Chapter C1
GENERAL

C1.1 SCOPE

Considerations for various structural and nonstructural measures to mitigate blast effects are included in this Standard. However, this Standard does not prescribe which buildings should be subject to its provisions, nor the size of explosive or specific performance criteria for a given situation. These decisions are intended to be the responsibility of the building owner, manager, or tenant, informed by consultation with a qualified user as defined in Section 1.4.

Certain U.S. Department of Defense (DoD) facilities are required to comply with the uniform explosives safety regulations specified in DoD 6055.09-STD (DoD 2009), and other facilities where ammunition or explosives are routinely present should conform to these or comparable requirements. Design of protective structures in such cases should be in accordance with UFC 3-340-02 (DoD 2008), rather than this Standard.

The scope of this Standard is generally limited to the evaluation of blast effects on structural and nonstructural elements and systems and does not include the evaluation of the subsequent behavior of a damaged structure, such as the potential for progressive collapse.

C1.4 QUALIFICATIONS

The statutes and administrative laws governing the practice of engineering in most United States jurisdictions include consultation, investigation, and evaluation—not just planning and design—within the scope of regulated activity for which licensure is legally mandated. Individual building owners, such as federal agencies, may establish their own minimum qualifications for individuals who perform blast effects analysis of their facilities.

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Chapter C2
DESIGN CONSIDERATIONS

C2.1 SCOPE

This chapter is intended to be a guideline that private-sector owners and their consultants can use to establish an appropriate scope of work for projects in this area. This chapter covers general conceptual issues, while subsequent chapters address specific design considerations. This chapter does not stipulate a particular size of explosive, but presents guidance on how to go about selecting one for a given situation. Also, this chapter does not specify a particular risk assessment methodology; rather, it provides basic principles and a framework for such a process.

C2.2 RISK ASSESSMENT

There are two approaches for establishing the appropriate structural design criteria for mitigating blast effects on a particular building. In some cases, requirements such as the size and location of the explosive and the acceptable response of building elements are prescribed by an Authority Having Jurisdiction. However, it is more prevalent for these parameters to be established on the basis of an assessment of the risk associated with a nearby explosion. This risk is traditionally defined as the combination (product) of three components: consequence, threat, and vulnerability.

There are many valid risk assessment methodologies in widespread use for various types of buildings and infrastructure. Examples include API RP 752 (API 2003) for accidental threats, and FEMA 452 (FEMA 2005) and UFC 4-020-01 (DoD 2007b) for malicious threats.

Risk changes over time. Consequently, a revised risk assessment is recommended at periodic intervals—for example, every 5 years—as well as under any of the following circumstances:

- A change of the mission and/or assets housed in the building
- A change in the building's threat environment
- Significant physical modification of the building itself
- Construction of a neighboring facility.

C2.2.1 Consequence Analysis. Relevant background information about the facility will include the number and type of tenants; the number of employees and visitors; the mission of each tenant; the area, by location and size, occupied by each tenant; and a physical description of the construction elements of the facility.

Except for certain critical facilities, the objective of design is to protect the occupants and contents of the building, not the structure itself. Consequence analysis is therefore directed at the assets—people, property, and information—that are housed in the building and the impact of their loss or compromise on the mission of the owner or users. These assets must be identified and then assigned a weight on the basis of such factors as criticality, replacement time, replacement cost, and quantity.

Building codes typically differentiate between "ordinary" occupancies and those that warrant greater protection from environmental effects. Examples of such structures include:

- Facilities where a large number of people congregate in one area
- Schools and daycare facilities where a large number of children are present
- Colleges and other education facilities where a large number of adult students are present
- Hospitals and other health care facilities
- Power generating stations and other public utility facilities
- Facilities that manufacture, process, handle, store, use, or dispose of significant quantities of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives
- Fire, rescue, ambulance, and police stations and emergency vehicle garages
- Designated earthquake, hurricane, or other emergency shelters
- Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response
- Aviation control towers, air traffic control centers, and emergency aircraft hangars
- Water storage facilities and pump structures required to maintain water pressure for fire suppression
- Buildings and other structures having critical corporate, government, or national defense functions.

