinforcing should be provided at corners of any openings.

Reinforcing should be provided near both wall faces to resist tensile forces from the reversal of bending due to oscillation in the system induced by the dynamic character of the load (rebound effect).

3.2.13 Metal Lath and Plaster Walls

Experience has shown metal lath and plaster walls perform favorably when subjected to explosive forces. They usually deform substantially and the wall(s) must be replaced, but the explosion is contained with little damage to adjoining protected areas.

Pressure-resistant walls, as recommended in this data sheet, can be either solid or hollow. The solid wall would consist of a 2 to 3 in. (50 to 75 mm) thickness of plaster on metal lath on steel channel studs. The hollow wall would consist of ¾ to 1 in. (19 to 25 mm) of plaster on metal lath on both sides of steel studs. The metal lath should be well secured to the steel studs with screws and washers or wire ties every 6 in. (150 mm) on center. The metal lath should be a minimum of 3.4 lb/yd^2 (1.85 kg/m^2) diamond mesh. When the story height is excessive (generally over 20 to 25 ft [6.1 to 7.6 m]) or the studs are shallow, this would involve backing by steel or concrete framing of adequate strength to resist the design force. If the story height is not excessive and deep studs (8 to 12 in. [200 to 300 mm]) are used, the studs should be designed as simple beams spanning vertically from floor to roof/floor above and should be firmly anchored at floor level and to the horizontal framing, which will resist the force transferred to it by the studs. When metal lath and plaster is provided on one side only (solid wall), the stud flanges on the opposite side should be laterally braced to prevent buckling during elastic rebound.

Provided the wall is well constructed according to modern practice, it can be assumed the metal lath and plaster wall itself can safely transfer a loading of up to 150 psf (7.2 kPa) to supports on 16 in. (41 cm) centers. The framing supporting the wall must be sized to resist the design overpressure.

3.2.14 Reinforced Brick Walls

Although the previous constructions are preferred, brick masonry walls are acceptable if strengthened with deformed steel reinforcing bars spanning vertically and grouted within cores or between wythes (vertical planes) of brick.

Materials should conform to ASTM C55 or C62 and Type S mortar (per ASTM C 270) should be used. Type M mortar may also be accepted but may be more difficult to work with. Type N mortar is not recommended. The Working Stress Design is preferable to Ultimate Strength Design.

* *3.2.15 Reinforced-Concrete Masonry Walls* SHOULD NOT BE LOAD-BEARING WALL

Concrete block walls can be used as vertical slabs spanning vertically between foundations and roof or intermediate framing. Nominal 12 in. (305 mm) thick block should be used.

Material and construction should be according to ASTM Standards. Grade N-I or N-II concrete block as specified by ASTM C90 is preferred. Mortar should be as described under Reinforced-Brick Walls. The design should be according to ASCE/ACI Standard 530. Running bond (vertical joints staggered) construction should be used. Vertical steel reinforcing bar should be provided. While the actual size and spacing of steel reinforcing bar will vary depending on the wall span and design loading, the maximum center-to-center spacing should be 16 in. (406 mm) so that there is at least one bar in every block. All cores containing rebar should be filled with grout (per ASTM C476); however, for maximum resistance to projectiles, the grouting of all cores is preferred. Masonry walls not containing vertical reinforcing bars are not recommended for pressure-resistant construction.

The walls should have horizontal joint reinforcing, at least in every other bed joint. This reinforcement will control shrinkage cracks, resist temperature stresses and otherwise provide a sound wall. It should be considered a supplement to, and not a replacement for, vertical steel reinforcing bars.

4.0 REFERENCES

Various building code requirements and specifications have been referenced. For locations outside the United States, comparable local codes and specifications may be used.

