Process Industry Practices
Structural

PIP STC01018
Blast Resistant Building Design Criteria
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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Blast Resistant Building Design Criteria

Table of Contents

1. Introduction ......................................... 2
   1.1 Purpose ........................................ 2
   1.2 Scope .......................................... 2

2. References .......................................... 2
   2.1 Process Industry Practices ............... 2
   2.2 Industry Codes and Standards ......... 2
   2.3 Other References .............................. 3

3. Definitions .......................................... 4

4. Requirements ....................................... 5
   4.1 General Responsibilities ................. 5
      4.1.1 Documentation Furnished by Owner ....... 5
      4.1.2 Engineer-of-Record's Responsibilities ... 5
   4.2 Design Parameters ............................ 6
      4.2.1 Building Performance ................. 6
      4.2.2 Building Configuration ............. 6
      4.2.3 Blast Loads ............................. 7
      4.2.4 Construction and Materials ......... 8
      4.2.5 Material Properties ............... 8
   4.3 Structural Design ................................ 11
      4.3.1 General .................................. 11
      4.3.2 Load Combinations ................... 11
      4.3.3 Analysis Methods .................... 11
      4.3.4 Deformation Limits .................. 13
      4.3.5 Component Design ................... 16
      4.3.6 Structural-Framing Design ......... 19
      4.3.7 Foundation Design .................. 19

4.4 Ancillary Items .................................. 21
   4.4.1 Blast Doors .................................. 21
   4.4.2 Windows .................................... 22
   4.4.3 Openings ................................... 22
   4.4.4 Penetrations ............................... 22
   4.4.5 Suspended Items ............................. 22
   4.4.6 Externally Mounted Items ............. 23
   4.4.7 Equipment and Internally Mounted Items .... 23

Appendix A: Commentary

Data Forms
STC01018-D - Blast Resistant Building Design Requirements (U.S. Customary Units)

STC01018-DM - Blast Resistant Building Design Requirements (SI Units)
1. Introduction

1.1 Purpose
This Practice provides structural design criteria for blast resistant buildings.

1.2 Scope
This Practice describes the minimum requirements for the design of permanent (non-temporary) blast resistant buildings including requirements for selection of structural systems, analysis methods, and design of ancillary items such as doors and openings. This Practice also contains design criteria for non-structural items (e.g., suspended architectural or electrical items, HVAC ductwork, etc.) that could pose a hazard to the occupants of blast resistant buildings.

2. References
Applicable parts of the following Practices, industry codes and standards, and references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 Process Industry Practices (PIP)
- PIP CVS02010 - Geotechnical Engineering Investigation Specification
- PIP STC01015 - Structural Design Criteria

2.2 Industry Codes and Standards
- American Concrete Institute (ACI)
  - ACI 318-11 - Building Code Requirements for Structural Concrete and Commentary
  - ACI 318M-05 - Building Code Requirements for Structural Concrete and Commentary (Metric)
  - ACI 318M-11 - Building Code Requirements for Structural Concrete and Commentary (Metric)
  - ACI 530/530.1 - Building Code Requirements and Specification for Masonry Structures
- American Institute of Steel Construction (AISC)
  - AISC 360 - Specification for Structural Steel Buildings
- American Iron and Steel Institute (AISI)
  - AISI S100 / AISI S100-C - North American Specification for the Design of Cold-Formed Steel Structural Members and Commentary
- ASTM International (ASTM)
  - ASTM A36/A36M - Standard Specification for Carbon Structural Steel
  - ASTM A276 - Standard Specification for Stainless Steel Bars and Shapes
  - ASTM A514/A514M - Standard Specification for High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Welding
– ASTM A572/A572M - Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel


– ASTM A615/A615M - Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

– ASTM A653/A653M - Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process

– ASTM A706/A706M - Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

– ASTM A992/A992M - Standard Specification for Structural Steel Shapes

– ASTM A1064/A1064M - Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete


– ASTM C90 - Standard Specification for Loadbearing Concrete Masonry Units


• Steel Joist Institute (SJI)
  – Standard Specifications and Load and Weight Tables for Steel Joists and Joist Girders (SJI)

• International Code Council (ICC)
  – International Building Code (IBC)

2.3 Other References

• American Society of Civil Engineers (ASCE)
  – Design of Blast-Resistant Buildings in Petrochemical Facilities, ASCE Task Committee on Blast-Resistant Design [Hereafter referred to as ASCE Design of Blast-Resistant Buildings]

• U.S. Department of Defense
  – UFC 3-340-02 - Structures to Resist the Effects of Accidental Explosions, Unified Facilities Criteria 3-340-02 (formerly Technical Manual TM 5-1300)

3. Definitions

angle of incidence: The angle between the direction of the blast wave travel and a line perpendicular to the surface of a structure at the point of interest

blast loads: The transient dynamic loads from the blast effects of an explosion, usually stated in terms of peak pressure and impulse or duration
conventional loads: Loads applied in the conventional (non-blast) design of structures including dead, live, wind, and seismic loads as required by local building codes. These loads are typically statically applied.

Dynamic Increase Factor (DIF): A multiplier applied to the static strength of a material to reflect the increased effective strength due to fast strain rates caused by rapidly applied blast loads

ductility ratio: A measure of the degree of plasticity in a member at maximum dynamic response, equal to the maximum displacement divided by the displacement at yield. This value is a key measure of dynamic response.

duration: The length of time from start of the initial positive phase of the blast pressure to the return to ambient pressure

dynamic reaction: The support reaction of a structural component to the dynamic blast loading, taking into account inertia effects

engineer-of-record: Purchaser’s authorized representative with overall authority and responsibility for the engineering design, quality, and performance of the civil works, structure, foundations, materials, and appurtenances described in the contract documents. The engineer of record shall be licensed as defined by the laws of the locality in which the work is to be constructed, and be qualified to practice in the specialty discipline required for the work described in the contract documents.

fragment resistant: The resistance to high-speed fragments that result from the breakup of equipment or structures that are close to the explosion source

impulse: A measure used, along with the peak blast pressure, to define the ability of a blast wave to do damage. Impulse is calculated as the integrated area under the positive pressure versus duration curve and is shown in units of psi-ms (MPa-ms).

Multi-Degree of Freedom (MDOF): Representation of a structure or component as a spring-mass system with more than one degree of freedom

negative phase: The portion of the pressure-time history typically following the positive (overpressure) phase in which the pressure is below ambient pressure (suction)

owner: Party who has authority through ownership, lease, or other legal agreement over the site wherein the blast resistant building will be used.

period: The fundamental natural period of a structural component if modeled as a single-degree-of-freedom (SDOF) system

positive phase: The portion of the pressure-time history in which the pressure is above ambient pressure

rebound: The deformation in the direction opposing the initial blast pressure. This occurs after a component has reached a peak deformation and returns in the direction of its initial position.

reflected pressure: The rise in pressure above ambient produced by a shock wave or pressure wave striking a surface facing the direction of blast wave propagation
response range: The degree of structural damage permitted for blast resistant buildings

Single Degree of Freedom (SDOF): Representation of a structure or component as a spring-mass system with one degree of freedom. Displacement of the SDOF system corresponds to the displacement of a single point in the real system, typically corresponding to the point of maximum deflection.

side-on pressure: The rise in pressure above ambient produced by a blast wave sweeping unimpeded across any surface (walls or roof) not facing the blast source

Strength Increase Factor (SIF): A multiplier applied to the nominal strength properties of a material to reflect its actual strength above minimum specified values

support rotation: The angle formed between the axis of a member loaded between its endpoints and a straight line between one endpoint and the point of maximum deflection. This value is a key measure of dynamic response.

ultimate capacity: The load applied to a structural element as the final plastic hinge, or collapse mechanism is formed

4. Requirements

4.1 General Responsibilities

4.1.1 Documentation Furnished by Owner

4.1.1.1 Data for each facility (building or project) shall be specified by the owner in the PIP STC01018-D or PIP STC01018-DM data sheet included with this Practice and provided to the engineer-of-record as a part of the job or project specifications.

4.1.1.2 The following blast design requirements information shall be included in the data sheet:

a. Building performance requirements and acceptable response range (low, medium, or high) (see Section 4.3.4.3, this Practice)

b. Performance categories (I - IV) for blast resistant doors (see Table 10, this Practice)

c. Blast loads specified as peak side-on positive pressure with corresponding impulse or duration at the building (see Section 4.2.3, this Practice)

4.1.2 Engineer-of-Record’s Responsibilities

4.1.2.1 ASCE Design of Blast-Resistant Buildings, Section 1.4 and Figure 1.1, delineate information to be provided by the owner and tasks to be performed by the engineer-of-record. Items with overlapping responsibility in the flowchart (see Appendix A, Figure A-2, this Practice) shall be the ultimate responsibility of the engineer-of-record.

4.1.2.2 The engineer-of-record shall be responsible for producing a design using sound engineering principles that meet the requirements of this Practice.
4.1.2.3 The engineer-of-record shall be responsible for designing the building to meet the performance requirements specified in the PIP STC01018-D or PIP STC01018-DM data sheet.

4.1.2.4 The engineer-of-record shall bring any items requiring clarification to the owner’s attention.

4.1.2.5 The final design shall be provided by the engineer-of-record and shall include the following documentation:
   a. PIP STC01018-D or PIP STC01018-DM data sheet
   b. Supporting calculations covering the design criteria, methodology, results, and the references and tools used
   c. Detailed structural drawings and specifications for construction, as appropriate

4.2 Design Parameters

4.2.1 Building Performance

The building response range shall be in accordance with the PIP STC01018-D or PIP STC01018-DM data sheet.

4.2.2 Building Configuration

4.2.2.1 Single-story construction shall be used if possible.

4.2.2.2 If multi-story construction is required, the number of stories shall be minimized and special design considerations shall be given to the inter-story response to the blast loading.

4.2.2.3 The floor plan and elevation preferably shall have clean rectangular profiles without re-entrant corners. Recessed areas shall be minimized.

4.2.3 Blast Loads

4.2.3.1 General

1. Each blast resistant building shall be designed for the dynamic blast loads in accordance with the PIP STC01018-D or PIP STC01018-DM data sheet.

2. Blast loads on individual building surfaces shall be calculated from the specified side-on pressure in accordance with ASCE Design of Blast-Resistant Buildings, Chapter 3.

3. Blast pressure amplification because of recessed areas or re-entrant corners shall be evaluated and considered during the design.

4.2.3.2 Component Loads

1. Each structural component that is part of the building's load-resisting framing, shall be designed for any one of the following:
   a. The direct tributary blast load applicable to the surface of the building on which it is located,
b. The dynamic reaction from a supported component, as appropriate, or
c. The ultimate load capacity of the supported component.

2. Doors and Windows

Doors and windows which are part of the building's exterior surface shall be designed for the blast loading applicable to that surface.