The same is true when designing for an explosion. Buildings that are occupied by a relatively large number of people or have occupants concentrated within a relatively small area have higher consequences of damage and failure than less populated or less densely populated structures such as industrial, maintenance, and storage facilities.

C2.2.2 Threat Analysis. Explosive threats to be used for blast-resistant design are typically classified as either accidental or intentional. Accidental threats are usually associated with explosive materials that are stored and handled at or near the facility. Intentional threats are military or improvised devices, which may be located inside a moving or parked vehicle, a suitcase or briefcase, or other place of concealment and delivery.

An increasingly common strategy in blast-resistant design is to specify at least two different design basis threats: a relatively small explosive against which the building must provide a relatively high level of protection, and a larger explosive against which it is acceptable for the building to provide a lower level of protection. This is analogous to performance-based seismic design, which typically aims for immediate occupancy in a mild earthquake and life safety in an extreme earthquake. This approach provides the building owner with a better understanding and expectation of performance in response to an inherently low-probability, high-consequence event.

C2.2.2.2 Malicious Threats. Security threats are acts or conditions that may result in loss of life; damage, loss, or destruction of property; or disruption of mission. Physical security personnel and design teams must understand the threat to the facilities that they are tasked to protect in order to develop effective security programs or designs, security systems, and/or structural upgrades. Historical patterns and trends in threat activity indicate general categories of threats and the common tactics that are used against facilities. Threat tactics and their associated tools, weapons, and explosives are the basis for the threat to facilities.

Criminal activities in the area may increase the likelihood of some threats. An identification of possible threats in the area should be obtained from federal, state, or local law enforcement officials. Within the United States and its territories, the Federal Bureau of Investigation (FBI) has primary responsibility for both foreign and domestic terrorists. The FBI and state and local law enforcement agencies are good sources from which to obtain criminal threat information. The possible threats, along with their preferred method(s) of attack, should be available from these agencies.

The threat must be described in specific terms to help determine the facilities' vulnerabilities or to establish protective measures. This description should include the tactics that aggressors will use to compromise the facility, as well as any weapons, tools, or explosives that are likely to be used in an attempt. For example, the threat might be described as a moving vehicle bomb consisting of a 4,000-lb (1,800-kg) vehicle containing a 500-lb (225-kg) explosive traveling at 30 mph (13 m/s).

The likelihood of the threat is analyzed for each applicable threat category by considering, in turn, five factors: the existence of an aggressor; the capabilities of the aggressor; the history of attacks by similar aggressors against similar assets; the intentions of the aggressor; and any intelligence indicating that the aggressor is actively targeting this facility (FEMA 2005). Threat likelihood is often correlated with threat magnitude based on the principles of risk acceptance; if the likelihood of an attack is low, the building can be designed for a less severe threat under the assumption that the aggressor will expend less effort and fewer resources on targets that are less attractive (DoD 2007b). However, unlike natural hazards, it is not feasible to develop a truly probabilistic approach to establishing design loads for intentional threats because the initiator is not a physical process, but, rather, an intelligent adversary.

C2.2.3 Vulnerability Analysis. Vulnerabilities are weaknesses in the facility's protective systems. They are identified by considering the tactics associated with the identified threat and the levels of protection directed against those tactics. Some vulnerabilities can be identified by considering the general design strategies for each adversarial tactic (DoD 2007b). The general design strategies identify the basic approach to protecting assets against specific tactics. For example, the general design strategy for a moving vehicle bomb is to keep the vehicle as far from the facility as possible and to harden the facility to resist the explosive at that distance. Examples of potential vulnerabilities include limited standoff distances, inadequate barriers, and building construction that cannot resist explosive effects at the achievable standoff distance.