4.1 FM Global

Data Sheet 1-7, *Wind Forces on Buildings and Other Structures.*

Data Sheet 1-21, *Fire Resistance of Building Assemblies.*

Data Sheet 1-54, *Roof Loads for New Construction.*

Data Sheet 5-1, *Electrical Equipment in Hazardous Locations.*

Data Sheet 7-14, *Fire and Explosion Protection for Flammable Liquid, Flammable Gas, & Liquefied Flammable Gas Processing Equipment and Supporting Structures.*

Data Sheet 7-16, *Barricades.*

Data Sheet 7-32, *Flammable Liquid Operations.*

Data Sheet 7-43/17-2, *Loss Prevention in Chemical Plants.*

Data Sheet 7-44/17-3, *Spacing of Facilities in Outdoor Chemical Plants.*

Data Sheet 7-45, *Instrumentation and Control in Safety Applications.*

Data Sheet 7-50, *Compressed Gases in Cylinders.*

Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fires.*

Factory Mutual Research Approval Guide.

4.2 NFPA Standards

National Fire Protection Association, NFPA 68, *Venting of Deflagrations,* 1998.

Note: NFPA 68 - 1994, *Guide for Venting of Deflagrations*, addresses this subject in Chapter 4. Differences between NFPA 68 and this standard are as follows:

1. For fuels other than ammonia design criteria based on NFPA 68 are generally more conservative than those based on this standard.

2. NFPA 68 recommends that the vent panel weight not exceed 2.5 lb/ft^2 (12.2 kg/m^2) for gases of comparable hazard to methane and ammonia, the vent panel weight may be increased up to a maximum of 8 lb/ft^2 (39.0 kg/m^2).

3. NFPA 68 does not list constants for fuels having a value of S_u greater than 1.97 ft/sec (60 cm/sec) which would allow determination of P_r. In this data sheet the fuel constant listed for propane in NFPA 68 is used for fuels having a value of S_u greater than 1.97 ft/sec. (60 cm/sec) and the results are represented in Table 5.

4.3 Others

American Concrete Institute, Standard 318, *Building Code Requirements for Reinforced Concrete,* 1995.

American Institute of Steel Construction, *Steel Design Manuals - Allowable Stress Design (ASD),* 9th Edition (1989); *Load & Resistance Factor Design (LRFD), 2nd Edition* (1994).

American Iron and Steel Institute, *Specifications for the Design of Cold Formed Steel Structural Members,* 1996.

American National Standards Institute (ANSI):

ANSI B16.3, *Malleable Iron Screwed Fittings.*

ANSI B16.5, *Steel Pipe Flanges and Flanged Fitttingsm.*

ANSI B16.9, *Wrought Steel Buttwelding Fittings.*

ANSI B16.25, *Buttwelding Ends.*

ANSI B31.1.0, *Power Piping.*

American Society of Civil Engineers/American Concrete Institute, Standard 530 and 530.1, *Building Code Requirements for Masonry Structures, Specifications for Masonry Structures and Related Commentaries,* 1995.

American Society for Testing and Materials:

Standard Specification for Grout for Masonry, Designation: C476, 1995.

Standard Specification for Mortar for Unit Masonry, Designation: C270, 1997.

Standard Specification for Load-Bearing Concrete Masonry Units, Designation: C90, 1997.

Standard Specification for Aggregates for Masonry Grout, Designation: C404, 1995.

Standard Specification for Concrete Building Brick, Designation: C55, 1997.

Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale), Designation: C62, 1997.

National Concrete Masonry Association, *A Manual of Facts on Concrete Masonry,* (Bulletins are individually updated).

APPENDIX A GLOSSARY OF TERMS

Approved: references to "Approved" in this data sheet means the product and services have satisfied the criteria for Factory Mutual Research Approval. Refer to the *Approval Guide* for a complete listing of products and services that are Factory Mutual Research Approved.

Deflagration: a rapid combustion reaction in which the flame front moves through the unreacted medium (flammable gas and air or combustible dust and air) at a velocity less than the speed of sound in that medium.

Detonation: an extremely rapid combustion reaction in which the flame front moves through the unreacted medium (see deflagration) at a velocity greater than the speed of sound in that medium.

Pressure Relieving Construction: lightweight, exterior wall panels secured with special Approved fasteners and designed to barely resist design wind loads and easily release during a deflagration.

Pressure Resistant Construction: internal wall and, if applicable, floor construction, which can resist over-pressures caused by a deflagration (considering the type of fuel, surface area of the enclosure and vent area provided) so as to protect the adjacent occupancy and structures.

APPENDIX B DOCUMENT REVISION HISTORY

September 2000. This revision of the document has been reorganized to provide a consistent format. Editorial changes were made in the May, 1998 revision.

