Design of Blast-Resistant Buildings in Petrochemical Facilities

Task Committee on Blast-Resistant Design
This publication is one of five state-of-the-practice engineering reports produced, to date, by the ASCE Petrochemical Energy Committee. These engineering reports are intended to be a summary of current engineering knowledge and design practice, and present guidelines for the design of petrochemical facilities. They represent a consensus opinion of task committee members active in their development. These five ASCE engineering reports are:

1) Design of Anchor Bolts in Petrochemical Facilities
2) Design of Blast Resistant Buildings in Petrochemical Facilities
3) Design of Secondary Containment in Petrochemical Facilities
4) Guidelines for Seismic Evaluation and Design of Petrochemical Facilities
5) Wind Loads for Petrochemical and Other Industrial Facilities

The ASCE Petrochemical Energy Committee was organized by A. K. Gupta in 1991 and initially chaired by Curley Turner. Under their leadership the five task committees were formed. More recently, the Committee has been chaired by Joseph A. Bohinsky and Frank J. Hsiu. The five reports were initially published in 1997.

Buildings codes and standards have changed significantly since the publication of these five reports, specifically in the calculation of wind and seismic loads and analysis procedures for anchorage design. Additionally, new research in these areas and in blast resistant design has provided opportunities for improvement of the recommended guidelines. The ASCE has determined the need to update four of the original reports and publish new editions, based on the latest research and for consistency with current building codes and standards.

The ASCE Petrochemical Energy Committee was reorganized by Magdy H. Hanna in 2005 and the following four task committees were formed to update their respective reports:

- Task Committee on Anchor Bolt Design for Petrochemical Facilities
- Task Committee on Blast Design for Petrochemical Facilities
- Task Committee on Seismic Evaluation and Design for Petrochemical Facilities
- Task Committee for Wind Load Design for Petrochemical Facilities

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This report was prepared to provide guidance in the blast resistant design of petrochemical facilities. Though the makeup of the committee and the writing of this document are directed at petrochemical facilities, these guidelines are applicable to similar design situations in other industries. Those interested in this report should include structural design engineers with dynamic design training and experience as well as operating company personnel responsible to establish internal design and construction practices. The task committee was established because of a significant interest in the petrochemical industry in dealing with costly process accidents, in interpreting government safety standards, and in the desire to protect employees. One purpose of this report is to help provide some uniformity to the current mix of internal and published criteria.

This report is intended to be a State-of-the-Practice set of guidelines. The recommendations provided are based on published information and actual design. The report includes a list of references to provide additional information. The reference list emphasizes an emphasis on readily available commercial publications and government reports. Because of their relevance to this report, several publications deserve mention here. Two widely used documents dealing generally with blast resistant design are UFC 3-340-02 (formerly TM5-1300), *Structures to Resist the Effects of Accidental Explosions* from the Department of Defense and PDC-TR 06-08, *Single Degree of Freedom Structural Response Limits for Antiterrorism Design*, from the US Army Corps of Engineers’ Protective Design Center.

In helping to create a consensus set of guidelines, a number of individual and groups provided valuable assistance and review. Reviewers included David Miller and Kieran Glynn. Assistance was also contributed by John Geigel, Anthony Emmons, and Sheng Wu.

Finally, the task committee would like to acknowledge the numerous contributions made to this task committee, the original report committee, and other technical committees over the years by James Lee. James passed away during the preparation of this report update.
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# Table of Contents

## Chapter 1: Introduction

1.1 Background ................................................................. 1  
1.2 Purpose and Scope ...................................................... 1  
1.3 Related Industry Guidelines, Specifications, & Codes .......... 3  
1.4 Blast Resistant Design Process ...................................... 3  

## Chapter 2: General Considerations ........................................ 6  

2.1 Introduction .................................................................. 6  
2.2 OSHA Requirements ................................................... 6  
2.3 Objectives of Blast Resistant Design .............................. 7  
2.4 Buildings Requiring Blast Resistant Design ..................... 7  
2.5 Siting Considerations .................................................. 8  
2.6 Offshore Facilities ........................................................ 9  
2.7 Non-Building Structures, Equipment, & Infrastructure ......... 9  

## Chapter 3: Determination of Loads ........................................ 12  

3.1 Introduction .................................................................. 12  
3.2 Types of Explosions ................................................... 12  
3.3 Blast Wave Parameters ............................................... 14  
3.4 Determination of Vapor Cloud Design Overpressures ......... 20  
3.5 Building Blast Loading ............................................... 24  
3.6 Computational Fluid Dynamics ..................................... 29  