3. Externally Mounted Items

Failure of externally mounted items may or may not be deemed to be threatening to the building or occupants. Thus the design of externally mounted items shall be designed for applicable blast loads, unless approved otherwise by the owner.

4.2.3.3 Foundation Load

The foundation for a blast resistant building shall be designed in accordance with this Practice using any one of the following:

1. The peak dynamic reactions from the supported superstructure treated statically,
2. The ultimate static capacity of the supported superstructure, or
3. The tributary area method. This method may be used in conjunction with the applied blast loads to determine foundation response using a dynamic analysis method.

4.2.4 Construction and Materials

4.2.4.1 General

The structural system and materials shall be selected to provide the most economical design in accordance with all performance requirements and in accordance with the contract documents.

4.2.4.2 Brittle Materials

Brittle materials (e.g., unreinforced concrete, unreinforced masonry (block, brick, clay tile), poured gypsum, and cement-asbestos panels) shall not be permitted for load-carrying components of blast resistant buildings.

4.2.4.3 Prestressed Concrete

1. Prestressed concrete shall be used only with prior written approval from the owner.
2. If prestressed concrete is used, non-prestressed reinforcement shall be added to carry tensile forces that may develop because of rebound or negative phase loading. The amount of rebound resistance shall be greater than one-half the resistance available to resist the blast load.
3. See UFC 3-340-02 for additional design requirements for prestressed concrete elements and their connections.

4.2.4.4 Advanced Materials

1. Advanced materials, such as composites, may be used if adequate test data are available to confirm their satisfactory performance for the intended application and if the owner provides prior written approval.

2. Test data shall include the ultimate capacity and behavior of the material under dynamic conditions representative of blast loading.

3. Satisfactory performance of the material under seismic conditions shall not be sufficient to indicate blast capacity.

4.2.4.5 Fragment Resistance

If fragment resistance is required in accordance with the

*PIP STC01018-D* or *PIP STC01018-DM* data sheet, reinforced concrete or fully grouted reinforced masonry of appropriate strength and thickness shall be used as cladding.

4.2.5 Material Properties

4.2.5.1 Dynamic Material Strength

Dynamic capacity of any structural element shall be determined in accordance with plastic or load resistance factor design for structural steel, and the ultimate strength design method for reinforced concrete or reinforced concrete masonry, as provided by *AISC 360*, *ACI 318 / ACI 318M*, and *ACI 530/530.1* respectively, with the following additions.

1. Dynamic yield stress, \( F_{dy} \), shall be calculated as follows:

\[
F_{dy} = F_y \times SIF \times DIF
\]

where:

\( F_{dy} \) = Steel dynamic yield strength, concrete dynamic compressive strength, or masonry dynamic compressive strength

\( F_y \) = specified steel yield stress, concrete compressive yield stress, or masonry compressive yield stress

\( DIF \) = dynamic increase factor

\( SIF \) = strength increase factor

2. Dynamic design stress, \( F_{ds} \), used to calculate the dynamic capacity of structural components shall be in accordance with Tables 1 and 2, this Practice, for structural steel and reinforcing steel, respectively.
Table 1. Dynamic Design Stress for Structural Steel

<table>
<thead>
<tr>
<th>Type of Stress</th>
<th>Maximum Ductility Ratio</th>
<th>Dynamic Design Stress (F_{dy})</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>µ ≤ 10</td>
<td>F_{dy}</td>
</tr>
<tr>
<td>All</td>
<td>µ &gt; 10</td>
<td>F_{dy} + (F_{du} - F_{dy}) /4</td>
</tr>
</tbody>
</table>

Where: µ = ductility ratio; F_{du} = dynamic ultimate strength

Table 2. Dynamic Design Stress for Concrete-Reinforcing Steel

<table>
<thead>
<tr>
<th>Type of Stress</th>
<th>Type of Reinforcement</th>
<th>Maximum Support Rotation</th>
<th>Dynamic Design Stress (F_{dy})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending</td>
<td>Tension and Compression</td>
<td>0 ≤ θ &lt; 2</td>
<td>F_{dy}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 ≤ θ &lt; 5</td>
<td>F_{dy} + (F_{du} - F_{dy}) /4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 ≤ θ ≤ 12</td>
<td>(F_{dy} + F_{du}) /2</td>
</tr>
<tr>
<td>Direct Shear</td>
<td>Diagonal Bars</td>
<td>All</td>
<td>F_{dy}</td>
</tr>
<tr>
<td>Diagonal Tension</td>
<td>Stirrups</td>
<td>All</td>
<td>F_{dy}</td>
</tr>
<tr>
<td>Compression</td>
<td>Column</td>
<td>All</td>
<td>F_{dy}</td>
</tr>
</tbody>
</table>

Where: θ = support rotation (deg.)

3. Dynamic ultimate strength, F_{du}, shall be calculated as follows:

\[ F_{du} = F_u * DIF \]

where:

F_u = specified ultimate strength
DIF = dynamic increase factor

4.2.5.2 Strength Increase Factor (SIF)

1. An SIF shall be applied to the specified minimum yield strength of structural materials to estimate the actual static value.

2. The SIF shall be in accordance with Table 3, this Practice.

Table 3. Strength Increase Factors for Structural Materials

<table>
<thead>
<tr>
<th>Structural Material</th>
<th>SIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Steel - Yield Strength of 345 MPa (50 ksi) or Less</td>
<td>1.1</td>
</tr>
<tr>
<td>Concrete-Reinforcing Steel of Grade 60 (420 MPa)</td>
<td>1.1</td>
</tr>
<tr>
<td>Prestressed Reinforcement</td>
<td>1.0</td>
</tr>
<tr>
<td>Cold-Formed Steel Cladding Panels:</td>
<td></td>
</tr>
<tr>
<td>- Yield Strength of 228 MPa (33 ksi) or Less</td>
<td>1.2</td>
</tr>
<tr>
<td>- Yield Strength of 345 MPa (50 ksi) or More</td>
<td>1.1</td>
</tr>
<tr>
<td>Concrete and Masonry</td>
<td>1.0</td>
</tr>
<tr>
<td>Other Materials</td>
<td>1.0</td>
</tr>
</tbody>
</table>
4.2.5.3 Dynamic Increase Factor (DIF)

1. To account for strain rate effects caused by rapidly applied blast loads, dynamic increase factors shall be applied to the static material yield and ultimate strengths to determine their dynamic values.

2. The DIF shall be in accordance with Table 4 or 5, this Practice.

**Table 4. Dynamic Increase Factors for Reinforced Concrete/Masonry**

<table>
<thead>
<tr>
<th>Stress Type</th>
<th>D I F</th>
<th>Reinforcing Bars</th>
<th>Concrete</th>
<th>Masonry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(F_{dy}/F_y)</td>
<td>(F_{du}/F_u)</td>
<td>(f'_{dc}/f_c)</td>
</tr>
<tr>
<td>Flexure</td>
<td>1.17</td>
<td>1.05</td>
<td>1.19</td>
<td>1.19</td>
</tr>
<tr>
<td>Compression</td>
<td>1.10</td>
<td>1.00</td>
<td>1.12</td>
<td>1.12</td>
</tr>
<tr>
<td>Diagonal Tension</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Direct Shear</td>
<td>1.10</td>
<td>1.00</td>
<td>1.10</td>
<td>1.00</td>
</tr>
<tr>
<td>Bond</td>
<td>1.17</td>
<td>1.05</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Where:

- \( F_{dy} \) = dynamic yield strength of reinforcing bars
- \( F_y \) = yield strength of reinforcing bars
- \( F_{du} \) = dynamic ultimate strength of reinforcing bars
- \( F_u \) = ultimate strength of reinforcing bars
- \( f'_{dc} \) = dynamic concrete strength
- \( f_c \) = concrete strength
- \( f'_{dm} \) = dynamic masonry strength
- \( f_m \) = masonry strength

**Table 5. Dynamic Increase Factors for Steel and Aluminum**

<table>
<thead>
<tr>
<th>Material</th>
<th>D I F</th>
<th>Yield Stress</th>
<th>Ultimate Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bending/Shear</td>
<td>Tension/Compression</td>
</tr>
<tr>
<td>ASTM A36/A36M</td>
<td>1.29</td>
<td>1.19</td>
<td>1.10</td>
</tr>
<tr>
<td>ASTM A572/A572M</td>
<td>1.19</td>
<td>1.12</td>
<td>1.05</td>
</tr>
<tr>
<td>ASTM A588/A588M</td>
<td>1.10</td>
<td>1.10</td>
<td>1.00</td>
</tr>
<tr>
<td>Prestressed Reinforcement</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Stainless Steel ASTM A276</td>
<td>1.18</td>
<td>1.15</td>
<td>1.00</td>
</tr>
<tr>
<td>Aluminum Alloy ASTM B308/B308M</td>
<td>1.02</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
4.3 Structural Design

4.3.1 General
All blast resistant buildings and their structural components shall be designed in accordance with the methods in *ASCE Design of Blast-Resistant Buildings*. Alternate design methods may be used only with owner’s prior written approval.

4.3.2 Load Combinations

4.3.2.1 The blast resistant structure shall be designed in accordance with the load combinations in *PIP STC01015* and for the following blast load condition:

\[ U(t) = D + aL + B(t) \]

where:

- \( U(t) \) = total applied time dependent load or its effect
- \( D \) = static dead load
- \( B(t) \) = time dependent blast load or its effect (horizontal and vertical)
- \( L \) = conventional static live load
- \( a \) = reduction factor applied to conventional live loads to reflect the portion of live load expected to occur simultaneously with the blast load. Zero shall be used for the reduction factor if doing so will result in a more severe condition.

4.3.2.2 The blast load combination shall consider either the direct loads or their effects.

4.3.2.3 In combining blast load effects with those from static dead and live loads, the time dependence of the blast loading shall be considered.

4.3.2.4 Wind, seismic, rain, and snow loads shall not be combined with blast loading.

4.3.2.5 Rebound effects shall be calculated and combined with the effects of negative phase blast loads, if any, based on time dependent response.

4.3.2.6 Ultimate strength design method shall be used with a load factor of 1.0 for dead, live, and blast loads in the blast load combination.

4.3.3 Analysis Methods

4.3.3.1 General
1. Analysis methods appropriate for the specific blast design shall be used.

*Comment:* The degree of complexity of the structural representation and analyses can vary considerably, depending on the effort required to achieve a safe, economical design. Except for the blast load determination, each of the following methods could
be improved through the use of more complex procedures. These procedures may involve a greater engineering effort, but still produce results limited by the blast load determination. The approach recommended in *ASCE Design of Blast-Resistant Buildings* is to use generally accepted procedures which maintain the blast load as the greatest approximation, produce the desired results, and utilize relatively simple calculations.

2. The selected methods shall adequately model the dynamic response of the structure to the applied blast loads and the structural component interaction.

