# Blast Protection of Buildings

*Revisions to ASCE/SEI 59*

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The events of 9/11 changed many owners' perceptions of the risk to their facilities. Their fear of malicious threats thrust practicing structural engineers into an unfamiliar role. As a result, structural engineers needed to learn how to quantify and analyze for blast effects as they assisted their private clients with the evaluation of threats to their facilities and the means to provide prudent, reasonable, and effective resistance. In response, the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) developed a new standard, ASCE/SEI 59 *Blast Protection of Buildings* (ASCE 2011), describing how engineers could design blast resistance into structures.

The original edition of ASCE/SEI 59, released in 2011, was the first authoritative standard intended for use by engineers designing private sector facilities. It is a voluntary document that provides the minimum requirements for planning, design, construction, and assessment of new and existing buildings when subjected to the effects of accidental or intentional explosions. It is written in mandatory language to be referenced in contracts for engineering services or adopted by regulatory agencies. Publication of the first revision to this standard is expected in late 2022 or early 2023.

The committee that developed and revised ASCE/SEI 59 drew from authoritative references, some of which were developed for the defense of government facilities, to prepare a comprehensive document containing the essential relevant information. It defaults to a practical design approach suitable for the prudent and somewhat conservative design of most buildings with conventional, regular framing systems and typical occupancies. Beyond this default procedure, the standard also allows for alternatives running up to the most sophisticated analytical approaches to encourage economical and innovative designs. As with most standards developed by SEI, a Commentary section provides background information and suggested application approaches and includes references and interpretations explaining the Provisions.

*Table of levels of protection.*

| Level | Performance Goal |
|---|---|
| I (Very Low) | Collapse Prevention |
| II (Low) | Life Safety |
| III (Medium) | Property Preservation |
| IV (High) | Continuous Occupancy |

## Overview of Chapter Content

### Chapter 1

The first chapter describes the general provisions relevant to the standard, beginning with a statement of the scope of the standard. It states: "This voluntary standard provides minimum planning, design, construction, and assessment requirements for new and existing buildings subject to the effects of individual accidental or malicious explosions, including principles for establishing appropriate threat parameters, levels of protection, loadings, analysis methodologies, materials, detailing, and test procedures. However, this standard is not applicable for the mitigation of multiple explosions, intentional explosions such as weapons testing, or potential accidents involving ammunition or explosives during their development, manufacturing, testing, production, transportation, handling, storage, maintenance, modification, inspection, demilitarization, or disposal."

The first chapter also includes the definitions and symbols common to all sections. It concludes with the important issues of user qualifications, information sensitivity, and a section listing other standards and reference documents.

### Chapter 2

The second chapter, on design considerations, covers security evaluation, security planning, and risk assessment. The risk assessment includes an analysis of the threat, the vulnerabilities, and the consequences. Given that structural design is just one way to minimize the outcome of an explosion, this chapter advocates for considering threat reduction, vulnerability reduction, and consequence reduction as part of the process of improving protection. In any event, one must acknowledge that some risk must be accepted inherently since designers and owners usually do not have complete control over events that threaten buildings, particularly when malevolent intent is involved.

### Chapter 3

The third chapter deals with performance objectives, building classification, and levels of protection. Primary goals include limiting the potential for structural collapse, maintaining the building envelope to protect persons and other assets inside a building, and minimizing flying debris that could induce localized damage. Recognizing that different facilities require different performance levels, the standard defines four levels of protection with the performance goals listed in the *Table*. Response limits for flexural and compression elements are calibrated to these levels to guide the user when determining the acceptability of a design.

Since the very rapid strain rates normally induced by impulsive blast loads lead to yield stresses and failure stresses that often are higher than for static loads, the standard includes strength increase factors that can be considered when judging performance.

## *Chapter 4*

The fourth chapter provides loading functions. It draws on research performed for government facilities, providing simplified procedures for external and internal explosions.

The basic procedure for external blast requires converting the design-base assumption about the explosive material and weight to an equivalent quantity of trinitrotoluene (TNT). The standard states peak overpressures and impulses for the equivalent quantity of TNT, considering the distance from the blast to the structure. Overpressures and impulses for the design of blast-facing surfaces include reflection coefficients that are functions of the angle of incidence of the shock front. The shock front loading is then idealized as an instantaneously applied triangular pulse in which the peak reflected pressure at the start and the total impulse magnitude over the duration are the same as the actual loading. Next, the peak dynamic pressure and its clearing time are calculated, and the corresponding loading is idealized as a triangular loading function. Finally, the two are combined, creating a bilinear loading function. Alternatively, just the shock front loading may be used if it has a lesser impulse. Also, a negative loading phase may be included if it is critical.

