COUNTERTERRORISM CIVIL ENGINEERING DESIGN

by

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Bachelor of Engineering in Civil and Environmental Engineering
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Abstract

Because of the increasing concern about terrorist attacks, engineers have shown a substantial interest in making buildings safer for people. In order to come up with the most adequate design, experts have to carefully define the level of risk on the new structure, since people don't want to live in bunker-like buildings. Then, a good understanding of explosive devices will be a major help to keep the damage localized, preventing the overall collapse of the structure which can cause a lot more deaths than the explosion itself.

The first and most important parameter is to secure the building's perimeter by increasing the standoff distance or by using security devices such as gates or even bollards around the building; careful site planning is essential and it costs a loss less when accounted for early in the design phase. Also, a wise choice of construction materials will mitigate blast effects; windows, doors, HVAC and firefighting systems should be designed to save lives and to not cause more injuries! Finally, the major driver for a successful blast protection is designing redundancies to carry the additional loads imposed by an explosion; structural members will therefore work as mediators for alternate load paths in the case of damage of their neighboring members.

Thesis Supervisor: Jerome J. Connor
Title: Professor of Civil and Environmental Engineering

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I would like to thank a few people for making this thesis, and almost everything else this year, possible.

Professor Connor, for his guidance and encouragement

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Introduction

Because of the acts of terrorism of April 19th 1995 in Oklahoma and September 11th 2001 in New-York City, and the recent wars around the globe, there is a growing concern on the safety of buildings. Nowadays, civil engineers have the responsibility of constructing buildings that could withstand severe loadings such as blast waves, and that could serve as shelters in the case of an attack, instead of causing more deaths by collapsing on the survivors.

All buildings are different and the recommendations described in this paper are not intended to apply to all structures; each building should be individually analyzed depending on a given threat. Because every structure is unique, the optimal design cannot be arrived at by a formula; there are many design options available and guidelines will be developed to attain a balance between the safest and most economically feasible design.

Some of the physical hazards that could be caused by an explosion are flying debris, broken glass, smoke and fire, blocked exits, power loss and communication breakdown, and most importantly progressive collapse of the structure. However, the major issue is the preservation of life since blast may cause serious injuries to the head, lungs and abdomen; people may also suffer from burns, amputations and most obviously, death.

1. Threat and Risk Assessment (1)

Defining the threat for a new structure is a key issue which will guide us through the design process. In fact, the designers ought to know what needs to be "protected" in order to recommend security measures. Usually this assessment is straightforward, but predicting threats gets very complicated since the potential attacks facing any structure are limited by the collective imaginations of the design team.

Threat assessment of a facility evaluates the potential aggressors and the type of tactics that they are most likely to employ; a complete spectrum of threats should be considered, including natural ones such as earthquakes, floods… and man-made ones which are most likely terrorist acts.

The result of the threat assessment should consist of a list of credible threats and attack scenarios. Some threats can be foreseen using crime statistics gathered by experts by law enforcement agencies such as the Federal Bureau of Investigation (FBI) or the Department of Defense (DOD); the assumption here is that where crime has been committed repeatedly, it is likely to occur again. Some institutions might offer no material gain for attackers but their function or politics make them probable targets. For the acts of terrorism, statistical data becomes very unreliable because of many observed anomalies; in fact, terrorists are usually not represented by the census data where the event occurred.

Risk assessment will incorporate a threat assessment, the physical security assessment, and the vulnerability assessment to evaluate the potential risks associated with each threat. A physical security assessment generally includes suggestions for countermeasures required to meet a desired protection goal and vulnerability assessment quantifies the potential impact from specific threat scenarios based on the planned conditions.

Risk mitigation's objectives are to quantify the existing risks and to make recommendations to reduce medium to high risks to the extent possible; this assessment will be a huge help in the development of design criteria. The overall mitigation plan will reduce risks through lowering the impact of loss from a successful attack by lowering the structure's vulnerability to an attack.

Most of the "Risk Mitigation" companies have their own proprietary software which evaluates the effect of attacks (impact of fire, blasts...), models the whole area around the site with the help of surveys and crime statistics, simulates many threats scenarios and has many more features. After inputting all the necessary data into these programs, security assessments and security plans will be developed for the structure to be designed.

After the events of September 11th 2001, engineers have modified how risk is assessed; the reason why is because there is two different aspects for risk: the actual risk and the sense of risk:

"The actual risk may not have changed, but everyone's perception of risk has changed"; Ted Meyer former chair of *ASME*'s (American Society of Mechanical Engineers) *Safety Engineering and Risk Analysis Division.* (1)

Gaining an understanding of terrorist organizations combined with some risk factors will help engineers determine what counterterrorism applications must be made and where. Finally, engineers will only be able to design against or even manage for the risks they expect; they will definitely not be able to eliminate the risk entirely.

2. Multi-hazard mitigation strategy (6) (8)

The majority of owners and users acknowledge the fact that terrorist attacks have high consequences but their low probability of occurrence make people not willing to allocate more funding for the protective counter-measures suggested by threat and vulnerability analyses. The problem remains that the damages inflicted on the unprepared buildings is very high; as seen in **figure 1** below by the *Sentinal* (Vol. I, No.3, 1993) "explosion has the highest average dollar loss of all perils" (2).

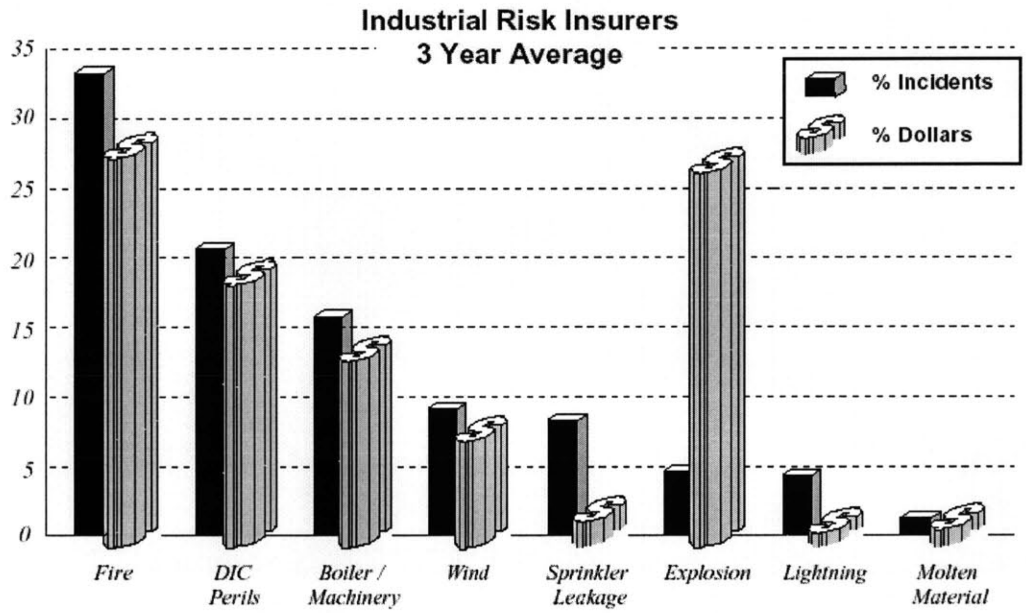


Figure 1: Industrial Risk Insurers 3-year average. (2)