3. Except as specified in Sections 4.3.3.2 and 4.3.3.3, this Practice, the analysis methods shall be in accordance with *ASCE Design of Blast-Resistant Buildings*, Chapter 6.

### 4.3.3.2 Single Degree of Freedom (SDOF)

1. The required resistance for each structural component shall be based on the peak blast pressure (or load) and duration, the natural period of the component, and the maximum allowable response (deformation).

2. An SDOF analysis can be used if the connected components differ in natural period by a factor of two or more.

3. The formulas and charts provided in *ASCE Design of Blast-Resistant Buildings*, Chapter 6, *UFC 3-340-02*, or other similar references for the approximate solution of the elastic-plastic SDOF system may be used in determining the required resistance.

### 4.3.3.3 Multi-Degree of Freedom (MDOF)

1. MDOF analysis shall be used if the structural component interaction cannot be adequately modeled using the simpler equivalent static load or SDOF methods.

2. The MDOF method can involve finite element analysis requiring the use of a special or general-purpose structural analysis computer program with non-linear transient dynamic analysis capability.

3. *ASCE Design of Blast-Resistant Buildings*, Chapter 6, may be used for the analysis.
4.3.4 Deformation Limits

4.3.4.1 Response Parameters

1. Structural members shall be designed for the maximum response (deformation) in accordance with the performance requirements or permissible damage level specified in Table 6, this Practice.

Table 6. Building Performance Requirements

<table>
<thead>
<tr>
<th>Building Classification</th>
<th>Example and Typical Performance Requirements</th>
<th>Building Response Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical/Essential</td>
<td>Central control center, main electrical station. Continued use; reusable with cosmetic repairs</td>
<td>Low - Localized building/component damage. Building can be reused; however repairs may be required to restore integrity of structural envelope. If elastic limit is specified, then no repairs are necessary. Total cost of repairs is moderate.</td>
</tr>
<tr>
<td>Normally Occupied</td>
<td>Administration and engineering offices, laboratory. Damage-limited for occupant protection; not reusable without major repairs/replacement</td>
<td>Medium - Widespread building/component damage. Building cannot be used until repaired. Total cost of repairs is significant.</td>
</tr>
<tr>
<td>Other</td>
<td>Operator shelters, warehouse. Collapse-limited; not repairable; abandon/replace</td>
<td>High - Building/component has lost structural integrity and may collapse from additional environmental loads (i.e., wind, snow, and rain). Total cost of repairs approaches replacement cost of building.</td>
</tr>
</tbody>
</table>

2. Deformation limits shall be expressed as ductility ratio ($\mu$), support rotation ($\theta$), or frame sidesway, as appropriate.

4.3.4.2 Building Response Range

The design response range (low, medium, or high) shall be based on the building design requirements provided in Table 6, this Practice.
### 4.3.4.3 Response Limits

Maximum response shall not exceed the limits specified in Tables 7, 8, and 9, this Practice, for structural steel, reinforced concrete, and reinforced masonry, respectively.

**Table 7. Deformation Limits for Structural Steel**

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Rolled Secondary Members (Beams, Girts, Purlins)(^3)</td>
<td>3</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Primary Frame Members (with significant compression)(^3,4,5)</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Primary Frame Members (without significant compression)(^3,4,5)</td>
<td>1.5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Plates(^8)</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Open-Web Joists</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Cold-Formed Light Gage Steel Panels (with secured ends)(^6,9)</td>
<td>1.75</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Cold-Formed Light Gage Steel Panels (with unsecured ends)(^7,9)</td>
<td>1.0</td>
<td>1.8</td>
<td>3</td>
</tr>
<tr>
<td>Cold-Formed Light Gage Steel Beams, Girts, Purlins, and Non-Compact Secondary Hot Rolled Members(^9)</td>
<td>2</td>
<td>3</td>
<td>12</td>
</tr>
</tbody>
</table>

**Notes:**

1. Response limits are for components responding primarily in flexure unless otherwise noted. Flexure controls when shear resistance is at least 120% of flexural capacity.
2. Response parameter: \( \mu = \text{ductility ratio}, \ \theta = \text{support rotation (degrees)} \).
3. Primary members are components whose loss would affect a number of other components supported by that member and whose loss could potentially affect the overall structural stability of the building in the area of loss. Secondary members are those supported by primary framing components.
4. Significant compression is when the axial compressive load is more than 20% of the dynamic axial capacity of the member. Axial compression should be based on the ultimate resistance of the supported members exposed to the blast pressure. See *ASCE Design of Blast-Resistant Buildings* for additional details.
5. Sidesway limits for moment-resisting structural steel frames: low = (height)/50, medium = (height)/35, high = (height)/25.
6. Panels must be attached on both ends with screws or spot welds.
7. Panels are not attached on both ends (for example standing seam roof panels).
8. Steel plate criteria can also be applied to corrugated (crimped) plates if local buckling and other response modes are accounted for in the analysis.
9. Light gage refers to material which is less than 0.125 inches (3 mm) thick.
### Table 8. Deformation Limits for Reinforced Concrete

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Response Range</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>μ</td>
<td>θ</td>
<td>μ</td>
<td>θ</td>
</tr>
<tr>
<td>Beams, Slabs, &amp; Wall Panels (no shear reinforcement)</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Beams, Slabs, &amp; Wall Panels (compression face steel reinforcement and shear reinforcement in maximum moment areas)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Walls, Slabs, and Columns (in flexure &amp; axial compression load)³</td>
<td>1</td>
<td>(^2)</td>
<td>(^2)</td>
<td>(^2)</td>
</tr>
<tr>
<td>Walls &amp; Diaphragms</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Components (shear control, without shear reinforcement)</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Components (shear control, with shear reinforcement)</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Prestressed Concrete ((w_p \leq 0.15))⁴</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Prestressed Concrete ((0.15 &lt; w_p &lt; 0.3))⁴</td>
<td>1</td>
<td>(0.25/w_p)</td>
<td>1</td>
<td>(0.29/w_p)</td>
</tr>
</tbody>
</table>

Notes:
1. Response limits are for components responding primarily in flexure unless otherwise noted.
2. Response parameter: \(\mu =\) ductility ratio, \(\theta =\) support rotation (degrees).
3. Applicable when the axial compressive load is more than 20% of the dynamic axial capacity of the member. Axial compression should be based on the ultimate resistance of the supported members exposed to the blast pressure. See ASCE Design of Blast-Resistant Buildings for additional details.
4. The reinforcement index, \(w_p = (A_{ps} / b d_p) \times (f_{ps} / f'_c)\)
   Where,
   - \(A_{ps}\) = area of prestressed reinforcement in tension zone
   - \(b\) = the member width
   - \(d_p\) = the depth to center of prestressing steel
   - \(f_{ps}\) = calculated stress in prestressing steel at design load
   - \(f'_c\) = the concrete compressive strength
5. A support rotation of 4 degrees is allowed for components that have compression face steel reinforcement and shear reinforcement in maximum moment areas.
Table 9. Deformation Limits for Reinforced Masonry

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Response Range</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µ</td>
<td>θ</td>
</tr>
<tr>
<td>Reinforced Masonry</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Walls &amp; Diaphragms</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Components (shear control, without shear reinforcement)</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Components (shear control, with shear reinforcement)</td>
<td>1.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Notes:
1. Response limits are for components responding primarily in flexure unless otherwise noted.
2. Response parameter: µ = ductility ratio, θ = support rotation (degrees).

4.3.5 Component Design

4.3.5.1 General

1. Ultimate strength (limit state) methods shall be used for designing structural components for blast resistance.
2. In-plane and secondary bending stresses shall be considered in the design.
3. Interaction of forces in two directions, including biaxial bending, shall be considered in accordance with *ASCE Design of Blast-Resistant Buildings*.
4. Dynamic strength properties shall be used to reflect increased material strength under rapidly applied loads.
5. Composite sections can be used for design; however, adequate rebound resistance shall be provided to ensure satisfactory response under rebound or negative phase loads.
6. Components shall be adequately laterally braced to prevent premature buckling failure during the positive and rebound response.
7. Connections shall be sized to transfer computed reaction forces and to ensure that plastic hinges can be maintained in the assumed locations. For reinforced concrete design, splices and development lengths shall be designed for the full yield capacities of the reinforcing. For structural steel design, connections shall be designed for a capacity greater than that of its supported member. Connection details are provided in Chapter 8 of *ASCE Design of Blast-Resistant Buildings*.
8. Design for compression elements, such as load-bearing walls and columns, shall consider bending effects including p-delta and slenderness.
4.3.5.2 Reinforced Concrete

1. Reinforced concrete components shall be designed, using ultimate strength methods, in accordance with ACI 318 / ACI 318M and ASCE Design of Blast-Resistant Buildings supplemented by the following specific requirements.

2. The strength reduction factor ($\phi$) shall be 1.0 for load combinations that include blast loads.

3. Deformation limits for shear shall be used if the member’s shear capacity is less than 120% of the flexural capacity.

4. Unless otherwise specified, a minimum 4000 psi (28 MPa) concrete compressive strength shall be used for the design of the concrete structures.

5. Reinforcing steel shall be in accordance with ASTM A706/A706M, except that ASTM A615/A615M Grade 60 (420 Mpa) can be used if in accordance with the requirements of ACI 318-11 / ACI 318M-11, Section 21.1.5.2.

6. The maximum reinforcing bar size shall be No. 10 (32 mm).

7. Wall and roof components shall be designed for in-plane and out-of-plane loads that act simultaneously by using the following equation:

   \[ \frac{\Delta_c}{\Delta_a} \]^2 + \left[ \frac{\Delta_c}{\Delta_a} \right]_i < 1.0 \]

   where

   $\Delta_c = $ calculated deformation (ductility ratio or support rotation)

   $\Delta_a = $ allowable deformation (ductility ratio or support rotation)

   \(i\) = in-plane deformations

   \(o\) = out-of-plane deformations

8. Slenderness effects shall be included for load-bearing walls and for members with significant axial loads.

9. Support shall be provided for roof slabs to prevent failure during rebound. Headed studs can be used for this purpose; however, unless composite action is required and included in the design, the studs shall be located and spaced to minimize composite action.

4.3.5.3 Structural Steel

1. Structural steel components shall be designed in accordance with AISC 360 using the LRFD provisions supplemented by the following specific requirements.

2. The resistance factor ($\phi$) shall be 1.0 for load combinations that include blast loads.
3. Materials with specified yield strength of 50 ksi (345 MPa) or less shall be used for flexural design.

4. Materials with specified yield strength greater than 50 ksi (345 MPa) can be used if ductile behavior is not required.

5. Oversize holes shall not be used in connections that are part of the lateral force-resisting system.

6. Column base plates shall be designed to develop the peak member reactions applied as a static load.

7. Dynamic material properties can be used for design of base plates.

8. Flexural members shall be laterally braced on both faces to provide consistent moment capacity for both positive and rebound responses.

