INTRODUCTION

The events of September 11, 2001, had a profound impact on the building design community. Although the weapons employed that day were fully 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. 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 began the process of establishing a new Codes & Standards Committee on Blast Protection of Buildings. Chaired by Donald O. Dusenberry, P.E., M.ASCE, of Simpson, Gumpertz & Heger in Waltham, MA, the committee set out 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 intentional explosions. Six task committees have been developing the mandatory provisions and accompanying commentary:

- General Provisions
- Fuels and Loadings
- Structural Systems
- Building Envelope and Glazing
- Materials Detailing
- Appurtenant Systems and Performance Verification

The resulting document is now in the midst of the balloting process, and the committee hopes to publish it sometime in 2009. The purpose of this paper is to summarize the structure and content of the first four chapters of the Standard, which are the responsibility of the first two task committees listed above and address the following subjects:

- General
- Design Considerations
- Performance Criteria
- Blast Loads

GENERAL

The first chapter of the Standard summarizes the scope of the document as a whole, noting that it includes principles for establishing appropriate threat parameters, levels of protection, loadings, analysis methodologies, materials, detailing, and test procedures. It then provides a comprehensive list of definitions for all terms, symbols, and notation used throughout the entire Standard. This ensures consistency between sections prepared by different task committees.

This chapter goes on to stipulate the qualifications that the committee believes are necessary for proper implementation of the Standard. Users should be licensed design professionals who are knowledgeable in the principles of structural dynamics and experienced with their proper application in predicting the
response of components and systems to the types of loading that result from an explosion. Finally, this chapter notes that, because it addresses vulnerabilities and risks, information generated by the use of the Standard for a specific building should be appropriately protected from disclosure to potential aggressors.

DESIGN CONSIDERATIONS

The second chapter of the Standard provides guidance for building owners and their consultants to determine appropriate principles and design criteria for the mitigation of blast effects. In some cases, these are established by applicable law, owner policy, recognized industry standards, or other prescriptive means. When this is not the case, it is necessary to conduct a rational assessment of the risk of a nearby explosion, whether accidental or malicious. Qualified professionals in the fields of process safety and/or physical security should be involved, as applicable, and the objective is the identification and prioritization of mitigation options.

The Standard does not stipulate a particular size of explosive for any given situation. Instead, it discusses some of the considerations that should be taken into account when selecting a design basis threat. The Standard also does not prescribe a specific risk assessment methodology; rather, it provides basic principles and a framework for such a process.

A valid risk assessment typically consists of four parts:

- Consequence analysis, addressing the potential impacts of an explosion within or near the building, given the missions of the owner and tenants and the specific people and assets associated with the building that support these missions.
- Threat analysis, addressing the potential causes of an explosion 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.

Reduction of consequences, threat, or vulnerability will also reduce a building’s overall risk due to blast loads. This chapter goes on to suggest mitigation measures other than structural design, including asset redundancy; site selection; contingency planning; remote storage of hazardous materials; policies and procedures for safe handling of hazardous materials; standoff distance enforced by appropriate perimeter barriers; access control and searches of vehicles and people approaching the building; visible security measures intended to deter an aggressor; and enclosure of columns in public areas.

Finally, this chapter notes that it is not possible to eliminate all risk associated with an accidental or intentional 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.

PERFORMANCE CRITERIA

The third chapter of the Standard states that the primary purpose of blast-resistant design is to reduce, to a defined extent, the risk to building occupants of injury and fatality and to building contents of damage and destruction in the event of an explosion of a specified magnitude and location. This leads to the following three objectives:

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

This chapter then 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 level of protection is associated with qualitative descriptions of damage to the structure as a whole, primary structural elements, secondary structural and non-structural elements, glazing systems, and doors. These are drawn largely from Department of Defense antiterrorism requirements, as well as industry standards.

Next, this chapter provides some information specific to the analysis of individual elements using dynamic system models with a single degree of freedom (SDOF), which is the most common simplified approach for determining blast effects on structures. There are tabulated limits on the flexural or axial response 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. These are derived from a combination of more sophisticated analyses and actual blast testing and reflect the best information currently available, as collected and disseminated by the U.S. Army Corps of Engineers Protective Design Center. Elements must also be checked to ensure that they are adequate for other failure modes, including flexural and direct shear, as well as load reversal and rebound.

This chapter concludes by discussing how to determine the effective strength of an element for blast analysis. There are factors for increasing the specified minimum properties, depending on the material and failure mode, to account for the average actual values, as well as the high strain rates associated with short-duration blast loadings. Consistent with current industry practice, it is permissible to use a strength reduction factor equal to 1.0. Finally, extreme event load combinations from the commentary of SEI/ASCE 7 indicate how to account for effects other than blast.

BLAST LOADS

The fourth chapter of the Standard provides the minimum blast design loads once the risk to a facility has been assessed. It describes the key blast load parameters and prediction methods. This chapter further discusses the estimation of the structural loading from these parameters.

A blast is a sudden release of energy that creates a propagating pressure wave, which in turn produces a load on the structures that it encounters. There are a variety of sources for a blast. High explosives are engineered materials that detonate and produce supersonic reaction fronts with a high energy density. Low explosives deflagrate and generate a more slowly propagating blast with a lower energy density. Some key parameters of a blast wave are shown in Figure 1.
The Standard draws on the results of decades of military research to estimate these blast parameters. The important independent variables include the energy density of the explosive material, its total quantity, and the intervening distance to the structure, \( R \). Figure 2 presents the key parameters as a function of \( R \) and the mass of an equivalent quantity, \( W \), of a standard high explosive, trinitrotoluene or TNT.

The Standard presents a basic procedure for commonly encountered structures loaded by external blast. This procedure provides approximate bilinear functions for the positive and negative phase pressures on directly-loaded surfaces. Both normal and oblique reflections are considered as shown in Figures 3 and 4, respectively.
Figure 2: Positive Phase Shock Wave Parameters for a Hemispherical TNT Explosion on the Surface at Sea Level [TM 5-1300].
A basic procedure for simple structures loaded by internal blast is also included. As illustrated in Figure 5, the peak gas pressure, $P_g$, is estimated from the loading density, $W/V_f$, in which $V_f$ is the internal free volume of the structure. $P_g$ is then applied statically, and conservatively, to the interior surfaces of interest.

The commentary for this chapter discusses the factors that can complicate the minimal situation. These factors include the effect of other structures and terrain between the source of the blast and the loaded structure. Depending on the particular situation, these can either mitigate or amplify the loading.
The commentary further explains appropriate techniques to employ when the limitations of the Standard are exceeded. These include a number of validated engineering algorithms for special situations, such as ray-tracing codes for internal explosions. The use of scaled physical models and first-principle continuum physics codes on high-performance computers is also discussed.

**CONCLUSION**

The first four chapters of the new Standard for Blast Protection of Buildings provide design professionals with the information that they need to carry out the analysis and design of blast-resistant structures and components in accordance with subsequent chapters. Risk assessment provides a rational basis for establishing a design basis threat and the associated blast loading, as well as an appropriate level of protection and the associated performance requirements.

**REFERENCE**