### Appendix 3  Blast Load Example .................................. 31  

## Chapter 4: Types of Construction ....................................... 34  

4.1 Introduction .................................................................. 34  
4.2 General Considerations ............................................... 34  
4.3 Common Systems for Petrochemical Buildings ................. 35  
4.4 Blast Resistant Modular Steel-Framed Buildings ............... 39  
4.5 Other Systems ............................................................ 45
Chapter 5: Dynamic Material Strength and Response Criteria .................. 48

5.1 Introduction ................................................................................................. 48
5.2 Static Versus Dynamic Response ................................................................. 48
5.3 Resistance-Deflection Function .................................................................. 49
5.4 Material and Structural Element Types ....................................................... 50
5.5 Dynamic Material Properties ....................................................................... 54
5.6 Deformation Limits ...................................................................................... 61

Appendix 5.A Summary Tables for Dynamic Material Strength ...................... 67
Appendix 5.B Summary Tables for Response Criteria .............................................. 69

Chapter 6: Dynamic Analysis Methods ......................................................... 72

6.1 Introduction .................................................................................................. 72
6.2 Key Concepts ............................................................................................... 72
6.3 Equivalent Static Method ............................................................................ 76
6.4 Single Degree of Freedom Systems ............................................................. 76
6.5 Multi-Degree of Freedom Systems ............................................................... 90
6.6 Applications ............................................................................................... 93

Appendix 6 Numerical Integration Method ....................................................... 97

Chapter 7: Design Procedures ....................................................................... 100

7.1 Introduction .................................................................................................. 100
7.2 General Design Concepts ............................................................................ 100
7.3 Member Design Process ............................................................................. 104
7.4 Reinforced Concrete Design ....................................................................... 106
7.5 Steel Design ............................................................................................... 109
7.6 Reinforced Masonry Design ....................................................................... 113
7.7 Foundation Design ..................................................................................... 114
7.8 Design Against Projectiles ......................................................................... 118

Chapter 8: Typical Details ............................................................................ 120

8.1 Introduction .................................................................................................. 120
8.2 General Considerations ............................................................................. 120
8.3 Enhanced Pre-Engineered Metal Building Construction ......................... 120
8.4 Masonry Wall Construction ....................................................................... 120
8.5 Metal Clad Construction ............................................................................ 121
8.6 Precast Concrete Wall Construction ........................................................... 121
8.7 Cast-in-Place Concrete Wall Construction ................................................ 121

viii
Chapter 9: Ancillary and Architectural Considerations ........................................ 127

9.1 Introduction ................................................................................................... 127
9.2 General Considerations ................................................................................ 127
9.3 Doors ............................................................................................................. 127
9.4 Windows ....................................................................................................... 131
9.5 Utility Openings............................................................................................ 133
9.6 Interior Design Considerations .................................................................... 133
9.7 Exterior Considerations................................................................................ 134

Chapter 10: Evaluation and Upgrade of Existing Buildings .............................. 135

10.1 Introduction................................................................................................... 135
10.2 Evaluation Strategies .................................................................................... 135
10.3 Blast Resistant Upgrade Options ................................................................. 137
10.4 Upgrades for Structural Member Connections ........................................... 139
10.5 Upgrades for Structural Framing Members ................................................ 142
10.6 Upgrades for Metal Panel Wall and Roof Systems .................................... 144
10.7 Upgrades for Concrete Masonry (CMU) & Concrete Walls ...................... 146
10.8 Upgrade with Blast Resistant Shield Wall .................................................. 152
10.9 Upgrades for Roof Systems ........................................................................ 155
10.10 Wall and Roof Catch System Upgrades .................................................... 156
10.11 Blast Resistant Shell Upgrades ................................................................... 157
10.12 Window Upgrades........................................................................................ 159
10.13 Door Upgrades.............................................................................................. 161

Chapter 11: Shear Wall Building Design Example .............................................. 164

