Original Research Articles

Researchers

A. VIJAY

Department of Structural Engineering

SRM University

Email- india2vijay@gmail.com

Structural Facilities Criteria for Anti-Terrorism (A Defensive Approach towards Safer Nation on Building Sciences)

Abstract:

Strategies for blast protection have become an important consideration for structural designers as global terrorist attacks continue at an alarming rate. Conventional structures normally are not designed to resist blast loads; and because the magnitudes of design loads are significantly lower than those produced by most explosions, conventional structures are susceptible to damage from explosions. With this in mind, developers, architects and engineers increasingly are seeking solutions for potential blast situations, to protect building occupants and the structures themselves.

In years past, blast resistant design was typically only used for facilities that housed or were in close proximity to explosive material or were known targets of attack. Munitions plants and storage facilities, strategic military and/or government facilities, and gas/oil refineries are a few examples of facilities that might have been designed specifically to resist blast. However, we are living today in an environment of enhanced risk that requires protective design and the management of risk for most facilities. This state of risk is punctuated by several major events over the past two decades. The main goal is to develop an adequate method that any competent structural engineering firm could follow without special expertise in blast or dynamics. Developed in this way, only the most special facilities require the attention of highly qualified blast specialists in the area of preventing progressive collapse.

Our mission is to move forward with a purpose of mind and with the will to not let our values and our great nation yield in the face of evil. We can win this war and we can succeed, but only if we stay the course, live our lives in an open and free society, and never yield to the temptation to ignore the truth that lies before us. Our long-term success will depend on our willingness to sacrifice and make the necessary investments in all aspects of security. The primary design objective is to save the lives of those who visit or work in these buildings in the unlikely event that an explosive terrorist attack occurs. In terms of building design, the first goal is to prevent progressive collapse which historically has caused the most fatalities in terrorist incident targeting buildings.

Beyond this, the goal is to provide design solutions which will limit injuries to those inside the building due to impact of flying debris and air-blast during an incident, and to limit harm to innocent civilians near the building perimeter. Finally, we seek to facilitate the rescue/recovery efforts by limiting the debris blocking access to the building and potential falling debris hazards which could harm rescue workers. In some cases, secondary objectives may need to be

considered such as maintaining critical functions and minimizing business interruption.

The recommendations/criteria's given are solution-focused. They are intended for designers who are tasked with implementing federally mandated anti-terrorist design criteria into projects, recognizing that these requirements need to be balanced and integrated with many other design constraints such as sustainability, construction and life-cycle costs, constructability, architectural expression and natural hazards protection. To maximize the benefit provided by the recommendations, anti-terrorist considerations should be implemented at the earliest planning and design stages possible. This will ensure that the resulting design maximizes protection while integrating with other design considerations.

Impacts:

- Creates a standardized approach for identifying and justifying security and anti-terrorism design criteria
- Creates standardized nomenclature and criteria for asset, threat, and level of protection definition
- Creates standardized process for evaluating design criteria and protection option based on risk management
- Provides guidance for incorporating security and anti-terrorism principles into installation master planning
- Does not have any adverse impacts on environmental, sustainability, or constructability policies or practices

Structural Planning and Designing:

Fundamentals:

Designing a safe, secure, and functional building involves many different disciplines, including, for example, structural, mechanical and electrical engineering, architecture, landscape architecture, security design professions, and law enforcement. In addition, the design for unpredictable, human made hazards such as terrorism involves many variables that may be difficult to accurately quantify.

To save lives, the primary goals of the design professional are to reduce building damages and to prevent progressive collapse of the building, at least until it can be fully evacuated. A secondary goal is to maintain emergency functions until evacuation is complete. For mission critical facilities, where the facility must be functional rapidly after an incident, a higher level of protection is required. Finally, good anti-terrorist design is a multidisciplinary effort requiring the concerted efforts of the architect, structural engineer, security professional and the other design team members. It is also critical for security design to be incorporated as early as possible in the design process to ensure a cost effective, attractive solution.