To overcome this problem and thereby support blast-mitigation building design, much of the research done has maintained a broad perspective, where new designs solutions can apply to other hazards, and therefore can be more readily accepted. For example, these measures might apply for blasts, fires, earthquakes, extreme winds... Although earthquakes and extreme winds may have similarities with blast effects, the fact that they are natural events and not malevolent acts makes it impossible to alter their timing to maximize the damage inflicted on people and buildings which is precisely the target of terrorist attacks. As part of this multi-hazard mitigation strategy, improved blast resistance will add very little costs, if any, to the overall construction costs.

3. Explosions

A. Commercial Vs Military Structures (2)

For years, military facilities have been designed to resist blast attacks and their focus was to sustain the structure for the purpose of maintaining its mission. In contrast to that, commercial buildings will be designed only to saves lives, and there will be no concern for saving the structure as a whole; localized damage will be allowed, but not total failure, to permit the rescue teams to evacuate the victims. The overall collapse of the structure usually causes a lot more deaths than the blast itself.

A lot of care must be taken when designing terrorist-resistant buildings because people are not willing to live or even work in bunker-like buildings. Keeping this in mind, we want our site to be as secure as possible; some parameters that directly influence the impact of an exterior blast are the keep-out distance and the degree on fenestration (number and size of windows). Obviously, the architectural and structural features of the building will be the key parameters in determining how our structure will respond to the blast loading. Before dealing with all these parameters, a good understanding of how bombs are categorized is essential for design purposes.

B. Blast loads (2) (9)

An explosion is a rapid release of stored energy; there are many different types of explosive devices, including TNT (Trinitrotoluene), C-4, Semtex, and Ammonium Nitrate & Fuel Oil (ANFO). To standardize the criteria, explosive devices have had their charge-weight scaled to an equivalent amount of TNT.

Dynamic loads induced by earthquakes and strong winds are very time dependent and their durations are measured in tens of seconds; however, those imposed by explosions are non-oscillatory pulse loads with durations 1000 times shorter. Blast loads are therefore more critical since the shorter the duration, the more pronounced the inertia forces; the structural design must be developed to fit the expected loading conditions. The graph of Impulse loading is shown in **figure 2** below.

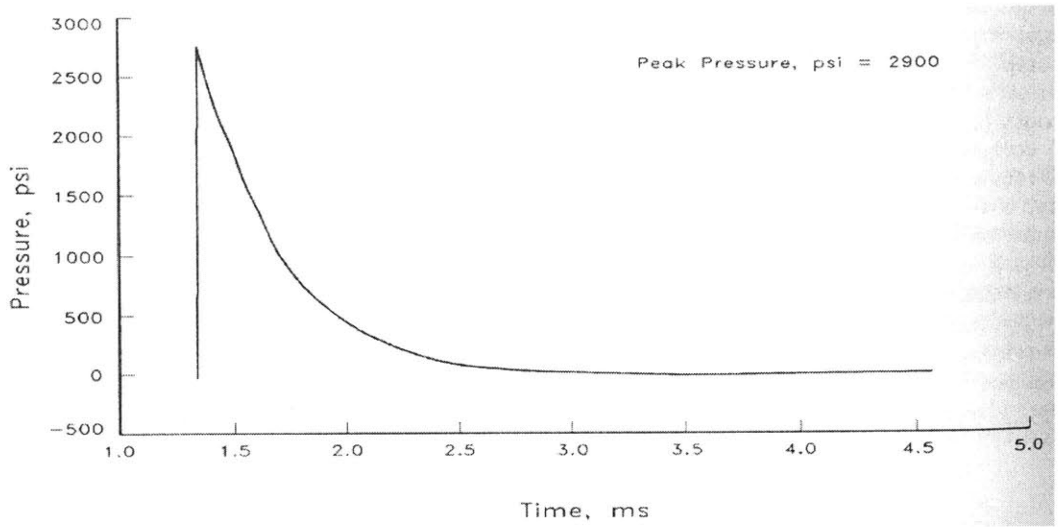


Figure 2: Graph of Impulse loading. (9)

A blast can be thought of as a large wave that goes over and around the building, but the two most important elements defining the threat of a bomb are its charge weight or size and the distance between the bomb and the target. In fact, as a bomb explodes at the ground surface (or near it), the blast pressures resulting from this hemispherical explosion (**figure 3**) will decrease as a function of the distance from the source; the ever-expanding shock front dissipates with range. However, there are exceptions to this rule since the incident peak pressures are sometimes amplified by a reflection factor when the waves encounter objects or structures on their path. The reflections factors are maximized when the obstacle is adjacent and perpendicular to the source and they diminish with the angle of obliquity relative to the source.

"Reflection factors depend on the intensity of the shock wave, and for large explosives at normal incidence these reflection factors may enhance the incident pressures by as much as an order of magnitude". (*Department of Defense*, 1990)

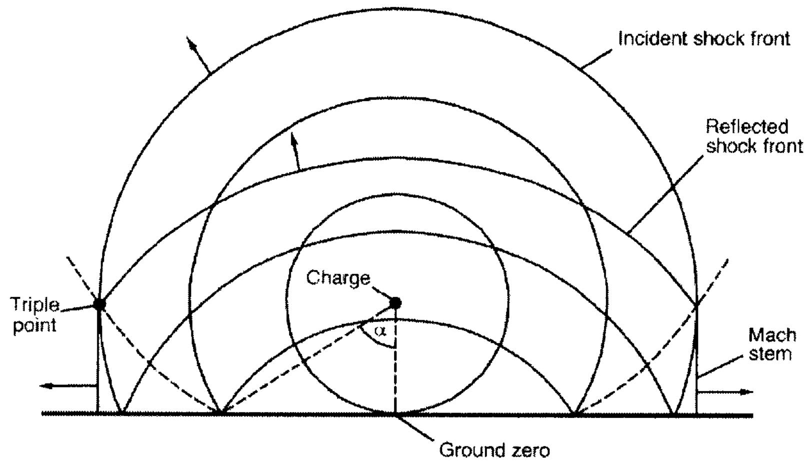


Figure 2.6 Reflection of shock waves for explosions above ground.

Figure 3: Hemispherical shock waves. (12)

For design purposes, blast effects on structural members are related to three principal products of an explosion:

1. The total impulse delivered.
2. The peak pressure delivered.
3. The delivered velocity, distribution, and mass of the fragments of cased explosives.