May, 1998. Editorial changes.

July, 1991. This document was completely revised.

APPENDIX C JOB AIDS

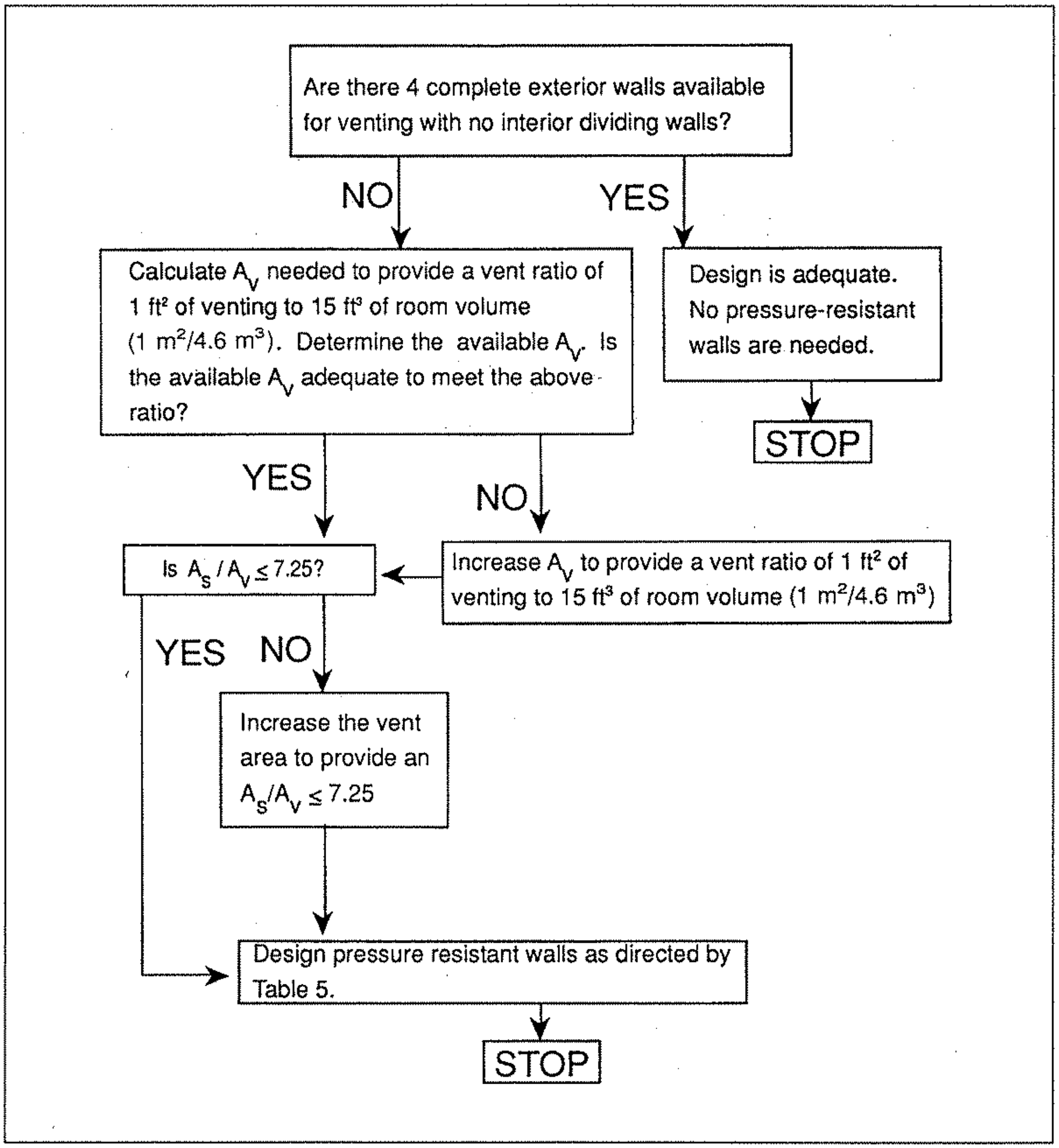


Fig. 10. Guidelines for complying with Recommendation No. 2.1.5, Section 2.1.