Preventing the building from collapsing is the most important objective. Historically, the majority of fatalities that occur in terrorist attacks directed against buildings are due to building collapse. Collapse prevention begins with awareness by architects and engineers that structural integrity against collapse is important enough to be routinely considered in design. Features to improve general structural integrity against collapse can be incorporated into common buildings at affordable cost. At a higher level, design for progressive collapse can be accomplished by the alternate path method (i.e. design for removal of specific elements) or by direct design of components for air-blast loading or by the indirect method of prescribing design features which promote redundancy and ductility.

Furthermore, building design may be optimized by facilitating evacuation, rescue and recovery efforts through effective placement, structural design, and redundancy of emergency exits and critical mechanical/electrical systems. Through effective structural design the overall damage levels may be reduced to make it easier for people to get out and emergency responders to safely enter. Multiple, easily accessible, protected primary egress routes; free of debris caused by exterior envelope failure will be a key to reaching these goals.

Beyond the issues of collapse, and evacuation/rescue our objective is to reduce flying debris generated by failed exterior walls, windows and other components to reduce the severity of injuries and the risk of fatalities. This may be accomplished through selection of materials and use of capacity design methods to proportion elements and connections. A well designed system will provide predictable damage modes, selected to minimize injuries.

Structural Engineering:

Structural engineering, or structural design, is the design of a building's internal support system. Structural design includes the selection of a framing method or structural system, as well as the selection and sizing of structural members, based on loading and architectural requirements. Structural members include beams, columns, the foundation, floor slabs, connections of these elements to each other, and other ancillary components.

Building design (structural and architectural) can contribute to infrastructure security by minimizing the extent and depth of damage in an attack. Structural integrity can help mitigate blast and fire damage to the building; protect inhabitants; protect equipment, property, and records; allow critical operations to function immediately after an attack; and allow rescue operations in and around the building preserved after an attack.

This section focuses on blasts and fires, describing engineering concepts for structural integrity and strategies for minimizing damage. The concepts discussed include: ***Blast loads, Blast damage, Progressive collapse, Blast mitigation, Fire damage***

The sections of most building codes relating to structural components address service loads and methods to determine the proper size of structural members and their connections. Service loads specified in building codes are based on the location and intended use of the proposed structure, and include: ***Minimum dead load:*** the weight of the structure, ***Live load:*** variable loads such as people, cars, furniture, etc., ***Earth load:*** earth pressure on buried structures, retaining walls, foundations, etc., ***Wind load:*** pressure applied to the structure by wind, ***Snow load:*** the weight of snow on a building, ***Seismic load:*** loads induced on structural members during an earthquake.

“Building codes do not usually address "blast loads"; the force exerted on a building from the detonation of an explosive device.”

Blast loads are different from the usual types of service loads considered by a structural engineer when designing a building. Service loads are relatively predictable in their magnitude and placement on the structure. In contrast, blast loads are much greater in magnitude, are unpredictable in size and placement. However, there are certain engineering strategies that engineers can use to enable a building to maintain its structural integrity after some of its components have been compromised or completely destroyed in a blast.

Principles of Blast-Resistant Design:

Maintain safe separation of attackers and targets. Design to sustain and contain a certain amount of bomb damage. Allow for limited localized damage and prevent progressive collapse and catastrophic total structural failure. Minimize the quantity and hazard of broken glass and blast-induced debris. Facilitate rescue and recovery operations. Permit safe rescue and adequate time for evacuation of the occupants.

Stand-Off Zone:

The primary impact on project scope for site work will be the establishment and maintenance of standoff distance. That standoff will have to be provided to any location that is accessible to vehicles. For the stationary vehicle bomb tactic those locations may be limited to those that have legitimate vehicle access such as parking areas and roadways. For the moving vehicle bomb tactic those locations will need to go beyond the areas that are legitimately accessible to vehicles and include those that are physically accessible.