These products are function of the keep-out distance, the type and the size of the explosives, their casing, and the media through which the blast propagates (very often air).

4. Architectural Considerations

A. Keep-out distance (2) (3)

This first mode of protection consists of creating a minimum distance between the explosion and our structure; since no matter what the bomb size is, the damage will be less severe the further the target is from the source. When charges are situated extremely close to the target, a highly impulsive loading will be imposed: a high intensity pressure load over a localized region of the structure. However, when the same charge is situated further away, the waves will impose a lower-intensity and longer duration uniform pressure-distribution over the entire structure. **Figure 4** below shows the attenuation of the impulse loading with standoff distance.

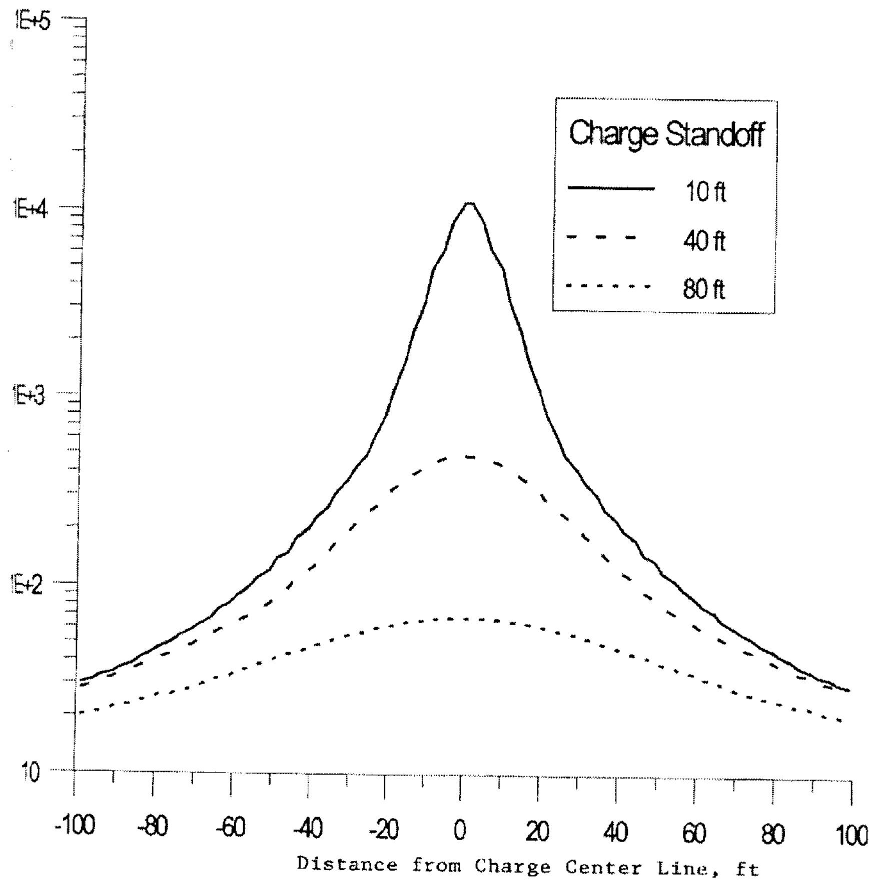


Figure 4-2. Typical Plot of the Effect of Standoff on the Spatial Distribution of Peak Reflected Pressure (from the Detonation of 2,000 lb of High Explosive at Standoffs of 10, 40, and 80 ft)

Figure 4: Effect of standoff distance on blast pressures. (9)

The first and most efficient safety measure is the passive protection of our site. In fact, the strategic placement of the building, its parking lot, gates and trees to reduce traffic volume and speed usually lead to the most economical solution. Engineering solutions have to be reasonably cost-effective, while security solutions must be effective without interfering with the project's operation. As a rule of thumb, counterterrorism measures will definitely cost less when considered early in the design phase of a project.

Primarily, good site planning will create a protective perimeter around our building. Stand-out distances vary by facility, location and threat; they may be reduced if vehicular access is restricted for example, and if the building has an optimized surveillance capability around the site. In urban areas, the required standoff distances are often unrealistic; they are therefore combined with devices such as plaza setbacks or landscaping (**figure 5**), to restrict vehicular access. In order to reduce the risk on our structure and protect its assets, daily routines as well as maintenance personnel of building facilities should be modified and the security forces should often be changed.

Figure 5: Planters used to increase the standoff distance.

"The more there are layers of protection between attacker and target, the less appealing the target. External barriers, either camouflaged as part of the landscaping or introduced as bold statements of defense, may be sufficient to deter attacks." (2)

B. Security

1) Requirements (2) (3)

For internal explosions, i.e. a device placed inside the building, the stand-off distance becomes zero and consequently, greater damage and a lot more injuries will be caused than if the same device was deployed outside the building. This is the main reason why an access control system should be implemented, minimizing the opportunity of explosives being introduced into a building.

Although the main lobby of the building should get most of our attention, all building penetrations are possible points for security breaches. Security in the lobby should be managed by its guards that will be equipped with screening equipment as well as metal detectors. Visible presence of closed-circuit TV cameras will make it hard for the criminals to succeed and they will increase the likelihood of them being recognized and apprehended on the spot or later on; or they might even discourage them of even trying... Identity card systems should also be implemented to keep visitors out of restricted areas and to monitor who goes in and out of the building. What should be kept in mind is that no protective measures will stop the most determined criminals that are often convinced of the sanity and the purpose of their crimes. Some might be actually motivated by the challenge of attacking a well guarded building. **Figure 6** shows a photograph of the lobby of a secured building.

Figure 6: Lobby security.

Security measures around the building should be carefully designed since they are the first line of defense against an attack, keeping the terrorists as far as possible from the building. Some of these measures include barricades, sliding gates, rising beams and bollards.

2) Rising barricades (7)

The first security measure that could be used is rising-barricades which are used to control the flow of vehicles but are also equipped for emergency situations to stop and disable a fast moving vehicle. In fact, strong barricades could withstand collisions with huge vehicles (more than 15,000lbs) going as fast as 75mph. The barricades can usually be lowered using a hydraulic or pneumatic system; they are usually equipped with emergency backup systems maintaining the site secure at all times. Barricades are usually made of heavy steel welded plates which are all mounted above grade and are therefore being rotated. Upon impact, the forces shall be first absorbed by the barricade assembly and then transmitted to the foundation of the unit. The removable portion of the barricade will be fastened with bolts which have their heads below the roadway level.

Barricades will provide excellent security, providing an almost insurmountable obstacle to non-armored vehicles. The barricade system shall be designed to stop a vehicle attacking from either direction and continue to operate normally. **Figure 7** shows a typical rising barricade.