**4.3.5.4 Cold-Formed Steel**

1. Cold-formed steel components shall be designed in accordance with *AISI S100*, using the LRFD provisions, supplemented by the following specific requirements.

2. Ultimate resistance shall be determined using a resistance factor \( \phi \) of 0.9 applied to the plastic moment capacity.

3. Tensile membrane capacity of wall panels can be used if adequate anchorage of panel ends is provided.

4. Tensile membrane capacity of cold-formed girts and purlins can be used in the design if the girts and purlins are supported on the exterior face of a frame member and are continuous over three or more spans.

5. Oversize washers shall be provided for wall panel anchorage screws to prevent failure caused by rebound or negative phase loads.

**4.3.5.5 Reinforced Masonry**

1. Design of reinforced masonry shall be in accordance with the ultimate strength method in *ACI 530/530.1*, and the *IBC* supplemented by the following specific requirements.

2. Hollow concrete masonry units (CMU) shall be in accordance with *ASTM C90* with a minimum compressive strength \( f'_m \) of 1500 psi (10.3 MPa).

3. All cells of hollow CMU shall be fully grouted.

4. Joint reinforcing shall be in accordance with *ASTM A1064/A1064M* with a minimum yield stress of 70 ksi (485 MPa) and a minimum tensile strength of 80 ksi (550 MPa).
5. Primary reinforcing bars shall be in accordance with ASTM A706/A706M except that ASTM A615/A615M Grade 60 (420 MPa) can be used if in accordance with the requirements of ACI 318-11 / ACI 318M-11, Section 21.1.5.2.

6. Wall components subjected to in-plane and out-of-plane loads shall be designed using the interaction equation in Section 4.3.5.2.7, this Practice.

### 4.3.6 Structural-Framing Design

4.3.6.1 Design of the overall structural-framing system shall include analysis of global response including sidesway, overturning, and sliding.

4.3.6.2 Sidesway analysis shall be performed with and without leeward side (rear wall) blast loads.

### 4.3.7 Foundation Design

#### 4.3.7.1 General

1. Foundation design shall be based on a geotechnical report in accordance with PIP CVS02010 and the geotechnical data summarized in the PIP STC01018-D or PIP STC01018-DM data sheet. The geotechnical report shall include allowable bearing capacity for blast load and combined dead and blast load cases.

2. Foundation components shall be designed in accordance with ASCE Design of Blast-Resistant Buildings to resist the peak reactions produced by supported components resulting from the dead, live, and blast loads, treated either statically or dynamically.

#### 4.3.7.2 Static Analysis

1. Static application of the peak dynamic reactions from the wall and roof components can be used to design supporting members and to calculate overturning and sliding effects.

2. For blast load combinations, the factor of safety for overturning shall be 1.2, and for sliding shall be 1.0.

#### 4.3.7.3 Static Capacity

1. Foundations shall be designed using vertical and lateral soil capacities.

2. For shallow foundations including footings and mats, vertical soil capacity shall be 80% of the ultimate net soil-bearing capacity.

3. For piles and other deep foundations, vertical soil capacity shall be 80% of the ultimate static capacities in compression and in tension.

4. Passive resistance of grade beams may be used to resist lateral loads if compacted fill is placed around the building perimeter.
5. Frictional resistance of spread footings and floor grade slabs shall be based on the coefficient of friction determined by the geotechnical study. The normal force shall be the sum of the dead loads and the applicable vertical load.

6. Frictional resistance of floating slabs shall not be used.

7. If only passive resistance, frictional resistance, vertical piles, or battered piles are used to support the lateral blast loading, the design resistance shall be 80% of the ultimate static value. However, if two or more of these resistances are used to support the lateral blast loads, the lateral capacity shall be limited to 67% of the combined ultimate static resistance.

8. Foundation sliding can be permitted if demonstrated that all underground and aboveground utility, electrical, and instrumentation lines entering and exiting the building have adequate flexibility to accommodate the slide.

4.3.7.4 Dynamic Analysis

1. To optimize the design, the foundation components can be analyzed dynamically for the calculated reaction-time history of the supported components.

2. The required dynamic material properties of the foundation soils, including resistance and stiffness, shall be determined on the basis of an appropriate geotechnical investigation.

3. Deformation limits shall not be used for dynamic response of foundations.

4. Based on the results of the dynamic analysis, it shall be determined whether the predicted maximum response is acceptable for the permissible damage level of the building.
4.4 Ancillary Items

4.4.1 Blast Doors

4.4.1.1 The performance category for the blast resistant doors shall be in accordance with the PIP STC01018-D or PIP STC01018-DM data sheet.

4.4.1.2 The response limits and other requirements shall be as given in Table 10, this Practice.

Table 10. Blast Door Performance Requirements

<table>
<thead>
<tr>
<th>Category</th>
<th>Door Condition after Blast</th>
<th>Panels</th>
<th>Ductility Limit</th>
<th>Edge Rotation (deg)</th>
<th>Door Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Operable</td>
<td>Elastic</td>
<td>1.0</td>
<td>1.2</td>
<td>Primary Exit or Repeated Blasts</td>
</tr>
<tr>
<td>II</td>
<td>Operable</td>
<td>Significant Damage</td>
<td>3</td>
<td>2</td>
<td>Prevent Entrapment</td>
</tr>
<tr>
<td>III</td>
<td>Inoperable</td>
<td>Substantial Damage</td>
<td>10</td>
<td>8</td>
<td>Prevent Blast from Entering Building</td>
</tr>
<tr>
<td>IV</td>
<td>Inoperable</td>
<td>Failure in Rebound</td>
<td>20</td>
<td>12</td>
<td>Prevent Door from Becoming Debris Hazard</td>
</tr>
</tbody>
</table>

4.4.1.3 In buildings large enough to require more than one egress door in accordance with local building codes, at least two doors shall be designated as egress doors for the purpose of limiting the damage to these doors if subjected to blast loads.

4.4.1.4 Designated egress doors shall not be located on the same side of the building.

4.4.1.5 Doors, door-frames, and door hardware shall be designed for the performance criteria and applied blast loads in accordance with the PIP STC01018-D or PIP STC01018-DM data sheet.

4.4.1.6 Doors shall be outward opening and shall seat against the frame in response to the positive phase blast wave.

4.4.1.7 Blast door manufacturer’s calculations or test data shall be provided to verify adequate blast resistance and door performance for the design load conditions.

4.4.1.8 Manually operated exit doors shall meet the requirements of the local building codes for the maximum opening force.

4.4.1.9 Power-operated doors shall be used for exit doors that exceed the maximum opening force.

4.4.1.10 Reinforced conventional fire-rated metal doors can be used if substantiated with a design calculation or with test data to verify adequate blast resistance and door performance for the design load condition.
4.4.2 Windows

4.4.2.1 Windows normally shall not be used in blast resistant buildings.

4.4.2.2 If windows are required, they shall be designed to provide protection in response to the applied blast load consistent with the overall building performance requirements specified in the contract documents.

4.4.2.3 The design shall include the window frames and anchorage.

4.4.2.4 Properly designed laminated glass, tempered glass in accordance with ASTM C1048, and polycarbonates shall be permitted for use in windows.

4.4.2.5 Performance of window products shall be substantiated by design and or test data.

4.4.3 Openings

4.4.3.1 Openings in the building envelope, such as intake ducts, shall be designed to prevent entry of excessive blast pressures.

4.4.3.2 Blast valves, blast attenuators, or other devices shall be used to limit excessive blast pressure entry into the structure.

4.4.3.3 Performance of the blast valve or attenuator shall be substantiated by test data and/or calculations.

4.4.3.4 Blast valves shall be provided for openings greater than 150 inch$^2$ (1000 cm$^2$) in any surface in which the peak applied pressure is greater than 10 psi (0.07 MPa).

4.4.3.5 Blast attenuators can be used for openings greater than 150 inch$^2$ (1000 cm$^2$) in any surface if the peak applied pressure is greater than 5 psi (0.035 MPa).

4.4.4 Penetrations

4.4.4.1 Wall and roof penetrations in reinforced concrete and masonry shall be sleeved.

4.4.4.2 Sleeves shall be anchored with a minimum of two each 1/2-inch diameter by 4-inch (12-mm diameter x 100-mm) long headed studs.

4.4.4.3 Penetrations in metal-clad structures shall be anchored with substantial framing attached to structural steel members.

4.4.4.4 Annular space packing between the sleeve and the utility shall be designed to remain in place (not become a projectile) during a blast event.

4.4.5 Suspended Items

4.4.5.1 Equipment and furnishings such as ceilings, HVAC ductwork, and light fixtures suspended from the roof inside the building shall be secured to structural framing members.
4.4.5.2 Anchorage shall be designed to resist a statically applied force equal to the mass of the item times the maximum acceleration of the roof or five times the weight of the item, whichever is less.

4.4.6 Externally Mounted Items

4.4.6.1 To avoid the potential for hazardous debris, large non-structural features such as canopies and signs on the building exterior shall not be permitted.

4.4.6.2 Small items such as instruments, fire alarms, lights, strobes, and beacons can be mounted on the exterior walls.

4.4.6.3 Roof- and wall-mounted equipment (e.g., HVAC equipment) shall be avoided.

4.4.6.4 If approved by owner, roof- and wall-mounted equipment shall be securely anchored and the supporting structural components shall be specifically designed for actual equipment dynamic loads if subjected to the blast.

4.4.6.5 Equipment and other items mounted on the exterior walls or roof shall be designed similarly to the structural components if they are to withstand the applied blast loads.

4.4.6.6 The reactions from externally mounted items shall be considered in the design of the supporting structural components.

4.4.7 Equipment and Internally Mounted Items

4.4.7.1 Instrumentation or electrical equipment shall not be mounted on the interior face of walls subjected to blast loads without owner’s prior written approval.

4.4.7.2 All fixed floor-supported items (e.g., lockers, electrical cabinets, racks), shall have a minimum clearance from exterior walls equal to the maximum calculated lateral blast load deflection.

4.4.7.3 The maximum deflection shall be the sum of both the overall building sidesway and the deflection of any wall component(s), and shall be calculated based on the maximum blast loads in accordance with the PIP STC01018-D or PIP STC01018-DM data sheet.

4.4.7.4 Supports and anchorage for equipment shall be designed to resist a lateral force equal to 20% of the equipment weight.
APPENDIX A – COMMENTARY to PIP STC01018

Commentary to PIP STC01018

Table of Contents

A-1 Introduction ......................... A-2
   A-1.1 Purpose ................................ A-2
   A-1.2 Scope ................................ A-2

A-2 References ......................... A-2

A-3 Definitions ........................... A-4

A-4 Requirements ....................... A-4
   A-4.1 General Responsibilities ...... A-4
   A-4.2 Design Parameters .............. A-4
   A-4.3 Structural Design ............... A-11
   A-4.4 Ancillary Items ................. A-19
A-1 Introduction

A-1.1 Purpose

PIP STC01018 focuses on the structural design of blast resistant buildings to be performed by a structural engineering professional (engineer-of-record). It is expected that the requirements for the conventional and the non-structural (architectural, electrical, HVAC, etc.) designs of such buildings will be covered separately by the owner.