11.1 Introduction ................................................................................................... 164
11.2 Structural System .......................................................................................... 164
11.3 Design Data ................................................................................................... 166
11.4 Exterior Walls (out-of-plane loads) ............................................................... 167
11.5 Roof Slab (in-plane loads) ............................................................................ 174
11.6 Side Wall (in-plane loads) ........................................................................... 179
11.7 Roof Slab (out-of-plane loads) ..................................................................... 184
11.8 Roof Beams ................................................................................................... 191
11.9 Roof Beam Connection ................................................................................ 197
11.10 Roof Girders ................................................................................................. 199
11.11 Roof Girder Connection ............................................................................. 205
11.12 Columns ........................................................................................................ 207
11.13 Column Base Plate and Anchor Bolt Design .............................................. 213
11.14 Foundation ................................................................................................... 215
<table>
<thead>
<tr>
<th>Chapter 12: Metal Building Design Example</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1 Introduction</td>
<td>222</td>
</tr>
<tr>
<td>12.2 Structural System</td>
<td>222</td>
</tr>
<tr>
<td>12.3 Design Data</td>
<td>225</td>
</tr>
<tr>
<td>12.4 Roof Decking</td>
<td>226</td>
</tr>
<tr>
<td>12.5 Wall Panels</td>
<td>231</td>
</tr>
<tr>
<td>12.6 Roof Purlins</td>
<td>235</td>
</tr>
<tr>
<td>12.7 Wall Girts</td>
<td>244</td>
</tr>
<tr>
<td>12.8 Rigid Frames</td>
<td>248</td>
</tr>
<tr>
<td>12.9 Braced Frames</td>
<td>255</td>
</tr>
<tr>
<td>12.10 Foundation</td>
<td>259</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 13: Masonry Retrofit Design Example</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1 Introduction</td>
<td>263</td>
</tr>
<tr>
<td>13.2 Structural System</td>
<td>263</td>
</tr>
<tr>
<td>13.3 Design Data</td>
<td>264</td>
</tr>
<tr>
<td>13.4 Existing Wall Evaluation</td>
<td>265</td>
</tr>
<tr>
<td>13.5 Option #1: Reinforce Existing Wall</td>
<td>268</td>
</tr>
<tr>
<td>13.6 Option #2: New Reinforced Concrete Wall</td>
<td>271</td>
</tr>
<tr>
<td>13.7 Conclusion</td>
<td>274</td>
</tr>
</tbody>
</table>

Nomenclature...................................................................................................................276

Glossary............................................................................................................................283

References........................................................................................................................287

Index.................................................................................................................................297
CHAPTER 1
INTRODUCTION

The focus of this report is on structural aspects of designing or evaluating buildings for blast resistance. Generally this involves quantifying the blast overpressures that could result from accidental explosions, establishing the design blast loads from these overpressures, setting the structural performance requirements, and designing the building structure to withstand these loads within the required performance limits. For existing buildings a similar approach may be adopted. The performance of the structure is checked against structural performance limits.

Blast resistant design, or the structural strengthening of buildings, is one of the measures an owner may employ to minimize the risk to people and facilities from the hazards of accidental explosions in a plant. Other mitigative or preventive measures, including siting (adequate spacing from potential explosion hazards) and hazard reduction (inventory and process controls, occupancy limitations, etc.), are not covered in this report.

1.1 BACKGROUND

Process plants in the petrochemical industry handle hydrocarbons and other fuels that can and have produced accidental explosions. Plants are designed to minimize the occurrence of such incidents. Although such incidents may be relatively rare, when they do occur the consequences can be extremely severe involving personnel casualty and financial loss and potentially impacting public safety. In some instances the consequences have involved plant buildings. For example, the 1989 explosion in Pasadena, Texas, occurred during maintenance of a polyethylene unit and included the collapse of a control building. Losses included 23 fatalities and 120 injured. The 2005 explosion in Texas City, Texas, occurred during the restart of a isomerization unit and included the destruction of trailers used as temporary offices. Losses included 15 fatalities and 170 injured. Other recent petrochemical plant explosions have resulted in a significant number of fatalities from the severe damage or collapse of buildings. The concentration of such fatalities in buildings points to the need to design plant buildings to withstand explosion effects in order to protect the people inside so that, at least, the building does not pose an added hazard to the occupants. In addition to personnel safety, some companies in the industry also consider blast resistance for certain critical buildings such as control centers, even if unoccupied, to minimize the impact of accidental explosions on plant operation.

For buildings, usually the overpressure from the blast wave is the most damaging feature of an accidental explosion in a process plant. However, in addition to the air blast effects, such incidents can result in fires, projectiles and ground transmitted shocks that also can be damaging to buildings and their contents.

Historically, blast resistant design technology in the petrochemical industry has evolved from equivalent static loads and conventional static design methods (Bradford and Culbertson), to simplified dynamic design methods that take into
account dynamic characteristics and ductility of structural components, and based on TNT equivalent blast loading (Forbes 1982), and finally to more complex and rational methods involving vapor cloud explosion models to characterize the blast loading and nonlinear multi-degree of freedom dynamic models to analyze the building structure. Current practices within the industry appear to cover all these approaches. This report is intended to provide guidelines on the various methods available for the structural design of blast resistant buildings in petroleum and chemical process plants.

1.2 PURPOSE AND SCOPE

The purpose of this ASCE report is to provide a guide to design engineers and others in the petrochemical industry involved in the design of new blast resistant buildings and in evaluating existing buildings for blast resistance. It provides the basic considerations, principles, procedures and details involved in structural design and evaluation of buildings for blast overpressure effects.