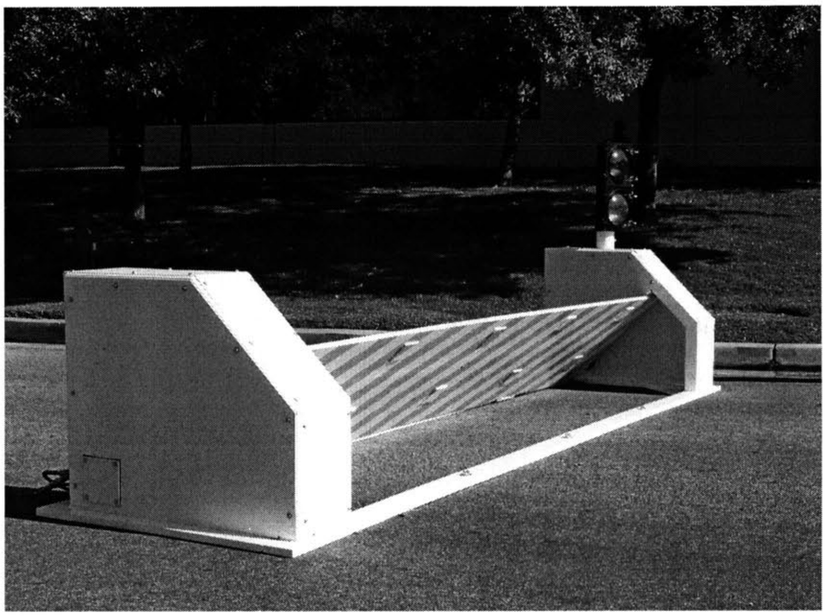
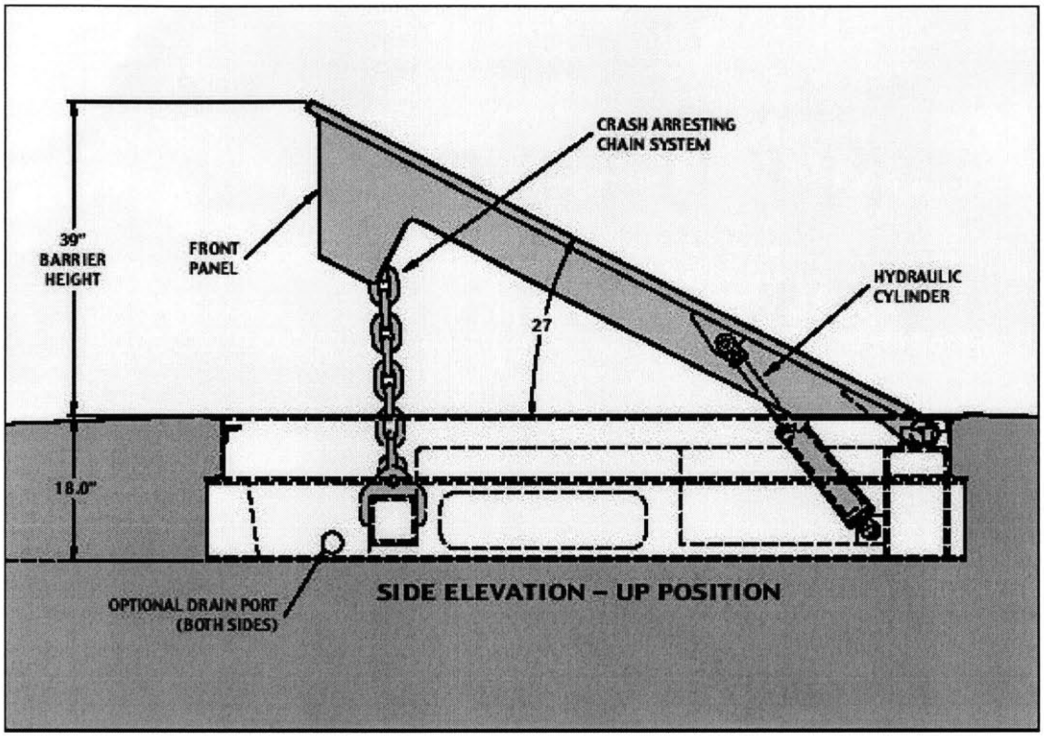


Figure 7: Rising barricade. (7)

3) Highest security barricades (7)

If the threat on our building is extremely high, such as a military bases or federal buildings, highest security barricades are the safest measure to keep vehicles away. In fact, these barricades are able to survive and operate after a 1.2 million foot-pound impact! This anti-terrorist barricade has a shallow foundation with a system that reduces installation complexity, time, and materials costs.

In the lowered position, the barrier ramp is completely flush with the roadway. It is usually raised and lowered to and from the guard position by hydraulic cylinders. The mechanism for raising and lowering the barricade is illustrated in **figure 8**. The barricade shall be a shallow frame below grade assembly which has a heavy steel ramp capable of being rotated to an above grade position. The guard position shall present a formidable obstacle to approaching vehicles. Upon impact, forces shall be first absorbed by the ramp which will then transmit them to the foundation of the unit.



<u>Figure 8</u>: Mechanism of a high security barricade. (7)

4) <u>Sliding gates</u> (7)

Another means of protection is sliding gates which do not allow the intrusion of unauthorized pedestrians and it is an almost impenetrable obstacle to high speed heavy vehicles. A typical sliding gate is shown in **figure 9**.

Sliding gates also consist of above grade assemblies with heavy steel structure. When the gate is closed, it shall present a large obstacle to approaching vehicles. Upon impact, forces will be first absorbed by the steel structure assembly and then transmitted to the end support buttresses and their foundations. The lower portion of the gate is usually a composite structure made of steel structural members; an end-support buttress-system will support it in the fully closed and open positions and will absorb the forces during a collision and transmit them to the foundations.

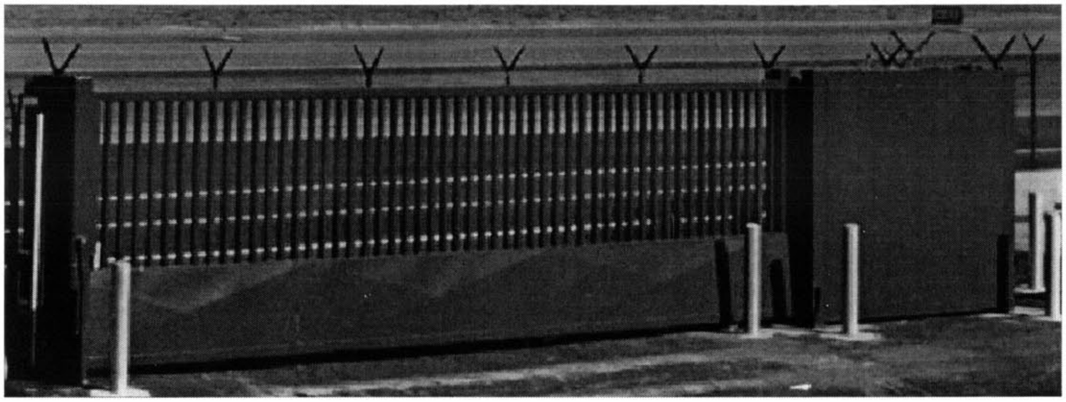


Figure 9: Typical sliding gate. (7)

5) Rising beams (7)

Typical rising beams are hydraulically operated; they consist of a rigid crash beam, support yoke and bearing assembly, hinge end support column and a locking end support column. **Figure 10** shows a regular rising beam.