C2.2.4 Risk Analysis. The prioritization of protection should be based on both the results of the risk assessment (Section 2.2) and the building owner's risk acceptance decisions (Section 2.4).

C2.3 RISK REDUCTION

Structural hardening to reduce vulnerability is often not the most cost-effective approach for protecting a building from blast effects. A variety of physical and operational measures should also be considered (API 2003; FEMA 2003a).

C2.3.1 Consequence Reduction. Asset redundancy reduces the impact should one of them be lost or compromised. Asset dispersal reduces the impact of an explosion near one of them.

Site selection is a key early step in the design process for a new facility. The effects of an accidental explosion can be mitigated simply by locating the building as far as possible from all possible sources of such an event. Similarly, consideration should be given when siting a new structure to the possibility of a bomb attack against a nearby target. Choosing an isolated location will minimize the potential for collateral damage.

It is possible to reduce the impact of an explosion by having policies and procedures in place for maintaining operations in the event of localized damage or shifting functions elsewhere if the building as a whole is affected. The facility should be equipped with a mass notification system to ensure that occupants can be advised of threats and given instructions about where to go and what to do (DoD 2007a).

C2.3.1.1 Nonstructural Components and Systems. Essential systems typically include emergency power or lighting and all utilities serving safe havens. It is unlikely that standard components will be able to withstand direct blast pressures. Careful positioning within the structure can reduce the loads, generally resulting in the most cost-effective solution. Special care must be taken to ensure that services required for continued operation of essential components and systems, such as power and water, are also designed to remain in operation, or that redundant systems are provided.

Design of nonessential components and systems is often addressed by specifying equivalent seismic loads. Great care must be taken with this approach, as the seismic loads specified often exempt many of the nonstructural items. It is preferable to specify the actual loads to be resisted, often as a multiple of gravity (DoD 2007a), or to specify a particular seismic design category that will result in loads of the desired magnitude. This is often not the code-mandated seismic design category for the project location. There are industry-specific guidelines for seismic design that can also provide a convenient method for specifying the design loads (SMACNA 1998).

The performance of essential nonstructural components and systems must be qualified by either full-scale testing or the use of data acquired from other sources. If the operational portions of the equipment or components are not directly exposed to blast loads, either because of their location within the building or by encasement in properly designed enclosures, then they need be qualified only for blast-induced ground or in-structure shock or the specified lateral and/or vertical loads. Nonessential components and systems may be qualified by either full-scale testing, experimental data, or analysis to ensure position retention. Qualification for a specific installation should include evaluation of anchorage and the support structure.

C2.3.2 Threat Reduction

C2.3.2.1 Accidental Threats. Accidental explosions typically occur when materials stored in or near a facility are inadvertently detonated or deflagrated. Items in these categories could include paints and paint thinners, gasoline, propane and similar gases, liquid natural gas (LNG), certain kinds of dust, fireworks, explosive charges and igniters, and cleaning solvents. Whenever possible, these items should be secured and stored in a separate building away from the main facility. If they have to be stored inside of the facility, the room storing these items should be designed to withstand the associated explosive force or vent it to the exterior to mitigate the risk of harm to the facility (NFPA 2007). Tenants should also develop and enforce appropriate policies and procedures for safe handling of hazardous materials (NFPA 2008).

C2.3.2.2 Malicious Threats. Malicious explosions are, by definition, the result of deliberate actions by intelligent human aggressors. In addition to standoff, discussed below, effective means of reducing the threat of such an attack include physical and operational security.

One approach to physical security involves creating a layered defensive system to deter hostile acts and prevent or delay access to a building. Such a system can include as many as five tiers: guarded perimeter, standoff zone, building exterior, interior access control, and safe havens. The complete system must be three-dimensional in construction and address the space above, below, and around the building to be protected.

