CHAPTER FOUR

GUIDELINES ON BUILDING DESIGN

Building design is a crucial part of protective security, particularly in densely populated urban environments where post-attack casualties may be greater than the damage caused by the blast itself. This chapter reviews site layout and orientation choices that can affect the impact of an explosives attack and presents recommendations designed to mitigate the hazards associated with debris in large explosions and to prevent collapse.

Site Layout and Orientation

Designing space within buildings to direct people and locate critical facilities away from vulnerable locations can help mitigate the effects of a terrorist attack. Accordingly, the NYPD recommends that High Tier buildings incorporate designs in which crowd surges in excess of 500 people are directed away from potential projectile sources, particularly glass atriums, windows, and curtain walls. Additionally, owners of High Tier buildings should attempt to place concession stands, newsstands, ticket windows, and concierge services away from main approaches or glass curtain walls and design the shape of buildings to help dissipate blast pressures.

The NYPD recommends that owners of Medium and High Tier buildings disperse critical facilities in order to reduce the potential for disruption of multiple critical systems during an attack. These critical facilities should be located in a building's least vulnerable areas, preferably in places that are out of public view and difficult for terrorists to observe or exploit.[1] Additionally, a backup system for critical facilities should be available and placed in a similarly secure location.

Box 7: Stadiums and Arenas

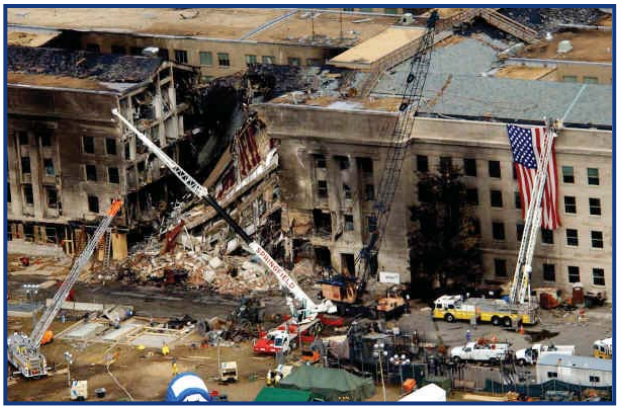
Seating bowls in stadiums and arenas present unique blast mitigation challenges because the pressure of a blast can cause seats to dislodge, leading to blunt injuries or death. Accordingly, the NYPD recommends that owners of major stadiums and arenas install primary structural elements and seating tie-down elements that achieve DBT levels in the M3 range from the true perimeter. The NYPD recommends that stadium and arena owners consult with blast engineers and the NYPD Counterterrorism Bureau to determine site-specific DBT standards within the M3 range. The determination is based on analysis of expected casualty levels given variations in occupancy, charge weight, standoff, geometry, and structural hardening.

Finally, to limit the collateral damage from an attack on a neighboring building, the NYPD recommends that owners of Medium and High Tier buildings orient glass facades away from nearby High Tier buildings, whenever possible.[2]

Reducing the Hazards of Debris in Large Explosions

An explosives attack against a building can produce casualties associated with the harmful debris caused by fragmentation. Accordingly, hazard mitigation measures aim to limit fragmentation thresholds, fragment sizes, and distances traveled by fragments. Such measures simultaneously shield occupants from injury and protect passersby and emergency responders from falling debris.

During the positive pressure phase of an explosion, secondary structural elements, such as exterior cladding, glass, and interior building walls, may break and blow away from the source of the blast.[3] As the explosion proceeds to the negative pressure phase, those same secondary structural elements are projected towards the source of the blast.[4] This chain reaction can threaten building occupants, block exits, and impede rescue attempts. Therefore, the NYPD recommends that owners of Medium and High Tier buildings ensure that secondary structural elements are designed to perform to acceptable fragmentation standards during an attack. This section proceeds from the exterior of a building to the interior, starting with the facade and exterior cladding; moving on to windows; and ending with interior walls.



The Pentagon, 2001

The structural performance of the Pentagon following the attacks of September 11, 2001, demonstrates the benefits of enhancing the resilience of secondary structural elements in High Tier buildings. Although more than 100 people were killed when American Airlines Flight 77 crashed into the western side of the Pentagon, certain blast-resistant renovations prevented a far greater number of casualties.[5] Other case studies demonstrate the drawbacks of poor secondary structural element performance during an attack, including casualties stemming from secondary blast effects. For example, in 2003, Al Qaeda-linked terrorists in Istanbul, Turkey, launched four large VBIED attacks over two days – simultaneous attacks against two synagogues on November 15, and near-simultaneous attacks against two British targets on November 20. The attacks killed at least 57 people and injured approximately 700 people. In all four bombings, most of the injuries, including lacerations and blunt trauma wounds, resulted from secondary blast effects.[6]

Facades

Because facades serve a number of important purposes, building owners should identify construction methods and materials that at once meet energy efficiency and aesthetic needs and perform well when presented with abnormal loads. Factors to consider include facade failure modes and failure limits of exterior cladding material.