Barriers are above grade assemblies containing a rigid crash beam presenting an imposing obstacle to approaching vehicles when in the down locked position. Upon impact with a vehicle, the force will first be absorbed by the beam assembly which then transmits it to the foundation bollards of the unit which is usually made of asphalt.

Figure 10: Rising beam. (7)

6) <u>Bollards</u> (7)

The last means of protection discussed are bollards which are the only security measure that could be used to accent and enhance the architecture of our buildings because of its huge variety of styles and shapes. Bollards are also very easy to maintain because the old sleeves can get straightforwardly replaced when damaged. **Figure 11** shows bollards which help maintain the keep-out distance around the building.

Bollards are usually used to protect the perimeter of our building as well as any access routes; they are usually raised into the guard position by a hydraulic or pneumatic power unit. The deployment and retraction of bollards can be controlled remotely by control panels, radio controls, automatic velocity sensors, etc...

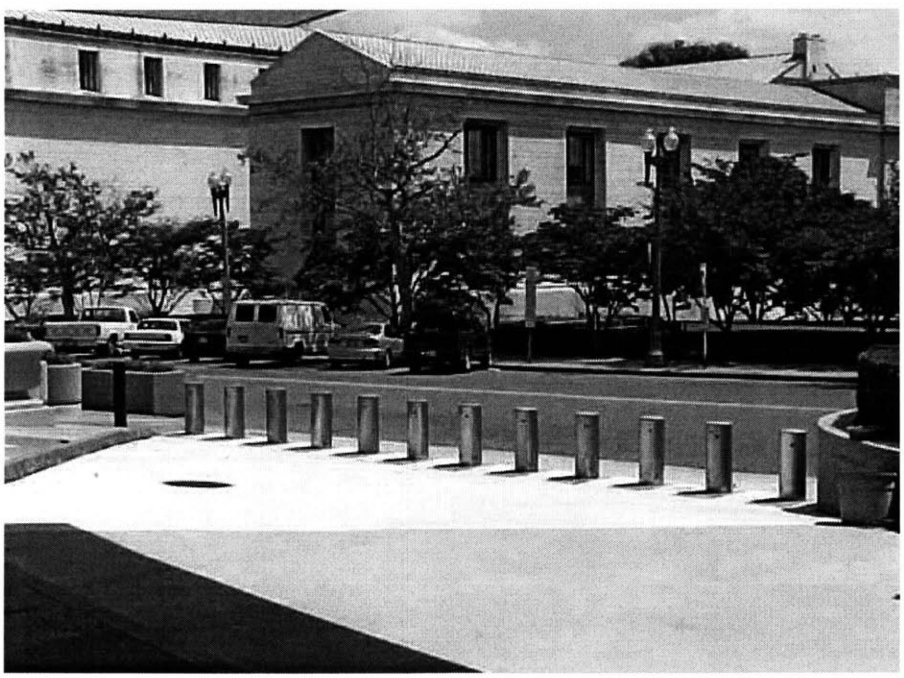


Figure 11: Bollards keeping cars at a safe distance from the building. (7)

Lift bollards are designed to provide a high level of security from illegal traffic movements, by stopping and destroying heavy vehicles traveling at high speeds.

The bollard-system will in fact destroy the front suspension system of cars, their steering linkage, engine crank case and portions of the drive train which will result in the loss of steering capacity and forward propulsion.

The bollard is a below grade assembly which consists of a foundation structure to which the heavy steel cylinder can be lowered. The guard position presents an obstacle to vehicles; upon impact, forces will be first absorbed by the cylinder which will then transmit it to the foundation of the unit. The underside of the Bollard is usually made of an asphalt emulsion coated for corrosion protection.

C. The building's exterior

1) The façade (2) (11)

A very delicate balance must be achieved between protecting people's lives and their property and providing a pleasant living/working environment. The architectural requirements of most of the buildings call for glass windows around the first floor. Severe damage will happen to the structural elements and the connections of the lower floors unless this area is constructed in cast-in-place reinforced concrete, instead of block walls or curtain walls.

At small standoff distances:

"To protect against a lower charge weight, a nominal 12in thick wall with 0.3% of steel doubly reinforced in both directions might be required.

For Intermediate charge weight protection, an 18in thick wall with 0.5% steel might be needed.

Finally, a large charge weight at small standoffs will likely breach any reasonably sized wall at the lower levels. Therefore precautions have to be taken and adjustments made for the design of the entire structure."

(2) By M. Ettouney, R. Smilowitz and T. Rittenhouse.

If ornamentation is to be used for the inner facade, lightweight materials such as wood or plastic are likely to cause less lethal injuries than brick or metal for example.

2) Windows (2) (3) (9)

The weakest links of the exterior of buildings are the glass windows. In fact, these pressure sensitive elements will be the first to fail in response to an explosion. The commonly used annealed glass behaves very poorly when loaded dynamically and its failure will produce large sharp-edged flying shards very similar to knives and daggers. As a matter of fact, the majority of the injuries of the Oklahoma City bombing of 1995 were caused by flying glass. As the windows will fail easily, the waves of the blast will enter the building causing more damage and injury. There is a direct correlation between the degree of fenestration (openings in the facade) and the amount of blast waves allowed to enter the structure: as we decrease the amount of fenestration, we will limit the blast effects. For example, fenestration is limited to 15% in embassies; however, this number does not apply to modern office buildings that request an open feeling and proper lighting. **Figure 12** shows the damage to a building's regular glazing after an explosion.