Physical security is most effectively achieved when the asset being protected is in the center of the defensive system, with the five tiers representing concentric layers of detection, delay, and response. Detection elements are capable of sensing the presence of unauthorized individuals or explosives and alerting security personnel accordingly. Delay elements are physical boundaries such as fences, gates, walls, doors, roofs, ceilings, etc. that take time for an aggressor to penetrate. Response elements are typically guard forces charged with intercepting aggressors after they have been detected, but before an attack can be carried out.

Detection elements should be installed adjacent to barriers to increase the probability of sensing an intruder. Detection elements should be mutually supportive and within the coverage of cameras, protective lighting, or other alarm assessment devices to facilitate response.

Visible security measures may serve as a deterrent to an attack since they make obvious the difficulty of carrying one out successfully. Vehicle searches at the site perimeter and personal searches at the building entrance limit the size of explosive that can be brought near and inside the facility, respectively. The effectiveness of such searches will be enhanced if they include gamma-ray inspection of cargo, x-ray screening of bags, magnetometer screening of individuals, and/or use of explosive trace detectors. Finally, access control for vehicles and/or persons will ensure that only those with appropriate authorization can approach and/or enter the building.

The following exterior security measures should be considered and applied as appropriate: perimeter barriers preventing unauthorized entry to the site; site layout to achieve maximum standoff in every direction, provide difficult approach zones, and limit areas of potential concealment within a particular distance around the building; separation between the building and other buildings, parking areas, public areas, and public transportation; guard stations; and control of vehicle access, such as eliminating lines of approach perpendicular to the building and restricting parking to authorized vehicles only.

Site design should include, to the greatest extent possible, the principles of Crime Prevention Through Environmental Design (CPTED). The four main concepts of CPTED are natural access controls such as properly located entrances, exits, and fences; target hardening such as access controls, surveillance cameras, and barriers; territorial reinforcement such as clearly demarcated boundaries; and natural surveillance such as eliminating visual obstructions.

Other specific elements in the guarded perimeter and standoff zones include clear zones, security lighting, intrusion detection devices, alarm systems and sensors, and alert and notification systems. These mutually supportive elements should be integrated with elements described elsewhere in this Standard, as well as the overall development of the building site, including landscaping, parking, roads, and other features. Standoff should be coupled with appropriate building details and site features wherever possible to provide the desired level of protection.

No guidance is provided herein to mitigate attacks with artillery-type munitions such as mortars or rockets. Direct-fire weapons that require a line of sight can be thwarted with predetonation screens and walls.

Security measures for the building exterior zone should account for all points of entry and exit for employees, visitors, and utility services to a building. Public access should be limited to the minimum number of entrances consistent with functional and life safety requirements. Service and utility entrance and exit points—such as air intakes, mechanical ducts, roof hatches, and water supplies—should be adequately safeguarded. Communications systems within the site should not be unduly vulnerable to accidental or intentional disruption.

For interior access control, the following security measures should be considered and applied as appropriate: building layout and compartmentalization; interior construction, including circulation routes and locations of elevators, stairwells, and entry control points; creation of well-defined and secured zones for controlling the flow of employees, contractors, visitors, and service personnel; securing of utility closets, mechanical rooms, and access doors to duct shafts and ceiling spaces; protection of nonstructural elements and systems that are necessary to fulfill the building's operational and functional requirements; and location of critical building systems away from areas considered to be potential targets, as well as all public access zones.

Operational security includes policies and procedures within the building or organization. Considerations include activities of guards, employees, visitors, and service personnel within the building. The following measures should be considered and applied as appropriate: coordinating central command center and satellite posts; maintaining building systems monitoring and control capabilities; implementing shipping and delivery procedures, especially for an underground parking facility or loading dock; and personnel/visitor screening and monitoring at the entrances.