The key to understanding the planning implications of the standoff distance is in knowing the type of vehicle and the explosive weight associated with the threat and determining where access of those vehicles will be controlled In addition, planners need to recognize that where a higher threat severity level applies, all those below it also apply. One approach, therefore, is to establish a standoff distance based on the largest applicable explosive weight based on the applicable threat severity level and require access procedures for entry past that perimeter to be applied to all vehicles at that standoff distance. In cases where the threat severity level is equal to or greater than "high" (where the threat vehicles are trucks), all vehicles would be required to be searched at that standoff distance.

The operational implications of that requirement may be impractical in most locations. Those operational challenges suggest another option for application at higher threat severity levels. That option capitalizes on the fact that trucks are assumed to carry more explosives than cars and recognizes that there are usually more cars than trucks that require access near facilities. The approach of this second option is to create a two tiered system of standoff distances where trucks are controlled at the standoff distance associated with the highest applicable threat severity level and a second tier of standoff distances is established within that outer perimeter at a distance associated with the largest explosive weight cars are assumed to carry, which is 100 kg (220 lbs). Note that where threats larger than 100 kg (220 lbs) apply, all threats smaller than them also apply. With the option of establishing two separate perimeters, trucks can be searched at the greater standoff distance and cars can be allowed to go up to the closer standoff distance before they have to be controlled and searched. This approach minimizes the operational challenges of searching all vehicles at the standoff distance associated with trucks. It can be anywhere the installation operations and security personnel wanted to establish access control, including the installation perimeter.

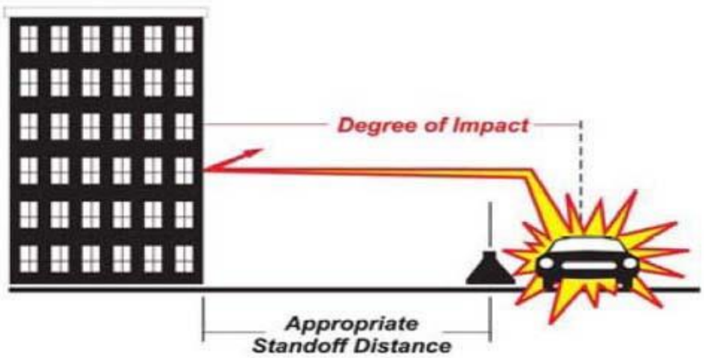

Fig.1 appropriate stand-off distance

- Bollards, planters, fountains, fences as obstacles to ramming vehicles/truck bombs. Provide operational bollards or fences to allow emergency vehicle access.
- Raise the building 4' above grade (provide ramps for barrier-free access).
- Keep parking away from the building. Restricted parking or no parking underneath the building.
- Secured access to loading dock. All deliveries should be registered, screened and logged prior to acceptance.
- Remove hiding spots for bombs -- trash receptacles, mailboxes, courier boxes, newspaper boxes, plant materials, garbage containers, etc.
- Bags-free zone – no backpacks, shopping bags, carts.

Access Control:

• Implement checkpoint at entrance and exits as temporary security procedure, e.g., high profile VIP stay/visit, political conference, terrorist alert, sudden wave of terrorist attacks. Build-in spatial and utility provision for hook-up.
• Provide security checkpoint airport-style
• Walk-through metal detector
• Scanning machine for guest luggage, bags
• Security screening and clearance for employees

Structural Reinforcement:

Facade Structure:

A façade is the outside face of a building or wall. It can refer to just the outer surface, or more generally to all construction between the exposed surface and the structural frame. In some instances, the structural frame is visible as an integral part of the façade.

• Avoid re-entrant corners on the exterior where blast pressures may build up.
• Eaves and overhangs to be designed to withstand high local pressure and suction during blast.
• Curtain walls and masonry walls break up readily and become secondary fragments during blast. Consider using reinforced cast-in-place concrete walls, at least for the lower floors. It minimizes flying debris and assists in carrying additional load.