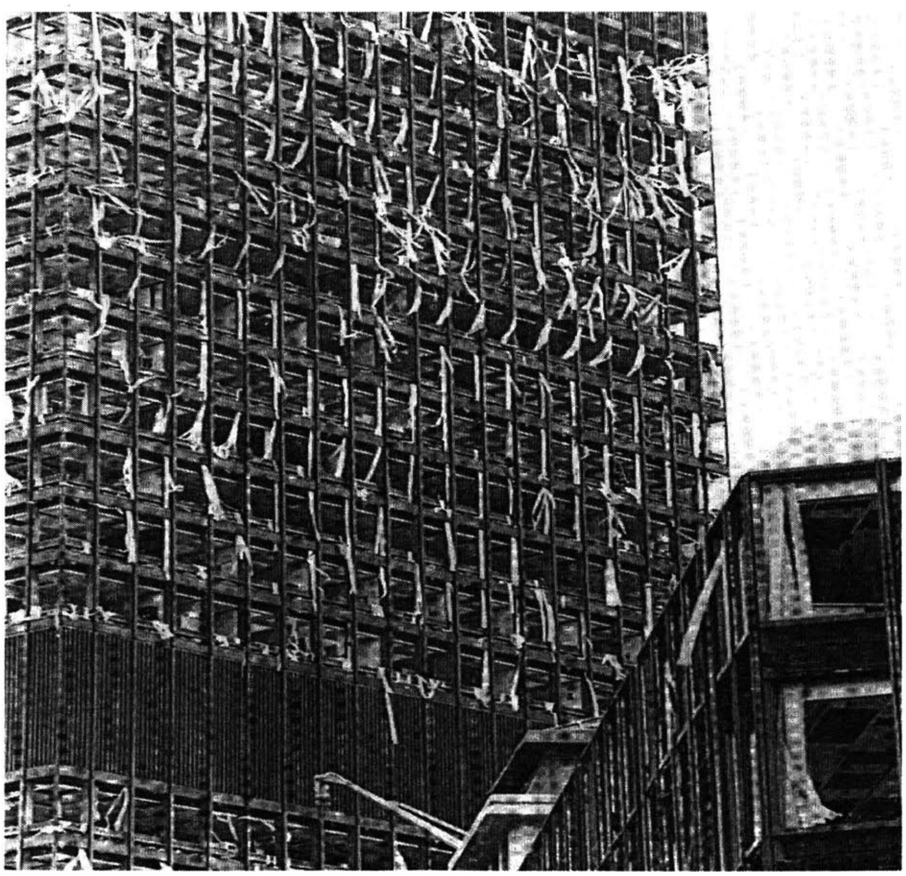


Figure 12: Glass damage on building after an explosion. (11)

Typical anneal glass can only resist low blast pressures, so in order to limit the amounts of flying shards, we could reduce the number and size of windows or use blast-resistant glazing. In fact, small windows will generally fail at higher pressures than larger windows making them less prone to breakage. The fact remains that windows, once the sole responsibility of the architect, have become a structural issue for the design of blast resistant buildings.

There are many types of blast-resistant windows which will solve the problem of flying shards:

1. *Composite windows* use layers of different glass types and thermoplastic coatings in specially designed frames. The total thickness of the window will depend on the security requirements.
2. *Bullet resistant windows* have many layers of glass and plastic bonded together to stop a projectile. In fact, the outer layer (sacrificial) will break into large pieces of glass which will remain bonded to a polycarbonate pane; many similar layers will create a barrier strong enough to resist prolonged physical attacks.
3. *Monolithic thermally tempered glass* will resist blast loads because the material used is much stronger than normal glass and the pane of glass used is massive; this will easily resist a transient impulse load.
4. *Polyester coating films* can be applied on the inner face of regular glass windows; its self-adhesive face will hold the glass together after its failure. Also, in case the blast was strong enough to blow the entire pane out of its frame, the projectile will travel a shorter distance than individual glass fragments, causing fewer injuries and less damage to sensitive equipment inside the building; **figure 13** compares the trajectories of the coated and uncoated panes after breakage. Structural members can also be added across the window, as seen in **figure 14** below, as a supplementary safety measure to stop the shattered pane.

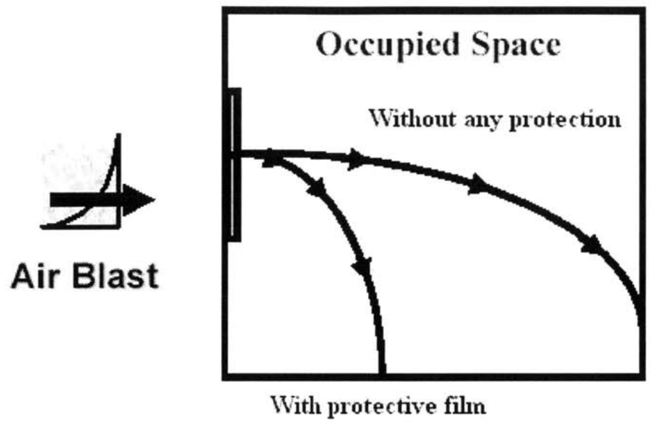


Figure 13: Panes' trajectories. (6)

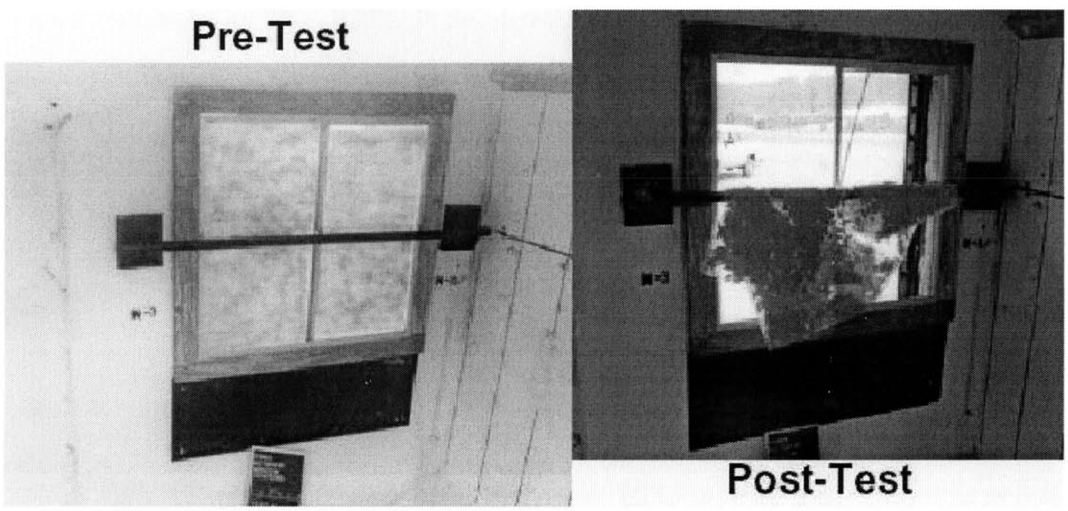


Figure 14: Structural member added to stop the shattered pane. (6)

The properties of blast-resistant transparent glass panes are essential to understanding their physical characteristics. A new generation of heat-hardened and chemically laminated glass as well as new window systems which include cheaper and thinner laminates for the anchors are currently being designed.

The first type of blast-resistant glazing consists of annealed glass heated to a temperature near its softening point and forced to cool rapidly; it is described as "**heat-treated**" glass. The heat treating process produces highly desirable conditions of induced stress which result in additional strength, resistance to thermal stress, and impact resistance. This glazing can be categorized as:

- *Fully tempered*: having a surface compression of at least 10,000 psi, it fractures into small, relatively harmless fragments. This phenomenon reduces considerably the likelihood of injury to people, as there are no sharp shards. (Used for the side and rear windows of cars)
- *Heat strengthened*: having a surface compression between 3,500 and 10,000 psi, the fracture characteristics of heat-strengthened glass vary widely from very much like annealed glass near the 3,500 psi level to similar to fully tempered glass at the 10,000 psi level.