In the basic procedure for an internal blast, the shock loading is calculated as for an external blast. Then, the peak gas overpressure is determined from the quantity of TNT simply and conservatively from the interior free volume and the vent area.

Since this approach for internal explosions can be very conservative, the standard allows for more sophisticated approaches using recognized literature.

These simplified approaches for external and internal explosions are often adequate for designing most structural forms subjected to explosions commonly assumed for protective design. However, the user is directed to other references that provide sophisticated methodologies for determining blast effects and structural performance for unusual circumstances. Of course, approaches that are more sophisticated than those provided as the default in ASCE/SEI 59 are allowed even for common scenarios, should the owner and the blast consultant wish to refine the design approach.

## *Chapter 5*

The provisions in the original edition of ASCE/SEI 59 contained limited information about the effects of bomb fragments (primary fragments) and site debris (secondary fragments) impact on structures. However, detailed information about these blast effects was published in the Commentary, recognizing that the most common blast design of commercial buildings does not consider fragmentation.

## *Chapter 6*

The sixth chapter describes methods and limitations for analyzing and designing structural elements and systems. It outlines analysis concepts, advanced analysis, blast design, modeling, materials, member and connection detailing, and touches on disproportionate collapse. Specified analysis methods include pressure-impulse charts (pre-determined, plotted element response as a function of peak pressure and impulse), lumped parameter models (single degree of freedom and multi-degree-of-freedom dynamic systems), and finite element dynamic models.

## *Chapter 7*

The seventh chapter provides guidance for isolating areas within a structure. The intent is to guide designs to protect occupants of a building from an interior blast in a specific location, such as a lobby, protect egress components, and design a safe haven where occupants can retreat within a building when a threat is made.

## *Chapter 8*

The eighth chapter describes processes for hardening the exterior envelope to protect the structure, occupants, and other assets. In addition to addressing exterior walls, this chapter provides guidance for the design and function of windows and exterior doors. This chapter addresses concrete, masonry, metal wall and window systems, and flat slab, metal deck, composite steel-concrete, and steel joist roof systems.

## *Chapter 9*

The ninth chapter specifies when to use and how to modify existing consensus materials standards for design, detailing, and construction to resist blast effects. When appropriate, the standard provides modifications for reinforced concrete and steel columns, beams, and floor and roof systems.

## *Chapter 10*

Design to resist explosions often requires novel structural systems and evaluation of distortions well into the inelastic range using sophisticated software. Sometimes performance of systems and components that resist blast effects is verified by testing. The tenth chapter provides guidance for validating the suitability of design tools and methodologies and structural constructions for blast resistance when conventional approaches for common environmental loads do not suffice.

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Often, and certainly for unusual and critical applications, designs should be reviewed by an independent team of registered design professionals. The tenth chapter discusses the need for peer reviews and outlines the qualifications of the reviewers.

## Specific Modifications

### *Definitions and Terms*

The committee that maintains ASCE/SEI 59 embarked on a review and revision cycle a few years ago. This review revealed that terms such as "element," "component," and "member" were not used consistently throughout the document. This could cause confusion when applying the provisions in the standard because it was not always clear to what portion of a structure some provisions applied. To add clarity, new definitions have been added for these terms and others, and text throughout has been updated to be consistent with the new definitions. For instance, the standard now defines these example terms as:

**Component**: Part of an architectural, mechanical, electrical, or structural system of a building.

**Element**: Assembly of structural components that act together in resisting forces, including gravity frames, moment-resisting frames, braced frames, shear walls, and diaphragms.

**Member**: Individual structural component that acts to resist forces, including columns, load-bearing walls, girders, beams, braces, struts, girts, purlins, joists, slabs, and decks.

### *Load Combinations*

The suitability of a design for blast resistance is verified by, among other means, comparing the blast-induced member forces to their remaining capacity after accounting for environmental loads acting simultaneously with a blast. In the original edition of ASCE/SEI 59, this available strength was evaluated using two formulas derived from the extraordinary events load combinations found in ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures* (ASCE 2005). One of those load combinations included point-in-time snow load and the other included point-in-time wind load. The load combination involving wind has been removed in the new edition of ASCE/SEI 59, following changes implemented in the 2016 edition of ASCE/SEI 7 (ASCE 2016).

### *Fragmentation*

Fragmentation is covered in much more detail in updated Chapter 5. While the original edition of ASCE/SEI 59 relegated analyses and design requirements to the Commentary, the new edition brings a simplified procedure for secondary fragments into the Provisions. Now the standard advocates for anchoring bulky site features against blast effects or, absent that, analyzing the impulse that propels unanchored features and the corresponding velocity. Chapter 5 now also contains simplified procedures to evaluate the potential for scabbing of concrete and masonry walls subjected to secondary fragment impact.