When subjected to air-blast pressures, glass, masonry, stone, pre-cast concrete, and architectural metals exhibit distinctive failure modes and mechanical properties. For example, glass tends to break into small pieces following a blast event, which can cause lacerations and puncture wounds. Brick, on the other hand, tends to break from a structure in larger pieces following a blast event, which can cause blunt trauma injuries.[7] The NYPD recommends that owners of Medium and High Tier buildings take into account failure modes when selecting facade materials. Additionally, the

NYPD recommends that owners of High Tier buildings limit the use of ornamentation that is susceptible to becoming dislodged following a blast event. Building owners who decide to use such ornamentation should consider lightweight materials, which are less prone to becoming harmful projectiles, and should ensure that such ornamentation is secured.[8]

In designing facades, owners of Medium and High Tier buildings should also consider the differential failure limits of exterior cladding materials. Because facade strength has implications for structural loading, over-fortification may have the unintended consequence of making a building more susceptible to collapse in the event of an attack. Therefore, the NYPD recommends that in modeling the effects of externally applied loads, engineers of High Tier buildings should consider facade performance as it affects structural loading relative to collapse as well as debris mitigation.

Windows

Windows present the most difficult challenge for building owners attempting to mitigate the hazards associated with debris impact, because glass is brittle and inflexible, making it particularly susceptible to failure.

Treated window glazing can incrementally increase the blast resistance capability of glass. Although no commercially available glazing can fully mitigate the effects of a close-range blast event, certain glazing systems may substantially reduce blast impact at greater distances. Window glazing can also reduce the distance that glass fragments travel upon failure. For these reasons, the NYPD sets out recommendations for performance levels of glass: as a general rule of thumb, for a blast in the M2 range, owners of High Tier buildings should ensure that windows achieve a performance condition of 3b on the General Services Administration's (GSA's) Performance Conditions for Window System Response Table; and for Medium Tier buildings, a performance condition of 4.[9] However, specific design levels may vary from this range based on the particular conditions at each site; professional security consultants should be retained to resolve these issues.

The type of protective glazing system used informs a window's performance level. Common types of glazing systems include: annealed, heat strengthened, fully thermally tempered, and laminated. Office buildings commonly incorporate annealed

and fully thermally tempered glass, which pose fragmentation hazards.[10] Accordingly, the NYPD recommends that owners of Medium and High Tier buildings avoid the use of annealed glass completely, and limit the use of fully thermally tempered glass to windows on upper floors, where increased distance from street level reduces potential blast pressure and glass fragmentation danger. For windows on lower floors, the NYPD recommends that owners of Medium and High Tier buildings use laminates. Generally, owners of Medium and High Tier buildings should consider occupancy type, glazing location, and the physics associated with the explosive threat when deciding between the use of laminates and fully thermally tempered glass.

To the extent that glass does not meet the applicable GSA performance conditions, the NYPD recommends the use of competent systems to protect against the hazards associated with glass fragmentation, including catch bar systems or blast curtains, in High Tier buildings.

The NYPD recommends limited fenestration on lower floors of High Tier buildings, to the extent possible. However, in certain districts, New York City zoning resolutions related to transparency and glazing may not allow for this practice.[11] In such situations, building owners should consult with professionals about the possibility of applying for waivers, variances, or exemptions to permit appropriate protective design measures. When such exceptions are unavailable, building owners should consider complementary protective security design measures to mitigate the associated risks, such as the installation of punched windows and the use of bollards to create increased standoff.

Window frames must hold glass in place long enough for the window to properly fail. Otherwise, a blast event can cause an entire pane of glass to dislodge from its frame before shattering. Accordingly, the NYPD recommends that owners of Medium and High Tier buildings ensure that the capacity of the frame system to resist blast loading exceeds the capacity of the glazing.[12] In the absence of a fully engineered blast resistant curtain wall detail, the NYPD recommends a bite depth for glass in a frame of at least ½-inch for Medium and High Tier buildings.[13] Window frames should be properly anchored to buildings to avoid the hazards associated with the dislodgement of entire frames containing intact panes of glass.

Interior Walls

Interior walls, particularly those that are not designed to be blast resistant, may become potentially harmful projectiles following a blast event. Fragmentation of interior walls can cause blunt trauma injuries and create debris that hampers access by first responders and blocks emergency egress routes.