The second type consists of "**chemically tempered**" (alkaline) glass which draws its strength from pre-compression of its outer skin. In some cases, chemically tempered glass can achieve very high levels of surface compression: up to 45,000 psi, but their cost is not competitive at all compared to all other blast resistant glazing.

The third and last type under consideration is a thermoplastic glazing: "**Polycarbonate**". This glazing is very difficult to break, and therefore often required to be equipped with a pop-out system for emergency cases. Its major problem is that it burns when exposed to open flames releasing carbon monoxide and carbon dioxide; however not generating the dangerous gases associated with the burning of plastics such as Cyanide and Chloride. Also, polycarbonate degrades when exposed to ultraviolet (UV) radiation and has a thermal expansion coefficient 10 times larger than that of regular glass. To solve these problems, urethane inter-laminar materials are used to permit relative motion due to its expansion and typical annealed glass is usually used as an exterior layer providing UV resistance; the large shards produced by the annealed glass will be held in place by the polycarbonate which will provide the blast pressure resistance. (Polycarbonate is used for the windshields of cars)

The direct costs as well as the maintenance costs associated with blast resistant glazing are extremely high. It is unlikely for a window to survive a terrorist attack; therefore, it might be wiser to allocate most of our blast-construction funds on structural upgrade in order for the structure to keep standing rather than securing the windows.

What is equally important to the design of the glass is the design of its attachments that are supposed to hold the window long enough for the failure stresses to develop on the surface of its pane. If the attachments fail before the window itself, the latter will dislodge intact causing serious injuries and damage. In order for the window assembly to behave properly, the glazing, mullions and anchorage must all be capable of transmitting the load to the surrounding structures. As the pressures on the windows increase, the exterior wall's size will dramatically increase too.

Frame elements for blast-resistant windows should be able to hold the full static capacity of the glazing. If the frame deflects excessively, higher principal tensile stresses will be induced in the pane and the total available strain energy to resist the blast waves will be reduced.

"Permissible frame deflections are limited to 1/230th of the supporting span for Thermally Tempered Glass (TTG) and 1/100th of the supporting span for polycarbonate and glass/polycarbonate layered systems."

(9) Meyers 1984, Keenan et al. 1986, Department of State 1990

Frame elements should also be designed to withstand the actual dynamic capacity edge shears transmitted by the blast-resistant glazing. The edge shears will be determined from the magnitude and duration of the applied load, the resistance of the glazing and finally, the inertia effects of the plate (calculated from the deflected shape of the plate). The frame will be analyzed for this combined loading.

D. Doors (9)

For internal threats, doors are the weakest links, both in the structural counter-blast design and the security design; therefore, they should be carefully designed to provide sufficient safety in our structure. Doors can be divided into two categories: **commercial** doors (personnel and equipment), and vault doors. Common personnel doors are usually made of hollow steel panels that can be reinforced with vertical channels, and filled with a noncombustible core. Personnel security doors are sometimes used as an external barrier and they are often made as a one-way secured entryway. Equipment doors however, can be corrugated metal roll-up doors, solid-panel sliding doors and rigid-panel overhead-type door. Unlike the very secure **vault** doors which are used in mercantile or banks vaults, commercial doors can easily be defeated with the appropriate tools and do not withstand any blast effects.

The design of doors to stop burglars or even terrorists with tools will not be covered in this paper; only a brief overview of blast effects on doors will be exposed. In fact, an explosive charge that is not in close proximity of the door will produce a uniform pressure which the door should be able to resist if properly designed. The materials most commonly used are reinforced concrete or solid steel; and the door sections are designed to resist the total pressure applied by blast waves as well as to stop the progression of fire as well as blocking the flying shrapnel. The supports of the door are as important as the door itself; frames and hinges should be carefully designed to withstand blast pressures in both directions (direction of the opening and closing of the door); the supports should resist at least as much as the total flexural resistance of the door's panel.

E. Securing appliances (2) (3) (9)

Trees can improve protection by obscuring assets (**figure 15**) and people; in fact, surveillance cameras can be discretely mounted on them to screen perpetrators. Communication systems are also important assets and should be protected by locking manholes and monitoring underground tunnels. As a general rule, building services such as gas, fuel, power and water supplies should be remote from any high risk zone; and if it is not possible, they should be encased with blast-resistant coverings in order to remain operational at all times. Also, locating electrical transformers inside the building will eliminate the possibility of them being accessed by unauthorized personnel. In the case of an emergency, alternate sources of energy should be considered, i.e. if one source of power is lost, a second one should substitute it. For example, backup generators could be located in the building's basement, (far from each other though!) and would operate automatically in the case of a loss of power on site.

The main problem is that any additional appliance located inside the building's perimeter will cause losses in rentable space and this will definitely not appeal to the building owners.

Figure 15: Landscaping used to protect building's facade.

F. Securing the delivery areas (2) (10)

One type of delivery area is loading docks; they are at a higher risk than the main building's entrance since bombs can easily be introduced through these docks and loading trucks may contain large amounts of explosives. For buildings where the threat is relatively high, loading docks should have hardened walls and their slabs and framing should be heavily reinforced.

Their location is a critical parameter; they should be placed away from electrical appliances, power and fuel lines, and most importantly away from critical life safety systems such as fire command and emergency systems. A good ventilation system should also be provided in case of a blast. (Mail rooms and receiving areas should be dealt with in the same manner). In high risk buildings, such locations should be located in a remote location, preferably off site even if it incurs more costs and inconveniences.

G. <u>Parking Facilities</u> (2) (3)

Parking lots located **outside** the building perimeter have to be secured to guarantee the required keep-out distance from the face of the structure. Also, street parking should not be allowed on the side of the street next to the building; the authorities might have to be compensated for that since the city gains a lot of money from street parking. In addition, depending on the approval of city officials, one lane of traffic (along the building's perimeter) could be removed and changed into an extended side-walk.

For the design of an **underground** parking garage located below the building, the concern is the progressive collapse in the event of a car's explosion. The design of the parking garage should be dealt with very carefully and all structural considerations detailed in the next section should be taken into account; emergency ventilation is also prudent. If an underground garage must be used, a space next to the building should be considered rather than just below the building.

Obviously, the parking lot should be **eliminated** but this happens to be very unpractical especially because of the lack of parking spaces especially in major cities such as New York City and Boston. Where parking cannot be excluded, the number of spaces should be limited to the tenants only, and depending on the threat assessed, parking security should be equipped with machine readable identifiers, vehicle-weight sensors and spot checks should often be performed.