C2.3.2.2.1 Standoff. It is desirable to keep the threat as far away from the building as possible. As described in Chapter 4, the effects of an explosion decrease rapidly with the distance between the source and the target. Increasing standoff is often the most cost-effective way to reduce potential vulnerability and associated risk, regardless of the assumed size of an explosive charge. Maximizing standoff also ensures that there is opportunity in the future to upgrade the building for increased threats or a higher level of protection or performance.

The standoff distance necessary to avoid hardening the building is a function of the type and weight of the explosive, the type of construction of the building, and the desired level of protection (DoD 2007b). Figures C2-1 and C2-2 indicate the minimum standoffs required by the DoD for inhabited buildings of conventional construction, i.e., without specific hardening for blast effects. It is important to recognize that these distances are calibrated to specific explosive sizes, the details of which constitute sensitive information that should not be made available to the general public (DoD 2007a).

Where standoff is limited, the presence of blast walls between the building and the assumed location of the explosion may be beneficial. However, blast walls typically have limited use in

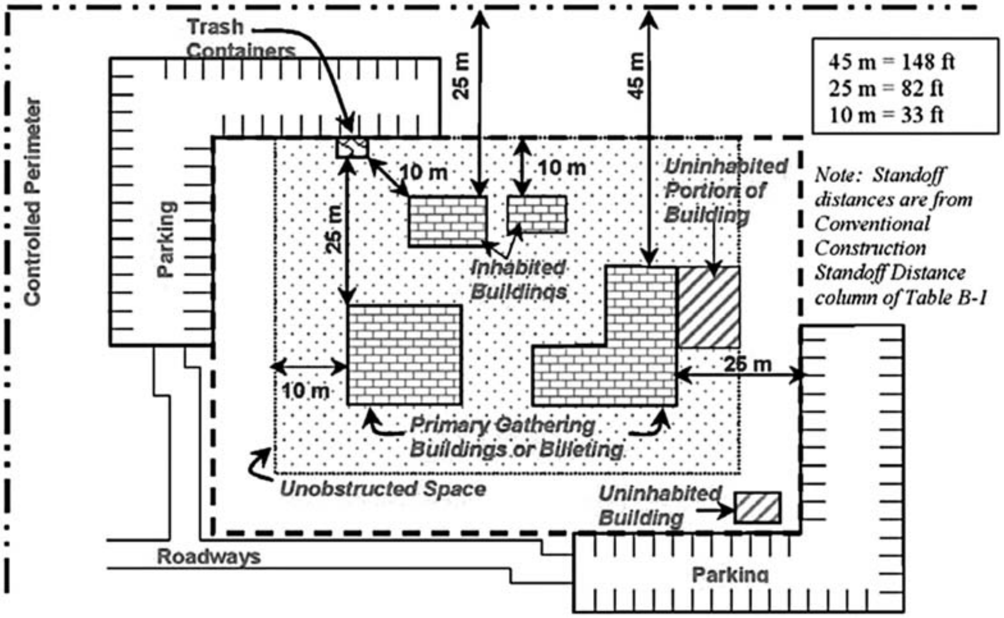

FIGURE C2-1. DoD MINIMUM STANDOFFS FOR BUILDINGS OF CONVENTIONAL CONSTRUCTION WITH A CONTROLLED PERIMETER (DoD 2007a).