This commentary to PIP STC01018 provides additional information regarding the selection and application of the blast design requirements. The commentary is not a part of the design requirements but is intended to assist the owner and engineer-of-record in applying the criteria during the course of the design.

A-1.2 Scope

PIP STC01018 is meant to cover new facilities if the owner invokes it. It does not specifically address existing facilities; however, the methods discussed are applicable to analysis of existing buildings and the design of retrofits for such buildings. The engineer-of-record should refer to the ASCE Design of Blast-Resistant Buildings for specific guidance on analysis of existing facilities.

Some buildings may not require design for blast for a variety of reasons, including negligible blast loads levels or non-essential functions, or they may not be occupied according to the owner’s occupancy criteria. The owner should determine whether blast design is required for each facility and specify this in the project or job specifications.

A common issue related to design of structures at petrochemical facilities is the lower limit of overpressure below which blast resistant design is not required. Many companies have cutoffs ranging from 0.5 psi (3.4 kPa) to 1.0 psi (6.9 kPa) side-on overpressure. This load level will produce damage to conventional buildings, with damage ranging from cosmetic to moderate requiring repair for continued use.

The most rational approach is to design each building at a site for the predicted blast load developed in hazard analysis studies. However, this may not always be practical, in which case an acceptable lower bound overpressure level must be established for conventional construction below which blast design need not be considered.

Building occupancy may be used in determining the need for blast resistance in new or existing buildings. Although addressed in other industry guidelines such as API RP 752 (commentary reference 1), PIP STC01018 does not cover occupancy criteria.

Application of PIP STC01018 for blast design may be influenced by future plant or process unit development. A building may be at risk at some point in the future if a process unit is modified or if a new unit is added that can produce higher overpressures at a given structure. A master plan for facility siting is highly desirable to address this issue.

A-2 References

PIP STC01018 is based primarily on the design methods and procedures provided in ASCE Design of Blast-Resistant Buildings. However, other similar references and guidelines
may be used. There are a number of other applicable references for design of blast resistant structures, including those developed for U.S. Department of Defense purposes. One of the most widely used of these references, *UFC 3-340-02*, is also applicable to petrochemical facilities. However, the *ASCE Design of Blast-Resistant Buildings* is a “how to” document, which covers all aspects of blast design for buildings at petrochemical plants.

This commentary lists additional references relevant to blast resistant design that are not included in the References Section of *PIP STC01018*:


8. *Blast Protection of Buildings*, ASCE 59 – American Society of Civil Engineers

9. *Notes on Blast Resistance of Steel and Composite Building Structures*, Steel Tips 05.2010, Structural Steel Educational Council (SSEC)


A-3 Definitions

The terminology used in this Practice is consistent with ASCE Design of Blast-Resistant Buildings and other blast design manuals such as UFC 3-340-02 and ASCE Manual No. 42 (commentary reference 2). Some differences in definitions, especially for symbols, may exist in blast load prediction manuals. The engineer-of-record should verify any conflicting definitions.

A-4 Requirements

A-4.1 General Responsibilities

A-4.1.1 Documentation Furnished by Owner

In addition to the need for blast resistance, PIP STC01018 requires that the owner provide certain data and requirements to the engineer-of-record performing the design in accordance with the PIP STC01018-D or PIP STC01018-DM data sheet.

A-4.1.2 Engineer-of-Record’s Responsibilities

The engineer-of-record is responsible for designing a structure that provides protection in accordance with the response criteria based on the building performance requirements provided by the owner or defined in accordance with PIP STC01018. In situations for which a particular blast protection requirement is not covered in PIP STC01018, conservative design assumptions should be made to ensure safety. The owner should cover topics or issues not addressed. The engineer-of-record should bring items requiring clarification to the owner’s attention as soon as possible to avoid project delays.

The PIP STC01018-D or PIP STC01018-DM data sheet should completely describe the design criteria, blast loads, structural system, and ancillary equipment. Material and section properties should be tabulated to aid in future evaluation of alternate blast loads.

A-4.2 Design Parameters

A-4.2.1 Building Performance

The required building performance is an important consideration by the owner in establishing the building response range under the design blast conditions. The building response range may be a function of many factors related to the acceptable risk for a given facility. A building response range should be selected, on the basis of the building performance required, and included in the PIP STC01018-D or PIP STC01018-DM data sheet. Such building performance requirements may be developed on the basis of the occupancy and function classification of the building as shown in PIP STC01018, Table 6.

The owner should decide what philosophy is to be adopted in setting the response range for evaluating and retrofitting existing buildings for blast resistance. In some cases because it is normally much less costly to incorporate blast resistance into a new facility than to retrofit a structure to
increase its blast capacity, greater damage to an existing facility may be more tolerable than would be permitted for a new design.

A-4.2.2 Building Configuration

Blast resistant buildings should preferably be one-story construction with eave heights ranging up to 18 ft (5 m). Two-story construction can be permitted, but should be used only if absolutely required. Two-story construction may be required if limited plot area prevents the layout of a single-story building. The floor plan for a building requiring blast resistance should be as simple as possible. A box type structure is preferable, in which the shorter side is exposed to the larger reflected blast load, and the longer side is exposed to the lower side-on blast load value. Roof overhangs, canopies, and re-entrant corners should be avoided if possible to avoid additional blast wave reflections. Architectural items such as canopies and signs should be designed with light construction materials, such as canvas, to avoid creating a debris hazard for the structure.

A-4.2.3 Blast Loads

*PIP STC01018* does not cover development of explosion scenarios or prediction of blast loads, which therefore remain for the owner to determine. Methods for blast load prediction and considerations for determining the design basis accident scenarios are provided in commentary references 2 through 6.

The owner should specify the design blast load data in the *PIP STC01018-D* or *PIP STC01018-DM* data sheet. As a minimum, the side-on overpressure at the building location should be provided. The engineer-of-record may use the procedures provided in *ASCE Design of Blast-Resistant Buildings* to calculate the component blast loads on the basis of given free-field blast effects. The owner may also provide more detailed information from a site-specific study, including the side-on or reflected pressure-time profile and orientation (angle of incidence) of the blast loading on each surface of the building. In this case, the engineer-of-record should verify the location of the point of reference for the design blast loads. If sufficient information is available, including the location of the explosion reference point (epicenter) and the attenuation of the blast effects with distance from this point, variation of the blast load over the surfaces of the structure may be considered in the design.

Generally there are two approaches to specifying blast load for designing new facilities:

1. Establishing company generic values
2. Basing the blast loads on site- or facility-specific explosion hazard studies

In some cases, it is appropriate to develop site- and building-specific blast loads on the basis of potential explosion hazards from any existing, planned, or future facilities. Default or generic blast loads are not based on the specific site hazard but on certain standard conditions such as spacing, process unit size, and hazard level. In addition, if the building location is...
not determined or if sufficient process information and physical configuration of the process unit is not available, the blast loads can only be approximated. In these situations, generic blast loads may be appropriate. Such loads may be based on a building category or classification defined by its occupancy or function following a blast and the separation distance from a potential explosion hazard, as illustrated in commentary Table A-1. This table can be used to show the company, project, or site specific blast loads.

### Table A-1. Building Classification Matrix

<table>
<thead>
<tr>
<th>Building Classification Based on Blast Severity or Spacing</th>
<th>Separation Distance ft (m)</th>
<th>Pressure psi (kPa)</th>
<th>Impulse psi-ms (kPa-ms)</th>
<th>Building Performance Requirement &amp; Damage Level (H, M, &amp; L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
<td></td>
<td>Building Performance Requirement &amp; Damage Level (H, M, &amp; L)</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td>Building Performance Requirement &amp; Damage Level (H, M, &amp; L)</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td>Building Performance Requirement &amp; Damage Level (H, M, &amp; L)</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>Building Performance Requirement &amp; Damage Level (H, M, &amp; L)</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td>Building Performance Requirement &amp; Damage Level (H, M, &amp; L)</td>
</tr>
</tbody>
</table>

#### A-4.2.3.2 Component Loads

The blast load on each component of a building depends on the orientation of the building surface on which it is located. The following is a discussion of the blast loads for the main building components:

a. **Wall Load**

   Normal reflection may be assumed without consideration of the angle of incidence of the blast wave. Clearing effects of the reflected blast wave may be considered by using the approach described in *ASCE Design of Blast-Resistant Buildings* or *UFC 3-340-02*.

b. **Roof Load**

   Roof load should be calculated using the methods provided in *ASCE Design of Blast-Resistant Buildings*, on the basis of the blast wave direction, component span, and spacing. For a flat roof (slope less than 20 degrees), roof load may be conservatively taken as the side-on value unless otherwise specified. For roofs sloped 20 degrees or greater, the effects of blast wave reflection should be considered.
c. **Side/Rear Wall Loads**

The blast loads on the side walls and rear wall relative to the explosion source should be considered in the analysis of the overall building. These loads may be calculated using the methods given of *ASCE Design of Blast-Resistant Buildings*, Chapter 3, or may be conservatively assumed to be the side-on values.

d. **Overall Building (Frame) Loads**

The overall structural framing should be designed for net vertical and lateral blast loads acting on the building, considering the time phasing of these loads, as provided in *ASCE Design of Blast-Resistant Buildings*.

The blast load on the rear face may be used to reduce the net lateral load for design of the overall structural framing system including diaphragm, shear walls, and foundation. The rear wall blast load may be ignored if considering the load produces a more conservative design. However, if the rear wall loading is considered in the overall lateral blast loading, the lag time (delay in time of arrival) should be taken into consideration.

e. **Negative Phase (Suction) Load**

A negative phase load following the positive (overpressure) phase should be considered in the design. The effects of such a load should be considered in combination with the rebound effect from the direct blast pressure load.

### A-4.2.4 Construction and Materials

A wide choice of construction types is available for blast resistant buildings, ranging from conventional construction to bunker-like concrete structures. The construction type is typically dictated by such factors as cost, blast load level, local practice, architectural considerations, and owner preference. *ASCE Design of Blast-Resistant Buildings*, Chapter 4, describes some of the common types of construction used for blast resistant buildings in petrochemical plants.

Conventionally designed buildings can provide some level of protection against blast loads. The degree of protection provided depends on the ductility and redundancy of the structure. Ductile structures, such as metal frame/metal clad, can typically respond well into the plastic range and absorb blast energy. If connections are robust, components can develop tensile membrane action, which significantly increases their capability to resist load.