The NIST report of 2005 noted that falling debris and fire rendered certain stairwells impassable in WTC1 and WTC2.[14] The New York City Building Code requires stairwells and elevator shafts in high-rise buildings to have impact resistant walls, but it leaves the establishment of minimum impact resistance standards to agency rulemaking.[15] Accordingly, to enable evacuation and life safety operations, the NYPD recommends that owners of all High Tier buildings and Medium Tier buildings taller than 600 feet reinforce egress routes, preferably with concrete encasements or other solutions engineered to achieve exit route survivability.

Additionally, owners of High Tier buildings should ensure that walls surrounding critical and sensitive areas are made of strong material, such as concrete, as opposed to weaker material, such as sheetrock. For existing buildings, certain walls that are not reinforced may be retrofitted with a sprayed-on polymer coating to improve air-blast resistance. This technique uses modern polymer materials to dissipate the energy from a blast, preventing shattering or, at a minimum, containing debris.[16]

Alfred P. Murrah Federal Building,
Oklahoma City 1995

Preventing Collapse

Beyond mitigating the hazards associated with debris in large explosions, building design criteria should account for the prevention of collapse. Specifically, certain design principles can effectively minimize the unique risks associated with progressive collapse. Progressive collapse is of

Box 8: Cantilevers

The term "cantilever" describes a structure that is supported on only one end, without external bracing. Engineers and architects use cantilevers to create large open lobbies, covered passenger discharges, balconies, and roadways under buildings. Because cantilevers lack alternate load paths, they present unique challenges in blast mitigation; failure at the sole support leads to failure of the structure. Additionally, when a blast occurs under a cantilever, reflective pressure magnifies the initial blast pressure. Accordingly, the NYPD recommends that owners of Medium and High Tier buildings generally limit the use of cantilevers and avoid their use altogether over roadways. Instead, engineers should create fully supported structures that provide alternate load paths.

special concern because of its potential to cause damage that is disproportionate in magnitude to the initial damage caused by the blast event.[17]

On April 19, 1995, Timothy McVeigh detonated a powerful VBIED in front of the Alfred P. Murrah Federal Building in Oklahoma City, killing 168 people. With less than 20 feet of standoff, the force of the blast caused the progressive collapse of part of the building, leaving occupants who were otherwise unharmed by the blast itself no time to evacuate.[18] It has been estimated that approximately 80 percent of the fatalities in the attack resulted not from the initial blast itself, but from the progressive collapse of the building.[19]

Buildings with effective structural design will resist progressive collapse following an attack. Generally, buildings designed to resist progressive collapse incorporate certain features: robust primary structural elements capable of withstanding initial air-blast pressures; and redundant load path systems that allow the entire structure to remain standing in the event that a critical structural element becomes compromised.[20] Therefore, the NYPD recommends that owners of High Tier buildings incorporate certain features into structural designs to prevent collapse and enable rescue, including: ductile primary and secondary structural elements that are

capable of deforming beyond the elastic limit without collapsing; sufficient primary and secondary structural element capacity to resist load reversals in the event of structural element failure; sufficient primary structural element capacity to resist an abnormal loading event that could lead to a shear failure; location of splices away from explosive threat zones; and other approved blast mitigation strategies.[21]

Design Methods

The American Society of Civil Engineers defines two general approaches to reducing the risk of progressive collapse for a building: Indirect Design and Direct Design.[22] Indirect Design is a prescriptive, event-independent approach to preventing progressive collapse that does not take into account the removal of structural members as a result of abnormal loading.[23] Direct Design is a more sophisticated approach to preventing progressive collapse that takes into account abnormal loading, and, in some instances, the removal of structural members as a result of those loadings.[24] Direct Design approaches include the Specific Local Resistance Method, which is threat-dependent, and the Alternate Path Method, which is threat-independent. The Specific Local Resistance Method designs specific primary structural elements to withstand abnormal loading events. The Alternate Path Method is a holistic approach that accounts for the interrelationships between failed columns and other primary structural elements; it designs the structure to localize damage to primary load-bearing structures by shifting the load to an alternate path.[25]

The New York City Building Code requires Direct Design for certain categories of buildings, including buildings greater than 600 feet in height or more than 1,000,000 square feet in gross floor area.[26]

The resilience of a column in the aftermath of the 1993 World Trade Center attack.

The NYPD recommends that all High Tier buildings incorporate Direct Design. Engineers of High Tier buildings using Direct Design should ensure that primary structural elements satisfy M3

standards for threats from the true perimeter; and M1 standards for threats from a contact charge, with events not occurring simultaneously. Engineers of High Tier buildings should also consider the use of threat-independent design methods, including the Alternate Path Method, informed by threat profile and the architectural and structural design of the building.

The NYPD recommends that engineers of Medium Tier buildings ensure that primary structural elements satisfy M1 standards for threats from a contact charge or account for the loss of a column using the Alternate Path Method.