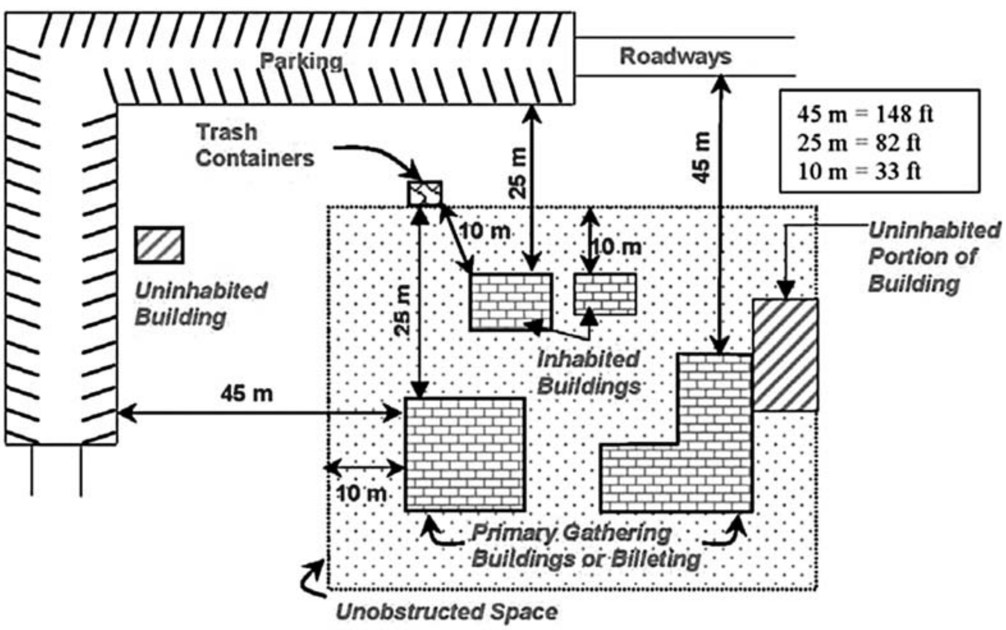

FIGURE C2-2. DoD MINIMUM STANDOFFS FOR BUILDINGS OF CONVENTIONAL CONSTRUCTION WITHOUT A CONTROLLED PERIMETER (DoD 2007a).

protective design because their effectiveness is highly dependent on the charge type and size and the distances between the explosive, wall, and building. Blast-induced shockwaves, although disrupted by the presence of a blast wall, can re-form behind the wall and may actually lead to greater localized demands than if the wall were not present. Test data suggest that blast walls with scaled heights of 0.8 ft/lb$^{1/3}$ (0.3 m/kg$^{1/3}$) to 2.0 ft/lb$^{1/3}$ (0.8 m/kg$^{1/3}$) will reduce the reflected pressure and impulse on building surfaces if they are located within a scaled distance of 3.0 ft/lb$^{1/3}$ (1.2 m/kg$^{1/3}$) from the explosive and a scaled distance between 1.0 ft/lb$^{1/3}$ (0.4 m/kg$^{1/3}$) and 20 ft/lb$^{1/3}$ (8.0 m/kg$^{1/3}$) from the building, although hardening is often more economical at scaled distances greater than 10 ft/lb$^{1/3}$ (4.0 m/kg$^{1/3}$). In all cases, values are referenced to the TNT-equivalent size of the

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explosive. Guidance for the adjustment of building loads when blast walls satisfying these constraints are present is provided in TM 5-853-3 (DoD 1994). Alternatively, computational fluid dynamics (CFD) tools can be used to characterize pressure distributions in the presence of blast walls.

Blast walls have been constructed from reinforced concrete, FRP composites, wood, and other materials. Some types of blast walls can mitigate the effects of fragmentation, even when the reduction of airblast effects is minimal. On the other hand, blast walls can also be the source of large secondary fragments that could be damaging to the structure that the wall is intended to protect. Consideration should be given to the construction of earth fill or other landforms, such as berms, behind the blast wall to capture these fragments, such as those caused by breach or spalling of reinforced concrete when the wall thickness is not sufficient to prevent these types of failure. Guidance for the design and construction of blast walls is provided in UFC 3-340-02 (DoD 2008).

C2.3.2.2.2 Vehicle Barriers. Perimeter barriers are required to enforce standoff for malicious explosions. The threat of a suicide attack using a moving vehicle requires the use of passive and/or active anti-ram structures, such as bollards, special planters, knee walls, gates, or pop-up devices. When only stationary vehicle bombs are being considered, it is usually sufficient to keep parking and roadways away from the building, especially if some kind of access control is in place. Hand-carried bombs can be hidden in trash containers, yard equipment, or even landscaping features. Therefore, the building should be surrounded by an unobstructed space that provides no opportunities for concealment of a small explosive device.