Commentary Table A-2 lists some common types of building construction in the petrochemical industry, typical building function/use, the blast load ranges for each type of construction, and the tolerable damage level appropriate for the building function/use.
Table A-2. Construction Type Matrix

<table>
<thead>
<tr>
<th>Construction Type</th>
<th>Typical Building Function</th>
<th>Blast Load Range, Side-on Overpressure psi (kPa)</th>
<th>Tolerable Damage Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete</td>
<td>Central control room</td>
<td>High 7 (48) 10 (69)</td>
<td>Low</td>
</tr>
<tr>
<td>Precast concrete</td>
<td>Lab, office</td>
<td>Moderate-Moderate 5 (34) 7 (48)</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>Reinforced masonry</td>
<td>Office</td>
<td>Moderate 3 (21) 5 (34)</td>
<td>Medium</td>
</tr>
<tr>
<td>Metal frame, metal clad</td>
<td>Maintenance shop</td>
<td>Moderate-Low 2 (14) 3 (21)</td>
<td>Medium-High</td>
</tr>
<tr>
<td>Pre-engineered metal building</td>
<td>Warehouse</td>
<td>Low 1 (7) 2 (14)</td>
<td>High</td>
</tr>
</tbody>
</table>

A-4.2.4.2 Brittle Construction

Brittle structures, such as unreinforced masonry, have little ductility and can fail under very low blast loads. Failures of brittle structures are sudden and should be avoided in all cases. For this reason, unreinforced masonry construction is not permitted for design of blast resistant structures.

Redundant construction is also desirable for blast design. Redundancy is accomplished by providing alternate load paths and designing the structure to redistribute loads if a single component failure occurs. In metal frame buildings, where resistance to lateral loads is provided by girts and main frames, redundancy may be provided by strengthening the roof deck to act as a diaphragm and to distribute the load to other frames. Specific provision for redundancy is not required for design; however, redundancy should be provided where feasible and cost effective.

Metal frame, metal clad construction is commonly used in petrochemical plants for warehouses, maintenance shops, and process support office buildings. This type of construction is appropriate for relatively low blast overpressures and should typically be located several hundred feet from major process units.

Moment-resisting frames are typically used in a metal building to resist the lateral load applied on its long side. Cross bracing is used between frames to resist loads applied to the end or short walls of the building. However, the engineer-of-record should be aware of special considerations for blast resistant design including the following:

1. Frame spacing should typically be closer, on the order of 20 ft (6 m), than for conventional construction, where frame spacing may exceed 30 ft (10 m).
2. Heavier gage wall panels and closer girt spacing are typically required to develop any significant blast resistant capability.
3. It may also be necessary to provide bracing for flexural members to develop a full plastic moment capacity for loads in both directions. This is a departure from typical construction, where bracing is normally required for a load in one direction only.
4. Cladding fasteners should also be detailed to ensure proper resistance to rebound and negative phase blast loading.

Masonry buildings used for conventional construction can be classified as load bearing or non-load bearing. The response for the load-bearing construction is limited to ensure adequate safety against collapse under blast load. If a steel or concrete frame is provided, infill masonry walls can be permitted to incur significantly more damage without risk of collapse. This non-load-bearing construction is preferred because it provides better redundancy and overall safety. Unreinforced masonry load-bearing construction may be adequate for relatively low blast overpressures (i.e., less than 1 psi (7 kPa)).

A metal deck can be used as a roof diaphragm for relatively low blast overpressures. A poured-in-place concrete deck is typically used for masonry construction that is subjected to blast loads. A concrete deck provides significantly more lateral capacity than does a metal roof deck. A substantial bond beam at the top of the wall or secure ties into a concrete roof deck should be provided for anchorage for wall rebound.

Precast concrete construction is widely used in petrochemical facilities for control rooms, plant offices, and process support buildings. Precast (non-prestressed) construction can be completed quickly and can provide significant blast resistance. The most significant consideration for blast resistant design is detailing of connections. Precast panels for conventional loads can have minimal blast capability if a small number of connectors are provided. For blast design, the number of connectors should be significantly increased and should be able to develop the full flexural capacity of the panel. If panel thickness is governed by architectural or mechanical considerations, the engineer-of-record should ensure that connections are designed on the basis of the panel capacity rather than the required resistance for the blast.

Precast construction, like masonry, can be classified as load-bearing or non-load-bearing structural systems. For load-bearing construction, detailing of connections to develop moment capacities is especially critical. Secondary bending effects, $P-\Delta$, caused by in-plane vertical loads should also be considered. For non-load-bearing construction, steel frames should be used to support the vertical loads. The frames should be recessed from the interior face of the wall panels to avoid applying lateral loads to the columns.

Cast-in-place reinforced concrete construction is typically used to provide resistance to severe blast loads. Wall thicknesses for structures in or immediately adjacent to large process areas are typically 8 inches (200 mm) to 12 inches (300 mm) but can be thicker for some special cases. Reinforced concrete is especially appropriate for short duration loading that produces an impulsive response. Its large mass, relative to the surface area, is especially effective in resisting these types of loads. Reinforced concrete construction is typically used if a protective structure is needed around an existing structure to resist large blast loads because of close proximity to a blast source.
A-4.2.4.5 Fragment Resistance

Structures that are required by the PIP STC01018-D or PIP STC01018-DM data sheet to have fragment resistance shall be designed in accordance with UFC 3-340-02 design procedures.

A-4.2.5 Material Properties

A-4.2.5.1 Dynamic Material Strength

The dynamic design stress ($F_{ds}$) is used to calculate blast capacity of a structural component. Because design strength is constant throughout the response history, an average value should be used. Figure A-1 illustrates the relationship of $F_{ds}$ to $F_{dy}$ and $F_{du}$. If the response is low, the portion of strength above yield is small because the actual stress is nearly equal to $F_{dy}$ for most of the response. If a large deformation is produced, the actual stress is closer to the dynamic ultimate strength ($F_{du}$). The tables provided in PIP STC01018 show the design stresses to use for given levels of response. If the anticipated response is incorrect, a new design stress should be calculated and new member properties determined.

![Figure A-1. Yield, Ultimate, and Design Stresses](image)

A-4.2.5.2 Strength Increase Factor (SIF)

The strength increase factor (SIF) is applied because the actual yield and ultimate strength of a material is typically greater than the minimum specified value. Use of the SIF provides more realistic member properties and results in higher structural resistance. Failure to include the SIF can result in underestimating the member resistance and the resulting shear loads and dynamic reactions. This may not be conservative.
A-4.2.5.3 Dynamic Increase Factor (DIF)

The dynamic increase factor (DIF) is used to account for the strain rate effects. Under blast-loading conditions, the material cannot respond as quickly as the load is applied and an apparent strength increase is produced. Failure to include the DIF can result in the under-prediction of member end shears and reactions. The strain rate can vary depending on whether the blast load is a pressure wave or a shock wave. A pressure wave may not produce strain rates sufficient to require DIFs as high as shown in *PIP STC01018* Table 4. *UFC 3-340-02* can be used for guidance on DIF values at relatively slow strain rates.

A-4.3 Structural Design

A-4.3.1 General

An overall process for designing blast resistant structures for petrochemical facilities is shown in commentary Figure A-2 taken from *ASCE Design of Blast-Resistant Buildings*. Most of the overlapping steps in the design process should normally be the responsibility of the engineer-of-record. If the owner has specific requirements in these areas, the requirements should be provided in the *PIP STC01018-D* or *PIP STC01018-DM* data sheet or the project/job design specifications. The engineer-of-record should bring any unclear requirements to the attention of the owner at the earliest possible time to avoid project delay.

The following references may be of assistance to the engineer-of-record.

a. AISC Steel Design Guide 26 (commentary reference 7)

b. ASCE 59 (commentary reference 8)

c. Steel TIPS 05.2010 (commentary reference 9)
Figure A-2. Overall Blast Resistant Design Process (from ASCE – Design of Blast Resistant Buildings in Petrochemical Facilities)
**A-4.3.2 Load Combinations**

Most design codes for conventional buildings have provisions for combination of design loads such as live, wind, seismic, snow, etc. For blast design, a decision should be made about which of these loads to include simultaneously with blast loads. Dead loads are always included, but most other transient live loads are not, although roof live loads (full or partial) are typically included.

The portion of live load to be applied in combination with blast load should be determined by the engineer-of-record on the basis of the amount of load that could reasonably be expected to occur at the same time as the blast load. This should include snow loads, roof live loads, and floor loads. The full floor live load should not normally be used because of the low probability of blast occurring during application of the full floor live load. It is not normal practice to combine blast loads with extreme environmental loads such as wind or earthquake. In rare situations, it may be appropriate to analyze structural response for the blast load following application of seismic loads (for example, where an earthquake causes damage to a process unit, which leads to an explosion).

Most conventional design codes specify load factors to be applied to provide a factor of safety in the design. These load factors are typically set at 1.0 for blast design because a blast load is an extreme event.

**A-4.3.3 Analysis Methods**

**A-4.3.3.2 Single Degree of Freedom (SDOF) - Numerical Integration**

The numerical integration method is the most commonly used method for blast resistant design. This method allows most structural components to be modeled as a single, spring-mass system, which greatly simplifies the analysis of the time-history response. This method can be used to model non-linear resistance functions and the differences in resistance in the positive and rebound phases. The numerical integration method can also be used to model complex pressure-time histories including negative pressure effects.

The time-varying end reactions can be calculated using the SDOF method. These reactions can then be applied to supporting members to model component interaction. Special consideration needs to be given to selection of the appropriate mass to be applied to supporting members, based on the relative time to maximum response of the member being supported.

Additional guidance is given in *ASCE Design of Blast-Resistant Buildings* and in commentary references 10 and 11 for modeling and analyzing the response of structural components as SDOF systems.

Pressure-impulse (P-I) curves, denoting lines of constant damage corresponding to a particular response limit, may be used to evaluate the response of a structural component to a number of blast loads. This approach is described in *ASCE Design of Blast-Resistant Buildings* and in other references (e.g., commentary references 3, 4, and 6).
A-4.3.3.3 Multi-Degree of Freedom (MDOF)

The multi-degree of freedom (MDOF) analysis method can be used to determine the dynamic response of interconnected members. Each component should be modeled as a one-degree-of-freedom spring mass system. Several SDOF systems can be combined numerically to produce a MDOF model. The MDOF method can model mass and dynamic reaction effects on supported members. A typical system for a wall design can be modeled as a three-degrees-of-freedom system consisting of a wall panel, girt, and frame column. MDOF analysis can result in a much lower maximum deflection than a SDOF analysis if the periods of vibration of the connected members are fairly close.

The MDOF method can be used to model non-rigid (spring) supports, which can reduce the required resistance of certain components. A spreadsheet can be used to perform numerical integration of simple models consisting of two or three degrees of freedom. Beyond this, a computer program is more appropriate. A limited number of special purpose computer programs are available that are suitable for this type of analysis although most of these programs have been developed for defense-related applications. Also a commercially available general purpose finite element program, that employs general spring elements to model and analyze non-linear MDOF systems subjected to transient blast loads, may be used.