Structural Framing:

• Avoid exposed structural elements such as columns on the exterior.
• Provide structural redundancy to carry severe dynamic loading and reduce the chance of progressive collapse.
• Provide alternate load paths. Build-in back-up support system to carry damaged slabs or columns.
• Contain concrete floor slab failure locally. Transfer load to adjacent horizontal support. (Same for Columns)
• Properly detail beam-column connections to resist upward or downward blast loads.
• Provide ductile details for structural connections to absorb the blast energy.
• Provide spandrel beams to tie the structure together.
• Provide drop panels at perimeter column capitals to reduce the supporting span of slab above.
• Provide additional beams at critical areas for additional vertical and lateral support.
• Limit the use of transfer girders which work against this principle.
• Additional structural reinforcement – composite fiber wrap, polymer lining, steel plates, geotextile fabric.

Glazing:

• Peoples do not want to stay in bunker-like buildings. Buildings want to be open and welcoming, with abundant natural light, operable windows – expression of cordial hospitality.
• Blast pressure from a car bomb can be hundred times higher than the allowable pressures of any glazing system, e.g., the blast pressure in Oklahoma City bombing was about 4000 psi.
• Install high performance window glass which will fail properly if overloaded. They require engineered support and attachment system. High cost and high maintenance.
• US embassies limit glazing to 15%.
• Orient glazing perpendicular to the street to reduce exposure to blast and projectiles.
•Standard window glass (2 psi)
• TTG Thermally Tempered Glass (30-40 psi). Breaks into rock salt pieces, as one side and rear windows of cars.
• ESP (Engineered Stress Profile) glass (15 psi)
• Laminated glass or polycarbonate, bullet-resistant glass. Remains one cracked piece, as on windshields of cars.
• Consider window safety laminate (Mylar film) or other fragment-retention film over glazing to reduce fragmentation.

• Others: Fiber composite material
• Blast curtains with Kevlar or just heavy drapes in high-threat areas

Space Planning:

• Analyze horizontal and vertical adjacencies
• Isolate high security spaces
• Locate assets as far into the interior of the building as possible.
• Place area of high visitor traffic away from assets.
• Locate critical assets in 24/7 zone and surveillance by multiple personnel.
• Place mail room on the building perimeter to minimize damage caused by mail bomb. Consider hardening the walls and ceiling similar a transformer vault.
• Stagger doors in corridor to limit effects of blast through the structure. Temporary Security Implementation
• Secured floor with controlled access.
• Provide secured, alternate entrance/exit routes.
• Internal logistics – designated elevators and timing, keep out other guests.

Utility:

• Primary goal for the mechanical and electrical systems is to continue operation of the key life safety systems after the blast.
• Build-in surplus operational capacity to survive the attack.
• Avoid mounting utility lines on vulnerable components -- inside of exterior walls, ceiling, and roof slab.
• Locate utilities away from likely area of attack – parking area, loading dock, and lobby.
• Harden the operational control areas and utility feeds from direct attack.
• Separate the prime power line and backup power line and keep apart as far as possible so that one bomb cannot disable the primary utility feed and the backup system.
• Fortify the computer server room.
• Provide manually activated or continuously active air filtration system to reduce risk of airborne contaminants.
• Battery check of emergency lights.
• Illuminate building access points to facilitate surveillance.

Design Methods:

The design approach to be used for the structural protective measures is to first design the building for conventional loads, then evaluate the response to explosive loads and augment the design, if needed, making sure that all conventional load requirements are still met. This ensures that the design meets all the requirements for gravity and natural hazards in addition to air-blast effects.

Take note that explosive load effects mitigation may make the design more hazardous for other types of loads and therefore an iterative approach may be needed. As an example, for seismic loads, increased mass generally increases the design forces, whereas for explosion loads, mass generally improves response. Careful consideration between the blast consultant and the structural engineer is needed to provide an optimized response. As an air-blast is a high load, short duration event, the most effective analytical technique is dynamic analysis, allowing the element to go beyond the elastic limit and into the plastic regime. Analytical models range from handbook methods to equivalent single-degree-of-freedom (SDOF) models to finite element (FE) representation. For SDOF and FE methods, numerical computation requires adequate resolution in space and time to account for the high-intensity, short-duration loading and non-linear response. Difficulties involve the selection of the model, the appropriate failure modes, and finally, the interpretation of the results for structural design details. Whenever possible, results are checked against data from tests and experiments for similar structures and loadings.