Most vehicle barriers rely on substantial foundations and ductile elements to absorb the kinetic energy of a moving vehicle. In many cases, the capacity of the barrier depends heavily on the construction of the foundation; therefore, the barrier and foundation must be considered as a single system. Surface-mounted barriers, such as blocks of concrete and boulders, rely primarily on their weight and friction, but may require a 1-in. (25-mm) embedment in the pavement or sidewalk to provide adequate resistance to sliding to limit vehicle penetration.

A maximum clear distance between an active anti-ram structure and an adjacent passive vehicle barrier is specified in order to prevent small vehicles from penetrating the barrier system. A minimum height for an anti-ram structure is specified to reduce the likelihood of an engine block penetrating the defensive perimeter and sliding into the protected building. These dimensions are used for most tested barriers and have been accepted by the (U.S.) General Services Administration and the U.S. Department of State.

The performance of an anti-ram structure is judged with respect to a design or moving vehicle threat, which is usually a particular vehicle weight moving at a selected speed. Typical threats are a 4,000-lb (1,800-kg) car moving at 30 miles per hour (13 m/s) or a 15,000-lb (6,800-kg) truck moving at 50 miles per hour (22 m/s). Design speeds can be reduced below these values if the maximum achievable speed, resulting from the installation of barriers or other impediments, is lower.

Results of full-scale testing of a vehicle barrier may be extrapolated to barriers of similar construction by analysis and design through appropriate scaling of the demand (e.g., vehicle weight, impact speed, impact direction) and the resistance (e.g., mechanical properties, geometry, strength and deformation capacity). Extrapolation of test data must address differences, if any, in the foundation and soils supporting the anti-ram structure.

C2.3.2.2.3 Landforms. Landforms can be used to provide effective standoff against vehicular attack and to prevent line-of-sight attacks using shoulder-fired munitions.

C2.4 RISK ACCEPTANCE

Risk acceptance is an informed decision to tolerate the consequences and likelihood of a particular attack scenario. There are two ways in which risk acceptance can be expressed: design to risk and design to budget, as described below. The decision on the level of risk acceptance is often based on a risk-cost assessment that attempts to balance these two approaches. Consideration should also be given to allowing incremental risk reduction over a period of time in order to reach the defined risk acceptance level. In all cases, the owner must recognize and accept that it is certainly possible that the building could be subjected to blast effects in excess of those used for design, which may result in damage greater than anticipated.

Risk analysis in accordance with this chapter may lead to the selection by the building owner of a specific set of scenarios for which the facility will be explicitly designed. In such cases, it is usually not feasible to attempt to accommodate the maximum conceivable risk; instead, design is based on what is considered to be the maximum acceptable risk level. This is the design to risk approach.

The range of design options available to decision makers is extensive, as are the potential costs. Parallel to the reality of risk is the reality of budget constraints. Owners and managers of constructed facilities are confronted with the challenge of responding to the potential for an explosive event in a financially responsible manner. When sufficient funds are not available to design the building against the postulated threat, tradeoffs must be made. The level of protection that can be provided within the project budget then dictates the amount of risk that the owner must accept. This is the design to budget approach.

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Chapter C3
PERFORMANCE CRITERIA

C3.2 DESIGN OBJECTIVES

C3.2.1 Limit Structural Collapse. The major cause of death and destruction when a building is subjected to the effects of a nearby explosion is collapse of all or a portion of the structure. Collapse can be mitigated by hardening key structural elements against a particular threat in conjunction with employing design and detailing practices that reduce the likelihood that a local failure will propagate through the structural system as a whole. Specific provisions that relate to the latter phenomenon are provided in Section 6.2.3.4.