Finite element analysis (FEA) can be used for analyzing a large system of components that cannot be accurately modeled using SDOF or MDOF methods. MDOF and FEA are essentially the same methods; however, FEA is usually distinguished as capable of modeling complex elements, whereas an MDOF method is based on equivalent spring elements. FEA is typically used to model response of a three-dimensional frame structure if biaxial bending and other three-dimensional effects are important.

A number of commercially available computer programs, referenced in *ASCE Design of Blast-Resistant Buildings*, provide general FEA capability and can predict dynamic response to transient loads. These programs are therefore suitable for blast resistant design. It is important to use a FEA program that can accurately model non-linear effects, both material and geometric, and that can incorporate the effects of increased material strength under rapidly applied loads.

A-4.3.4 Deformation Limits

A-4.3.4.1 Response Parameters

For blast resistant design, the adequacy of the structural response is determined in terms of maximum deflection rather than stress level because the response typically will be in the plastic region of the stress-strain curve. It is normal practice to design blast resistant structures for plastic deformation if subjected to the extreme blast loads from accidental explosions. It is not cost effective to design such structures to remain elastic.
The two key parameters for evaluating structural response are support rotation (θ) and ductility ratio (µ). Support rotation is a function of the maximum deflection to span ratio. Commentary Figure A-3 illustrates support rotation for a simple beam.

Ductility ratio is a measure of the degree of plastic response. A ductility ratio of 2 means that the maximum deflection is twice the deflection at the elastic limit. Steel members can achieve relatively high ductility ratios if buckling and shear modes of failure are prevented. The limits on deformation provide some conservatism for these effects.

Ductility ratio is an appropriate criterion for steel members, but it is a less reliable performance indicator for reinforced concrete components. Concrete members tend to be very stiff, which produces a very low elastic deflection. Therefore, small dynamic deflections can produce large ductility ratios. Support rotation is a more reliable measure of performance for concrete or masonry.

**Figure A-3. Definition of Support Rotation**

θ₁ = Support rotation  
θ₂ = Center hinge rotation = 2*θ₁

**A-4.3.4.2 Building Response Range**

The structural response or allowable damage level should be in accordance with the owner-specified performance requirements for the building. The recommended response limits in PIP STC01018 correspond to three damage levels (low, medium, high) described in PIP STC01018 Table 6.

**A-4.3.5 Component Design**

**A-4.3.5.1 General**

Structural components designed using SDOF analysis should include in-plane loads and secondary bending effects. These effects are typically incorporated as statically applied loads together with the flexural response to the transient loads.

Components should be designed to develop the full flexural capacity to avoid brittle failure modes. This type of response provides the maximum blast-absorbing capability and results in a controlled failure mode. This type of response requires that components have sufficient shear and connection capacities. The shear and connection capacities of a component are typically based on the component’s full flexural resistance. Adequate
bracing should also be provided to prevent lateral buckling, which can result in sudden failures.

The primary response for short span components is in shear, and it is not feasible in many cases to develop the full flexural capacity. In these cases, the maximum resistance produced by the transient load should be determined for the entire response history. End shears and reactions should be based on 120% of the maximum attained resistance applied as a uniform load on the member.

**A-4.3.5.2 Reinforced Concrete**

Design of reinforced concrete should be in accordance with the ultimate strength method of *ACI 318 / ACI 318M* or comparable concrete design methods. The customary strength reduction factor (φ) should be 1.0, and a dynamic strength factor (SIF * DIF) should be applied with the strength increase factor (SIF) and dynamic increase factor (DIF) in accordance with *PIP STC01018* Sections 4.2.5.2 and 4.2.5.3, respectively. In addition, because of the importance of adequate shear capacity to develop ductile flexural behavior in reinforced concrete components, the minimum static compressive strength for blast resistant design should be 4,000 psi (28 Mpa). Compressive strength less than 3,000 psi (21 Mpa) should not be permitted. The higher strengths can assure a more reliable performance in shear. A compressive strength of 5,000 psi (35 Mpa) is considered acceptable for concrete design. However, compressive strengths greater than 5,000 psi (35 Mpa) have not been adequately tested to assure proper dynamic performance under blast load conditions.

Reinforcing steel greater than Grade 60 (420 Mpa) should not be permitted. Bar sizes greater than #10 (32 mm) should not be permitted because of decreased ductility for large bars. Use of a greater number of smaller bars is preferred to decrease development length requirements.

Time phasing of the interaction equation may be used; however, because of inaccuracies in load-time phasing and response, it is important to apply some conservatism to the design.

Prestressed concrete members are typically limited to roof members only. Prestressed components are typically designed for load application in one direction and do not provide adequate rebound resistance. If permitted these elements require special attention to insure that they have sufficient non-prestressed reinforcement added to the compression zone to prevent catastrophic failure during rebound or negative phase loading. Additionally, careful attention to the design and selection of precast concrete connections is required to ensure constructability and sufficient strength to transfer forces through the connections. Because of the relative lack of ductility of prestressed concrete, conservative response limits should be established. *UFC 3-340-02* provides guidance for the design of prestressed concrete.
A-4.3.5.3 Structural Steel

The load and resistance factor design (LRFD) method in accordance with AISC 360 or comparable limit state methods may be used for the blast resistant design of structural steel. Similar to reinforced concrete design, resistance factor ($\phi$) should be 1.0, and a dynamic strength factor (SIF * DIF) should be applied with the strength increase factor (SIF) and dynamic increase factor (DIF) in accordance with PIP STC01018 Sections 4.2.5.2 and 4.2.5.3, respectively. Steel material with 50 ksi (345 Mpa) yield strength should be used because of the variation in material strength for ASTM A36/A36M steel. Use of ASTM A36/A36M material, which has an actual yield strength significantly greater than 36 ksi (250 Mpa), can result in an unconservative prediction of reaction forces and required shear resistance.

A-4.3.5.4 Cold-Formed Steel

The LRFD method in accordance with AISI S100 or a comparable strength limit state method may be used for the blast resistant design of cold-formed steel members. A resistance factor ($\phi$) of 0.9 should be applied to plastic moment capacity if computing an ultimate resistance to reflect the potential buckling of a section before developing the full plastic moment. A dynamic strength factor (SIF * DIF) should be applied with the strength increase factor (SIF) and dynamic increase factor (DIF) in accordance with PIP STC01018 Sections 4.2.5.2 and 4.2.5.3, respectively.

A-4.3.5.5 Open Web Steel Joists (OWSJ)

OWSJ are less suited for blast design because of difficulties in developing ultimate moment capacity. Web buckling can occur, especially at member ends, resulting in premature failure. Instability of the bottom chord during rebound can significantly reduce the rebound capacity, but this potential problem can be remedied by supplying additional bracing to the bottom chord. If used, OWSJ should be designed on the basis of applicable standard specifications by the Steel Joist Institute – Standard Specifications, Load Tables and Weight Tables for Steel Joists and Joist Girders (commentary reference 12). Joist manufacturers’ allowable load capacity tables may be used in determining the ultimate capacity of OWBJ under blast loading by multiplying the listed stress-based values by the applicable safety factor and by the appropriate dynamic strength increase factors.

Quality control by the OWSJ manufacture can be an issue. Welding of bar joists is typically not in accordance with AWS D1.1/D1.1M (commentary reference 13) and may not be capable of developing the plastic moment capacity of the joist. Because of these potential deficiencies in blast resistant designs, OWSJ should be used with caution.

A-4.3.5.6 Reinforced Masonry

Only fully inspected reinforced masonry (concrete or brick) should be used for blast resistant design. ACI 530/530.1 and the IBC requirements for ultimate strength for reinforced masonry should be used for blast resistant design, particularly the requirements pertaining to seismic design. ASCE
Design of Blast-Resistant Buildings and UFC 3-340-02 also provide guidance for the design of reinforced masonry for blast resistance.

Masonry construction responds similarly to singly reinforced concrete. Fully grouted cells normally provide adequate compression and shear capacity to develop flexural strength. Horizontal truss or ladder type reinforcing provides minimal flexural capacity and is not generally classified as reinforced masonry.

Connections at floor and roof are typically weak links in conventional reinforced masonry construction. The connections should be capable of resisting inward and rebound loads. Connections for load-bearing construction are especially critical. Walls should be doweled into floor and roof slabs.

A-4.3.6 Structural Framing Design

Analysis of frame sidesway should include analysis with and without blast overpressure on the leeward side of the building. Normally, excluding this load will produce the maximum response; however, in some cases the load applied to the leeward side may produce the maximum response if it occurs in phase with the rebound response. Accurate calculation of time of arrival for the blast wave is important for this part of the analysis.

Dynamic analysis of sliding and overturning effects requires judgment on allowable deformations. Some guidance is provided in Design of Structures to Resist the Effects of Atomic Weapons and Overturning and Sliding Analysis of Reinforced Concrete Protective Structures (commentary references 14 and 15, respectively). Vertical movement on the order of 1 inch (25 mm) is considered acceptable, while lateral movement as much as 2 inches (50 mm) may be acceptable. Using static methods, it is normally possible to show an adequate resistance to overturning and sliding. However, multi-story structures and buildings with a large aspect ratio floor plan may require dynamic analysis to show acceptable response.

ASCE Design of Blast-Resistant Buildings, UFC 3-340-02, and other references (e.g., commentary references 10 and 11) provide guidance for modeling and calculating the dynamic response of structural systems to blast loading.

A-4.3.7 Foundation Design

Analysis of explosion accident data has shown that foundation failure is rare because of the inability of the supported structure to transfer the entire blast load to the foundation. Also, foundation members are typically massive compared with superstructures and provide greater resistance to blast loads than does the supported building. Usually foundation components are simply designed statically for the capacities of the structural components they support. However, if this proves to be too conservative or costly, a more accurate dynamic analysis of the structure/foundation system can be performed.
A-4.4 Ancillary Items

A-4.4.1 Blast Doors

The owner should specify whether blast doors are required for the building. Blast doors are expensive, even for low blast loads, and may not be cost effective at low risk levels. Conventional hollow metal doors may not be operational above approximately 1.0 psi (7 kPa) applied peak pressure. If blast pressure entering a structure is not sufficient to cause damage, a conventional door may be acceptable.

Door hardware may not be required to remain operational if additional protected exits are provided. This may be the case for doors on a wall receiving reflected loads. It may be appropriate to permit these doors to be substantially damaged if a sufficient number of doors are located in building faces receiving side-on blast loads. The owner should select an allowable response category for design of each door and specify the categories on the PIP STC01018-D or PIP STC01018-DM data sheet. Additional information regarding door performance and design is provided in ASCE Design of Blast-Resistant Buildings.