Exterior envelope components such as columns, spandrels and walls can often be modelled by a SDOF system and then solving the governing equation of motion by using numerical methods. Handbook methods may be used to evaluate the peak displacement response of structural components using graphs that require only that the designer define a few parameters including the ultimate resistance, fundamental period, and elastic limit deflection. Other charts are available which provide damage estimates for various types of construction based on peak pressure and peak impulse based on analysis or empirical data. Military design handbooks typically provide this type of design information. The design of the anchorage and supporting structural system may be evaluated by using the ultimate flexural capacity of the member.

For SDOF systems, material behaviour may be modelled using idealized elastic, perfectly-plastic stress-deformation functions, based on actual structural support conditions and strain rate enhanced material properties. The model properties selected provide the same peak displacement and fundamental period as the actual structural system in flexure. Furthermore the mass and the resistance function are multiplied by mass and load factors, which estimate the actual portion of the mass or load participating in the deflection of the member along its span. For more complex elements, the engineer must resort to finite element numerical time integration techniques and/or explosive testing. The time and cost of the analysis cannot be ignored in choosing design procedures. Because the design process is a sequence of iteration, the cost of analysis must be justified in terms of benefits to the project and increased confidence in the reliability of the results. In some cases, an SDOF approach will be used for the preliminary design and a more sophisticated approach, using finite elements, and/or supported by explosive testing may be used for the final verification of the design.

A dynamic non-linear approach is more likely to provide a section that meets the design constraints of the project compared with a static approach. Elastic static calculations are likely to give overly conservative design solutions if the peak pressure is considered without the effect of load duration. By using dynamic calculations instead of static, we are able to account for the very short duration of the loading. Because the pressure levels are so high, it is important to account for the short duration to mitigate response. In addition, the inertial effect included in dynamic computations greatly improves response. This is because by the time the mass is mobilized; the loading is greatly diminished, enhancing response. Furthermore, by accepting that damage occurs we are able to account for the energy absorption of ductile systems that occurs through plastic deformation. Finally, because the loading is so rapid, we are able to enhance the material strength to account for strain rate effects.

Response is evaluated by comparing the ductility (i.e., the peak displacement divided by the elastic limit displacement) and/or support rotation (the angle between the support and the point of peak deflection) to empirically established maximum values which have been established by the military through explosive testing. Note that these values are typically based on limited testing and are not well defined within the industry at this time. Maximum permissible values vary depending on the material and the acceptable damage level.

Author Details:

At present, he is pursuing M.Tech Structural Engineering in SRM University, Chennai. His thirst of helping the needy led to the start of a NGO named Shamrock Foundations to empower people to empower themselves. Hope it would be a right platform to equip social entrepreneurial skills. His project experiences include:

- **Accomplished a Research Project titled "STRUCTURAL FACILITIES CRITERIA ON ANTI-TERRORISM" followed by designing of a "High Safety Structure".**
- **Accomplished a Design Project titled "Design of a Heliport".**
- **Accomplished a Survey Project titled "Thirupachur Tank Bund Road" for the benefit of Thirupachur (Thriuvallur TK&DT) village peoples.**

<u>NOTE:</u> *Currently engaged in Anti-Terror Research which was assessed and appreciated by ISRO and in Deep under Military Base and Space Research (DUMBSI) Infrastructure. This research work is in progress which includes a detailed analytical study on bay-by-bay design of a structure, computational deformations study using software packages, experimental study of my new design philosophy through a proto type, and study on FRC & clubbing Green Building Concepts.*

**General standards for new structures and existing structures are formulated*