Protective structural design generally follows two main principles: redundancy, which provides an alternative means of resisting the applied loads, especially for enhancing progressive collapse prevention; and target hardening, which involves performance improvements, such as strength and ductility, of individual elements and their interaction. The effectiveness of these measures depends on the characteristics of the building and of the expected blast load. Design and implementation should account for practicality and effectiveness in terms of costs—such as construction cost, relocation cost; and productivity loss—interruption to building operations, and intrusiveness to occupants. Priorities for vulnerability reduction should be given to the perimeter elements of the building.

A building's structural resistance is provided by integrating two load-carrying systems: the gravity load system and the lateral load system. A gravity load system is designed to carry the gravity load from the floors to the beams, to the girders, to the columns, and to the foundations. A lateral load system is designed to transfer horizontal loads from the superstructure to the foundations and to control the overall and interstory drift. The horizontal and vertical elements and their interfaces must be properly designed to withstand gravity and lateral loads and stress reversals.

Redundancy is related to both structural integrity and providing an adequate load path in the event of the failure of one element such that the structure remains stable. Redundancy usually requires ductility in individual elements and continuity in the structural system. Generally speaking, ductile moment frames with seismic detailing are typical of redundant systems, while unreinforced masonry walls and nonductile frames are representative of nonredundant systems.

The possibility of an explosive event larger than the design scenario should be recognized. The structure should be able to sustain local damage without destabilizing the whole structure. If local damage occurs under the assumed blast event, the structure should not collapse or be damaged to an extent disproportional to the original scope of the damage. For example, the failure of a primary structural element such as a beam, a slab, or a column should not result in failure of the structural system below, above, or in adjacent bays. In the case of column failure, damage to the beams and girders above the column should be limited to large inelastic deflections. Adequate redundancy and alternative load paths should be provided to reduce the vulnerability of a building against progressive collapse.

Performance considerations for vulnerability reduction in structural elements include adequate strength, ductility, and stiffness for each element and the interaction between connecting elements. Individual elements must meet the capacity and demand criteria for each element. Structural integrity and alternative load paths can be maintained through satisfactory interaction between connected elements, specifically proper connection detailing to ensure an adequate load transfer mechanism. However, reducing the vulnerability of individual elements by upgrading their strength and ductility characteristics is usually more effective than hardening only the connections.

In addition to considering the vulnerability reduction of structural elements, such as columns, walls, slabs, and beams, it is also desirable to consider vulnerability reduction for nonstructural elements such as non-load-bearing exterior and interior walls; window and framing systems; architectural, mechanical, electrical, and fire protection elements and systems; and these elements' interactions with the building structure.

Material design and detailing requirements vary from one construction material to another. Guidelines for concrete, steel, masonry, FRP, and other materials such as wood and cold-formed steel are available. Consideration of vulnerability reduction for existing buildings must take into account the compatibility of materials used and the impact on the structure's local and global response.

C3.2.2 Maintain Building Envelope. The envelope is the boundary between the exterior and interior of a building. Its primary function is to protect the controlled interior environment from the effects of uncontrolled exterior events, whether natural (such as temperature, rain, and wind) or human-induced (such as impact, forced entry, and blast). In the case of an exterior explosion, an envelope that remains intact will significantly reduce the hazards to people and property inside the building by preventing them from being subject to direct blast effects.

C3.2.3 Minimize Flying Debris. Where there is no building collapse, the major causes of injuries and damage are flying glass fragments and debris from walls, ceilings, and fixtures (nonstructural features). Flying debris can be minimized through building design and avoidance of certain building materials and construction techniques. The glass used in most windows breaks at very low blast pressures, resulting in hazardous, dagger-like shards. Minimizing those hazards through reduction in window numbers and sizes and through enhanced window construction has a major effect on limiting mass casualties. Window and door designs must treat glazing, frames, connections, and the structural elements to which they are attached as an integrated system. Hazardous fragments may also include secondary debris such as those from barriers and site furnishings.