This report focuses primarily on “how to” design or evaluate buildings for blast resistance once the blast loading is defined for a postulated explosion scenario. Chapter 2 discusses the basic philosophy and general considerations involved in establishing design requirements for blast resistance in buildings to resist the effects of accidental explosions in petrochemical processing plants. Chapter 3 describes the types of explosions that may occur and the general characteristics of the resulting blast load, but does not prescribe magnitudes for design. The chapter provides a brief review of the approaches used in the industry to quantify blast loads for design purposes and gives typical examples of such loads. In Chapter 4 the types of building construction appropriate for various levels of blast resistance are discussed. The dynamic ultimate strength design criteria, including the dynamic material properties and deformation limits applicable to blast resistant design are covered in Chapter 5.

The methods and procedures for blast resistant design can vary considerably in complexity, accuracy, cost and efficiency from simple conventional static design approach to complex transient nonlinear, multi-degree of freedom dynamic design methods. To assist engineers in striking a balance among these, Chapter 6 provides a discussion of the various blast resistant analysis methods, identifying the main features, advantages and disadvantages of each method. Chapter 7 outlines recommended procedures and provides aids for the design of the various components of reinforced concrete, reinforced masonry and structural steel buildings. Chapter 8 provides some typical structural details for doors and frames, wall penetrations, and connections for steel and reinforced concrete components. Blast protection considerations for non-structural items such as interior details, windows, openings, and HVAC ducts are covered in Chapter 9. Chapter 10 gives guidance on strategies for evaluating the blast resistance of existing buildings and provides practical measures for upgrading masonry and metal buildings, the most common types of building construction for plants in the petrochemical industry. Design examples are provided in Chapters 11 to 13 to illustrate the use of these procedures and tools in the design of typical buildings for blast resistance.
1.3 RELATED INDUSTRY GUIDELINES, SPECIFICATIONS, & CODES

Currently, there are no specific industry standards or guidelines for blast resistant design of process plant buildings. However, the design practices used by some operating companies and contractors are based on a number of existing documents dealing with this subject including:


b. *An Approach to the Categorization of Process Plant Hazard and Control Building Designs*, (CIA), Chemical Industries Association. (being revised)

c. *Design of Structures to Resist Nuclear Weapons Effects*, (ASCE Manual 42), American Society of Civil Engineers

d. *Structures to Resist the Effects of Accidental Explosions*, (UFC 3-340-02), Department of the Army, Navy, and Air Force. This manual was formerly designated as TM 5-1300.

The SG-22 and CIA documents are similar and cover the siting, design and construction of control buildings in petrochemical plants for a specified set of TNT equivalent blast loads and the simplified dynamic (elasto-plastic, single degree of freedom) design approach. The other documents cited above are more comprehensive but are generally geared to design for high-yield explosives for military and munitions applications. However, the fundamentals and design principles covered in these documents are applicable to designs for other types of explosions.

In addition to the publications cited above, the American Institute of Chemical Engineers, Center for Chemical Process Safety (CCPS) committee and the American Petroleum Institute (API) have addressed various aspects of blast protection technology relevant to this report. In particular, CCPS has developed *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs* (CCPS Explosion Guidelines), and *Guidelines for Evaluating Process Plant Buildings for External Explosions and Fire* (CCPS Building Guidelines). API published a recommended practice titled *Management of Hazards Associated With Location of Process Plant Buildings* (API RP 752).

1.4 BLAST RESISTANT DESIGN PROCESS

The overall process involved in the evaluation and design of petrochemical plant buildings for explosion hazards is illustrated in Figure 1.1. This flowchart shows fifteen basic steps in the overall blast evaluation and design process, as follows:

a. Define Scope: Steps 1 and 2 are to define the owner's requirements and needs for the building.
b. Analyze Explosion Hazards: Steps 3 and 4 are to identify the explosion scenarios to be used to quantify the design blast overpressures (refer to Section 5.6).

c. Determine Performance Criteria: Step 5 is to determine how the building should perform during the explosion scenario (refer to Chapter 3).

d. Determine Blast Loads: Step 7 is to determine the blast loadings for the various components of the building (refer to Chapter 3).

e. Select Structural System and Material and Response Criteria: Steps 6, 8, and 9 are to choose the structural materials and systems for the building and the associated structural properties and response limits consistent with the performance requirements for the building (refer to Chapters 4 and 5).

f. Perform Structural Analysis and Component Design: Steps 10 to 12 are to select and perform the level of structural calculations appropriate for the particular situation (refer to Chapters 6 and 7).

g. Finalize and Detail Design: Steps 13 to 15 are to proportion and detail building components and document design (refer to Chapters 8 and 9).

It is expected that the owner will provide or direct items a, b and c, (steps 1 to 5). CCPS Building Guidelines, CCPS Explosion Guidelines, and API RP 752 provide guidance on these steps. The design engineer's responsibilities fall in d to g (steps 6 to 15) of the process. These steps are the main focus of this ASCE report.
FIGURE 1.1: Petrochemical Buildings, Blast Resistant Design Process