Support for blast door frames is very important. Typically, subframes are provided by the building contractor during wall construction. This allows construction to continue while blast doors are being fabricated, which may take several weeks or months. Door framing should be provided by the door manufacturer.

A-4.4.2 Windows

Windows should be avoided in buildings subjected to significant blast loads. However, laminated glass and polycarbonate glazing can provide substantial blast resistance if they are either:

a. Wet-glazed into the window frames using a structural sealant, or
b. Equipped with a large rebate (bite) to prevent the glazing from pushing through the frame

If blast resistant windows are designed by a window supplier, supporting calculations and test data should be provided to substantiate performance.

A-4.4.3 Openings

Small openings or low applied blast loads may not produce an appreciable increase in pressure in the building. In these cases, blast valves or other pressure relieving devices should not be required. For structures near a process unit, leakage pressures through air intake openings can be significant and valves or attenuators are required. Methods used for predicting leakage pressure through openings should be in accordance with UFC 3-340-02.

Blast valves typically incorporate a moving disk that seals the opening and prevents entry of blast pressures. Blast attenuators significantly reduce leakage pressures but do not completely eliminate the blast.

Passive blast valves have no moving parts and reduce blast pressures by creating a tortuous exit path rather than a seal.
A-4.4.4 Penetrations

Pre-manufactured multi-cable transits (MCT) for use in blast resistant buildings have a frame that is anchored into the concrete or masonry. Flexible collars are placed around pipes running through the MCT and are clamped down to prevent leakage of the blast pressure into the structure. MCTs are available in a variety of sizes.

A-4.4.5 Suspended Items

Light fixtures in suspended ceilings can produce a serious hazard to occupants during a blast. Ceiling grids, unless seismically rated, will not support fluorescent light ballasts and ventilation dampers. These items should be anchored to the roof framing with heavy gauge wire or threaded rod. Any item weighing more than 10 pounds (5 kg) should be independently anchored.
Blast Resistant Building Construction:

- **Building Response Range:** [ ] Low [ ] Medium [ ] High
- **Building Structural System:** Note: Check construction type from each column below. Provide details on page 3 if necessary.

### Frame

- [ ] Cast-in-Place Concrete
- [ ] Hot-Rolled Steel
- [ ] Pre-Engineered Metal
- [ ] Load Bearing Wall
- [ ] Other: ___________

### Wall

- [ ] Cast-in-Place Concrete
- [ ] Precast Concrete
- [ ] Tilt-Up Concrete
- [ ] Single Sheet Metal Panel
- [ ] Insulated Metal Sandwich Panel
- [ ] Insulated Metal Deck
- [ ] Reinforced Masonry/CMU
- [ ] Other: ___________

### Roof

- [ ] Cast-in-Place Concrete
- [ ] Precast Concrete
- [ ] Single Sheet Metal Panel
- [ ] Insulated Metal Sandwich Panel
- [ ] Insulated Metal Deck
- [ ] Composite Concrete Deck
- [ ] Other: ___________

Fragment resistant required: [ ] Yes [ ] No

Blast Load Design Requirements:

For each load case defined in "Table A" and referencing "Figure A" on page 2, the blast on each surface shall be determined using procedures provided in ASCE "Design of Blast Resistant Buildings in Petrochemical Facilities", Chapter 3 based on the peak side-on pressure and corresponding durations or impulses.

**Table A - Blast Load Parameters, Notes 1, 2, 3**

<table>
<thead>
<tr>
<th>Load Case, Note 4</th>
<th>Description</th>
<th>Reflected Wall, Note 4 (N, S, E, W)</th>
<th>Load Shape and Angle</th>
<th>Peak Side-On Pressure, PSI</th>
<th>Duration, Msec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A, B, Note 5</td>
<td>g, Note 5</td>
<td>P1, P2, T1, T2, T3, T4</td>
<td></td>
</tr>
</tbody>
</table>

Notes for Table A:

1. Blast loads shall be computed at the wall nearest the blast center.
2. Roof shall be considered loaded by the peak side-on pressure.
3. Depending on the load shape, some of the parameters may not be applicable.
4. Each load case may impact a different reflected wall. Indicate the wall (N, S, E, or W) facing the blast for the current load case.
5. Indicate angle of blast source (in degrees) measured from the line normal to the reflected wall.
FIGURE A - LOAD SHAPES AND BUILDING ORIENTATION

BLAST RESISTANT BUILDINGS
(U.S. CUSTOMARY UNITS)

OCTOBER 2014

DATA SHEET

ASSOC. PIP
STC01018

BLAST DOOR REQUIREMENTS:

TABLE B SUMMARIZES THE DESIGN REQUIREMENTS FOR EACH BLAST DOOR LOCATED IN THE EXTERIOR WALLS:

TABLE B - BLAST DOORS

<table>
<thead>
<tr>
<th>BLAST DOOR ID OR NO.</th>
<th>BUILDING FACE WHERE DOOR IS LOCATED (N, S, E, W)</th>
<th>PERFORMANCE CATEGORY- SEE PIP STC01018, TABLE 10 (I, II, III, IV)</th>
</tr>
</thead>
</table>
FOUNDATION TYPE AND GEOTECHNICAL REQUIREMENTS: (REFER TO PIP CV302010)

- **MAT FOUNDATION:**
  - **ULTIMATE BEARING CAPACITY WITH WEIGHT OF SOIL DEDUCTED ABOVE FOOTING:**
    - **PSF AT DEPTH:** ____________ **FT**
  - **DYNAMIC MODULUS OF SUBGRADE REACTION:** ____________ **PCF**
  - **SLIDING FRICTION COEFFICIENT:** ____________
  - **PASSIVE PRESSURE COEFFICIENT:** ____________

- **SPREAD FOOTING FOUNDATION:**
  - **ULTIMATE BEARING CAPACITY WITH WEIGHT OF SOIL DEDUCTED ABOVE FOOTING:**
    - **PSF AT DEPTH:** ____________ **FT**
  - **SLIDING FRICTION COEFFICIENT:** ____________
  - **PASSIVE PRESSURE COEFFICIENT:** ____________

- **PILE - SUPPORTED FOUNDATION:**
  - **PILE DESCRIPTION:**
  - **MAXIMUM VERTICAL PILE CAPACITY:** ____________ **KIPS**
  - **MAXIMUM HORIZONTAL PILE CAPACITY:** ____________ **KIPS**
  - **VERTICAL PILE SPRING CONSTANT:** ____________ **KIPS/IN**
  - **HORIZONTAL PILE SPRING CONSTANT:** ____________ **KIPS/IN**

OTHER REQUIREMENTS:

- **BLAST VALVES**
- **BLAST ATTENUATORS**

OTHER REQUIREMENTS:

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ISSUED FOR: PROPOSAL  PURCHASE  AS BUILT

FACILITY NAME/LOCATION:

ITEM NAME:  PURCHASER/LOCATION:

SERVICE:  PURCHASER ORDER NO.:

UNIT:  SUPPLIER/LOCATION:

P&ID NO.:  SUPPLIER ORDER/_SERIAL NO.:

BLAST RESISTANT BUILDING CONSTRUCTION:

BUILDING RESPONSE RANGE:  LOW  MEDIUM  HIGH

BUILDING STRUCTURAL SYSTEM:  NOTE: CHECK CONSTRUCTION TYPE FROM EACH COLUMN BELOW.

LOAD BEARING WALL

FRAGMENT RESISTANT REQUIRED:  YES  NO

BLAST LOAD DESIGN REQUIREMENTS:

FOR EACH LOAD CASE DEFINED IN "TABLE A" AND REFERENCING "FIGURE A" ON PAGE 2, THE BLAST ON EACH SURFACE SHALL BE DETERMINED USING PROCEDURES PROVIDED IN ASCE "DESIGN OF BLAST RESISTANT BUILDINGS IN PETROCHEMICAL FACILITIES", CHAPTER 3 BASED ON THE PEAK SIDE-ON PRESSURE AND CORRESPONDING DURATIONS OR IMPULSES.

TABLE A - BLAST LOAD PARAMETERS, NOTES 1, 2, 3

<table>
<thead>
<tr>
<th>LOAD CASE, NOTE 4</th>
<th>DESCRIPTION</th>
<th>REFLECTED WALL, NOTE 4 (N, S, E, OR W)</th>
<th>LOAD SHAPE AND ANGLE</th>
<th>PEAK SIDE-ON PRESSURE, MPA</th>
<th>DURATION, MSEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A, B</td>
<td>g, NOTE 5</td>
<td>P1</td>
<td>T1</td>
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<td>P2</td>
<td>T2</td>
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<td></td>
<td></td>
<td></td>
<td>T3</td>
<td>T4</td>
</tr>
</tbody>
</table>

NOTES FOR TABLE A:

1. BLAST LOADS SHALL BE COMPUTED AT THE WALL NEAREST THE BLAST CENTER.
2. ROOF SHALL BE CONSIDERED LOADED BY THE PEAK SIDE-ON PRESSURE.
3. DEPENDING ON THE LOAD SHAPE, SOME OF THE PARAMETERS MAY NOT BE APPLICABLE.
4. EACH LOAD CASE MAY IMPACT A DIFFERENT REFLECTED WALL. INDICATE THE WALL (N, S, E, OR W) FACING THE BLAST FOR THE CURRENT LOAD CASE.
5. INDICATE ANGLE OF BLAST SOURCE (IN DEGREES) MEASURED FROM THE LINE NORMAL TO THE REFLECTED WALL.
FIGURE A - LOAD SHAPES AND BUILDING ORIENTATION

BLAST DOOR REQUIREMENTS:
TABLE B SUMMARIZES THE DESIGN REQUIREMENTS FOR EACH BLAST DOOR LOCATED IN THE EXTERIOR WALLS:

TABLE B - BLAST DOORS

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</tbody>
</table>
FOUNDATION TYPE AND GEOTECHNICAL REQUIREMENTS: (REFER TO PIP CV02010)

- **MAT FOUNDATION:**
  - Ultimate Bearing Capacity with weight of soil deducted above footing: __________ KN/m² at depth: __________ m
  - Dynamic Modulus of Subgrade Reaction: __________ KN/m³
  - Sliding Friction Coefficient: __________
  - Passive Pressure Coefficient: __________

- **SPREAD FOOTING FOUNDATION:**
  - Ultimate Bearing Capacity with weight of soil deducted above footing: __________ KN/m² at depth: __________ m
  - Sliding Friction Coefficient: __________
  - Passive Pressure Coefficient: __________

- **PILE - SUPPORTED FOUNDATION:**
  - Pile Description:
  - Maximum Vertical Pile Capacity: __________ KN
  - Maximum Horizontal Pile Capacity: __________ KN
  - Vertical Pile Spring Constant: __________ KN/m
  - Horizontal Pile Spring Constant: __________ KN/m

OTHER REQUIREMENTS:

- **Blast Valves**
- **Blast Attenuators**

OTHER REQUIREMENTS:

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