Blast Protection of Buildings

Introducing the New SEI Standard

By Jon A. Schmidt, P.E., SECB, BSCP

The events of September 11, 2001 had a profound impact on the building design community. Although the weapons employed that day were fueled commercial aircraft, the industry turned considerable attention to the most common tactic historically employed in terrorist attacks around the world: the improvised explosive device (IED). While information for addressing this threat existed, it was largely confined to military and other government publications that were neither readily available nor directly applicable to facilities constructed by the private sector.

Recognizing this, in 2002 SEI accelerated an effort that was already underway to develop a new ANSI-accredited standard for the planning, design, construction and assessment of new and existing buildings subject to the effects of accidental or malicious explosions. Chaired by Don Dusenberry of Simpson, Gumpertz & Heger in Waltham, MA, the responsible committee organized itself into six task committees to develop the mandatory provisions and accompanying commentary:

- General Provisions, chaired by Jon Schmidt of Burns & McDonnell in Kansas City, MO.
- Fuels and Loadings, chaired by Paul Mlakar of the US Army Corps of Engineers in Vicksburg, MS.
- Structural Systems, chaired by Bob Smilowitz of Weidlinger Associates in New York, NY.
- Building Envelope and Glazing, chaired by Lorraine Lin of the University of California in Berkeley, CA.
- Materials Detailing, chaired by Gene Corley of CTLGroup in Skokie, IL.
- Appurtenant Systems and Performance Verification, chaired by Andrew Whittaker of the University of Buffalo in Buffalo, NY.

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The resulting document, *Standard for Blast Protection of Buildings*, has been through its first ballot cycle, and the committee hopes to be ready to publish it sometime in 2009.

General Provisions

Chapter 1 of the new Standard, "General," addresses the scope of the document, appropriate qualifications for its users, and the definitions, symbols and notation that are common to all sections. Facilities intended to accommodate the development, manufacturing, testing, production, transportation, handling, storage, maintenance, modification, inspection, demilitarization, or disposal of ammunition or explosives are specifically excluded. The Standard is intended to be implemented only by licensed design professionals who are knowledgeable in the principles of structural dynamics and experienced with their proper application in predicting the response of elements and systems to the types of loadings that result from an explosion.

Chapter 2, "Design Considerations," outlines the minimum requirements for a valid risk assessment when project criteria are not established by applicable law, owner policy, recognized industry standards or other prescriptive means. There are typically four parts:

- Consequence analysis, addressing the potential impacts of an explosion within or near the building.
- Threat analysis, addressing the potential causes of an exposion within or near the building and their relative likelihood.
- Vulnerability analysis, addressing structural and non-structural elements whose failure in a blast event would result in the loss or compromise of people or assets associated with the building.
- Risk analysis, combining the results of the other three steps to determine and rank the relative risk associated with each combination of asset, threat, and building element.

The Standard provides some suggestions for non-structural risk reduction measures and notes that it is not possible to eliminate all risk associated with an explosion. The building owner must always establish the level of risk that is acceptable, based on a specific set of threats for which the building must be designed, the available budget for construction or renovation, or a combination of these.

Chapter 3, "Performance Criteria," states that the primary purpose of blast-resistant design is to reduce, to a defined extent, the risk to building occupants of injury or fatality and to building contents of damage or destruction in the event of an explosion of a specified magnitude and location. This leads to three objectives:

- Limit structural collapse.
- Maintain the integrity of the building envelope.
- Minimize the potential for flying debris.

The Standard describes levels of protection (LOP) that must be defined for the building as a whole or each portion thereof and for each specific component, taking into account use and occupancy considerations, consistent with the following performance goals:

- LOP I (Very Low) - Collapse prevention.
- LOP II (Low) - Life safety.
- LOP III (Medium) - Property preservation.
- LOP IV (High) - Continuous occupancy.

Each LOP is associated with qualitative descriptions of damage to the structure as a whole, individual elements, glazing systems, and doors. The Standard then provides some information specific to the dynamic analysis of elements using models with a single degree of freedom (SDOF), which is the most common simplified approach for determining blast effects on structures. There are limits on the permissible deflection of an element in the form of a maximum ductility ratio and/or maximum support rotation that are based on the element type and material. The Standard also provides for the modification of element strength to reflect actual vs. specified values, strain rate effects, and the presence of loads other than blast.

Blast Characterization

Chapter 4, "Blast Loads," provides basic procedures for calculating design loads on directly and indirectly loaded surfaces due to an explosion using relevant factors such as the type and quantity of explosive, its distance from a responding element, and the angle of incidence of the shock wave. Basic procedures are outlined for external and internal explosions that satisfy certain simplifying assumptions. Extensive charts and tables are provided for determining various parameters; although, in many cases, the same information can be obtained using readily available computer software. More sophisticated approaches are permitted for all structures and required for irregular structures.