### *Foundations*

In the section of Chapter 6 dealing with the modeling of members, the revised standard acknowledges that foundation members are permitted to settle and move laterally in response to blast effects. However, despite that, the foundations must be designed to the same performance criteria as the walls they support, and the structure above must remain stable should foundations move.

### *Roof Structures*

Chapter 6 also clarifies that roof structures that act as diaphragms and contribute to the structure's overall stability must be treated as part of the lateral load resisting system.

### *Glazing*

In the original edition of ASCE/SEI 59, glazing could be designed using static procedures for medium and lower levels of protection. In the revised edition, the section of Chapter 8 dealing with blast-mitigating window systems allows static procedures to determine the capacity of glazing but requires dynamic analyses or full-scale dynamic testing to demonstrate that window systems meet the expectations of the required level of protection.

Connections and anchorages for window systems are required to have ultimate strength that equals at least 150% of frame and mullion strengths. However, in the revised edition, energy dissipating systems, such as energy-absorbing anchors, are allowed to reduce blast forces on surrounding walls. The performance of those energy-dissipating systems must be demonstrated through explosive or shock tube testing or detailed analytical models that have been validated with test data.

### *Oversized and Rollup Doors*

The standard's original edition required oversized and metal rollup doors to meet the same performance criteria as common doors. In the revised standard, oversize and rollup doors that do not meet performance criteria for common doors may be used if they are augmented with a debris-mitigating catch system.

### *PT Panels*

Chapter 8 of the original edition required pretensioned and post-tensioned concrete panels to have straight tendons for resistance in both directions to account for rebound. This requirement is removed in the revised edition, provided the reinforcing steel needed for blast resistance is mild steel.

### Materials Detailing

The Provisions and the Commentary of Chapter 9, dealing with materials detailing, are substantially revised in the updated edition of ASCE/SEI 59. A few examples of the changes are summarized below.

The original version of Chapter 9 prohibited the use of lightweight concrete in blast-resistant structures unless tests or rational analyses demonstrated that the lightweight concrete could satisfy the performance criteria of the standard. In the revised edition, lightweight concrete is permitted without restriction beyond limiting its maximum strength to 5,000 psi and requiring that design for blast resistance not violate conventional requirements for lightweight concrete.

### Concrete Slabs and Walls

The requirements for concrete slabs and walls are updated in the revised standard. For instance, reinforcing steel splices in slabs are required to be near supports and may be class B tension splices, mechanical splices, or welded connections. In addition, minimum reinforcing steel ratios are eliminated for concrete walls.

Structural steel used in blast-resistant design is limited in strength to 50 ksi in the revised standard. Plates 2 inches thick in built-up members must meet prescribed Charpy V-notch requirements. In the revised standard, structural steel connections must have ductile failure modes or be designed for 130% of the forces associated with the ultimate flexural capacity of the supported members unless they are designed based on the results of nonlinear dynamic analyses. In that case, connections must be designed for 150% of the calculated forces.

### Welded Connections

The requirements for welded connections in structural steel have been updated substantially. Now there are new requirements for weld configuration and filler metal. Testing and inspection requirements are expanded. The standard now advocates for short-slotted holes oriented perpendicular to the direction of service force in shear connections where possible.

### Open Web Joists

A new section is added in Chapter 9 to cover the requirements for open web joists. Among other provisions, the revised standard requires the bottom chord of open web joists subjected to downward loads to yield before failure of the top chord and webs while considering that the blast load is applied as a transverse load along the top chord. In addition, joist seats and their connections must be designed for the flexural strength of the joist. Alternatively, joists can be designed for 150% of the calculated loads when performance remains elastic.

### Composite Steel and Concrete Columns

New sections are added for composite steel and concrete columns (steel tubes filled with concrete) and steel plate composite walls (concrete cores with steel faceplates).

### Fiber-Reinforced Polymer Composite Sections

The fiber-reinforced polymer composite section is updated substantially. Limitations are added for the static strength of resin and its adhesion to the substrate, imposing pull-off failures to be controlled by the strength of the substrate.

## Summary

The revision of ASCE/SEI 59 represents a modest update of this critical standard. The committee's goal was to add clarity and expand guidance when appropriate, based on feedback and experience gained through the use of the original edition. Given that this article has been prepared while the process to revise this standard is nearing completion, its contents are still subject to change up to final printing. Please visit ASCE's website (**www.asce.org**) for information about the status of the standard and to purchase the latest edition once it is complete.▪

References are included in the PDF version of the online article at **STRUCTUREmag.org**.

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## References


ASCE 2005, *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-05, American Society of Civil Engineers, Reston, VA.

ASCE 2011, *Blast Protection of Buildings*, ASCE/SEI 59-11, American Society of Civil Engineers, Reston, VA.

ASCE 2016, *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-16, American Society of Civil Engineers, Reston, VA.