Chapter 5, "Fragmentation," describes design considerations and analytical procedures for taking into account the effects of fragments, whether from the explosive casing (primary) or damaged elements (secondary). Although this phenomenon is usually neglected, risk assessment may indicate that it should be included in certain situations. Most of the detailed technical information is provided in the commentary, rather than in the mandatory portion of the Standard, which simply lays out a few basic requirements.

Modeling and Analysis

Chapter 6, "Structural Systems," describes several different approaches to evaluating elements that are subject to blast effects, in order of increasing complexity:

- Pressure-impulse charts.
- Single element response analysis using single- or multi-degree-of-freedom inelastic dynamic methods.
- Structural system multi-degree-of-freedom finite element analysis.
- Nonlinear finite element analysis.

The Standard goes on to discuss material-specific considerations for the flexural, shear, and axial response of steel, concrete, and masonry elements to blast loading. Although flexural behavior is usually the focus, it is critical that elements also be checked for other potential modes of failure, especially those that may be brittle. Stability is also addressed, including a brief discussion of progressive collapse, although that phenomenon is not a major component of the Standard's scope. Detailed guidance is provided for the application of loads, including spatial and temporal distribution and element-to-element transfer, as well as the design of several common structural systems:

- Steel moment frames.
- Steel braced frames.
- Concrete moment frames.
- Concrete frames with concrete shear walls.
- Precast or tilt-up concrete wall panels.
- Reinforced masonry bearing and shear walls.

Chapter 7, "Protection of Spaces," applies to areas within a building that need extra resistance to blast effects. For facilities with controlled access, it suggests hardening measures for walls and slabs intended to isolate internal threats, which may be required for locations such as loading docks, mailrooms, designated screening rooms, stairwells, and plenums. The Standard also includes provisions for locating and designing safe havens when they are desired by the building owner or required by the authority having jurisdiction. Such spaces must generally provide a high level of protection (LOP IV) and explicit resistance to progressive collapse.

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Chapter 8, "Exterior Envelope," contains provisions for the first line of defense against an external explosion. Two design approaches are acceptable:

- Resistance-based, in which non-structural components must fully resist blast loads.
- Hazard-based, in which large portions may require replacement after an explosion, but failure is expected to occur in a manner that reduces the risk of injury to building occupants.

Hazard-based design also requires balanced design, which means that connections and supporting elements can carry the full capacity of the directly loaded elements, so that the latter serve as the "weak link". Glazing is treated in significant detail, because it behaves very differently from other materials in response to blast loads. The Standard also offers specific guidance for exterior wall and roof systems of various materials and a range of retrofit options for existing buildings:

- Security window films.
- Blast curtains.
- Catch bar systems.
- Secondary window systems.
- Geotextile fabrics.
- Fiber-reinforced polymers (FRP).
- Secondary wall systems.

Other Considerations

Chapter 9, "Materials Detailing," outlines the features that elements must have in order to meet the levels of protection specified in Chapter 3 and satisfy the assumptions underlying the analysis methods described in Chapter 6. The provisions are based on existing guidance for improving resistance to both explosions and earthquakes, and are intended primarily to ensure ductility. This ductility, combined with strength, provides toughness, which is a critical structural attribute for withstanding blast effects. Several different types of construction are included:

- Concrete – general detailing requirements, columns, beams, beam-column joints, slabs, walls, and tension ties.
- Steel – materials, welds, bolts, connections, and slenderness limits.
- Concrete slab on metal deck - fasteners, thickness, reinforcement, and shear studs.
- Masonry – general design and detailing requirements, materials, vertical and horizontal wall reinforcement, and control joints.
- Fiber-reinforced polymer – delamination due to stress wave propagation, strengthened reinforced concrete beams and slabs, strengthened masonry walls, concrete column confinement, and solid sections.

Finally, Chapter 10, "Performance Qualification," indicates procedures that can be followed to demonstrate compliance with the Standard as a whole, such as peer review of calculations and drawings and full-scale testing or analysis and design of components:

- Site perimeter components, such as barriers, anti-ram devices, or street furniture.
- Building structural and non-structural components.
- Shielding structures, such as blast walls.
- Building facade components, such as glazing systems and doors.

Conclusion

In the wake of September 11, 2001, structural engineers concerned about the potential effects of accidental or malicious explosions on their projects had little guidance on what to do to protect these facilities. In the near future, SEI will provide detailed recommendations for assessing the blast resistance of buildings in a document that will be accessible to all practitioners.▪

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