H. Choosing materials (4) (5) (11)

The blast loads have a very short duration and a high intensity, so the ductility and the natural period of our structure are going to govern its response. As a rule of thumb, tall buildings have lower natural frequencies therefore longer natural periods than short buildings. Individual structural elements such as beams and columns might have their response time approaching the loading duration; this is the main reason why ductile elements will be safer in the case of an attack. In fact, ductile members made of steel or reinforced concrete will absorb a lot of strain energy before breaking and therefore can undergo substantial bending; however, brittle elements made of glass, brick, wood, or cast-iron for example will fail abruptly without going through any deformation.

Concrete is the most widely used construction material, and its most important property when designing impact resistant structures is its compressive strength. However, when concrete is exposed to blasts, spalling and fragmentation will occur; but this may be reduced if internal reinforcements are added to increase the strength and fracture toughness of the concrete or if fiber-reinforcements are applied on its surface. Typical reinforcements include steel bars or wires, fiberglass, carbon, and other polymer materials. Polymer materials (relatively inexpensive) sprayed on the surface of concrete will hold fragments together although the concrete might undergo severe cracking.

Metals are also very commonly used as construction materials; they include steels, aluminum alloys and titanium. Metals are highly useful in protecting structures against explosions because of their inherent strength, toughness and energy absorption capability. They are also useful in designs due to their relatively low cost and flexibility in modifying their characteristics: ductility, strength... For example, a higher ductility will allow a greater deformation of the metal thus permitting the penetrating shrapnel to proceed farther through it. In addition, some metals have high impact strengths, which are indicators of their toughness and resilience to fracture when hit by a projectile and also their ability to sustain multiple hits. Another very important characteristic when considering sustained loads is fracture toughness which determines how resistant a metal is to crack propagation; high hardness metals are poor structural materials because they are more susceptible to a brittle fracture; conversely, lower hardness metals have good structural qualities, but are not as effective in resisting fragment penetration. A good balance must be found to pick the adequate material.

Of the majority of metals used, steel has the greatest resistance to penetration, but at the expense of added weight to the application; Titanium however provides very good resistance at a much lower density than steel but at a premium price; finally, Aluminum alloys usually require a much greater thickness to attain a comparable penetration resistance to that of steel and Titanium.

A new set of construction materials being used are **composites**. One example of composite materials is the *Polymer Matrix Composite* (PMC) that combines the beneficial properties of both polymer resins (ability to absorb and mitigate kinetic energy) and high performance fibers (high to ultrahigh modulus of elasticity). High performance composites possess higher specific strengths (ultimate tensile strength divided by density) than metals, and they are capable of providing equivalent blast resistance at reduced weights. Polymer matrix composites commonly used are fiberglass (lowest cost), aramid fiber, and polyethylene fiber composites.

Thermosets, however, are matrix resins used in conjunction with fiber materials; they are easier to process, they have higher operating temperatures, and are more chemically resistant, but are more susceptible to cracking, and are toxic in their uncured state. Epoxy resins are generally used for the best energy absorption properties while phenolic resins are used for fire, smoke and toxicity resistance. Layered composite back-plates utilizing epoxy and phenolic materials are used in some cases to combine the beneficial properties of both resins. Because many of these composite materials can be expensive to apply in structural protection, with judicious selection and design, they may be applied in a very cost effective manner in selecting critical areas where performance criteria demand them.

The last type of materials discussed is **ceramics**. In fact, ceramic armor materials are used for the containment of blast fragments and bullet penetrations; they offer the advantage of weight reduction as well as higher impact energy absorption than the majority of metals. Unlike metals that absorb kinetic energy through plastic deformation, ceramics absorb the energy through fracture; any protection scheme utilizing ceramics must therefore use backing plates providing structural support during the impact event; these backing plates can be made of metal, polymers, or composites. Tiles are used to limit the fracture area, and thin coverings also prevent flying ceramic shards.

The most common ceramic materials used for armor applications are Alumina (Al_2O_3 which is the cheapest), Boron Carbide (B_4C), Silicon Carbide (SiC), and Titanium Diboride (TiB_2).

In addition, the use of materials withstanding extreme heat will mitigate the risk that shattered pieces will become shrapnel. For example, sheeting made of flame-retardant composite material such as gypsum will retard the spread of **fire**. Also, high performance steel has higher resistance against impact and heat; and a new form of lighter and stronger concrete is being developed to reduce the total weight of structures and gain space. The use of both steel and concrete in beams (steel beams reinforced in concrete not reinforced concrete beams) will add more protection in the case of a prolonged fire; a delicate balance between the amount of steel and concrete has to be achieved.

"Steel is strong but can bend under intense temperatures. Concrete holds up longer against heat, but can crack and break under extreme temperatures."
Klemencic (5)

I. <u>Choosing shapes</u> (10) (11)

Concerning the architectural shapes of our structure, high-mass and long span elements such as beams and slabs are relatively flexible components. On the other hand, rigid, short span and light-weight elements are very poor energy absorbers which will fail catastrophically.

The response of the structure (as a whole entity) will depend not only on the materials used, but with the way, these materials are used too. In fact, a concrete building could be built as a flexible frame or a much more rigid, fortress-like structure. Obviously, massive structures will behave better than those of lightweight construction. More importantly, structures with re-entrant corners (U or L shaped) should be avoided since blast effects will be magnified; these corners will cause pressures to build up. Typically, symmetrical buildings will have the best behavior when subjected to blast loadings.

J. <u>HVAC systems</u> (3) (9)

In the event of an explosion, a lot of equipment from the buildings' interior, such as false ceilings, Venetian blinds (better to use curtains), ductwork and air conditioners, might become airborne. Heavy equipment such as air-conditioners should be placed closer to the floor rather than the ceiling since they might cause serious injuries if explosions detach them.

The major issue concerning ventilation for a building remains the placement of air intakes, since the biological threat is one of the most serious ones. Securing air intake for high rise buildings is relatively easy; vents should be located at least 50 to 60 feet high to prevent toxic materials released at the ground level from entering the Heating Ventilating and Air Conditioning (HVAC) of the building. Common practice is to place these intakes on the roof and concealing them, making it a lot harder for terrorists to contaminate the air supplies; however, these intakes cannot be left unattended. They should be guarded and secured against contaminants; a security camera kept operational at all times should be mounted on the roof to monitor any unauthorized access.

In case of a fire inside the building, HVAC systems should be designed in such a way not to permit the smoke to migrate to the rest of the building. The main lobby and delivery areas should have dedicated supply and return HVAC systems, independent of the rest of the building because of the higher risks in these areas. Taking the security of HVAC systems to the next level would consist of adding negatively pressured ducts which would suck toxic agents into a filtering system; but this would come at very high costs since units will have to be oversized to get enough flow in and out of the building (because of the small size of the openings of the biological filters).

K. Firefighting Systems (3)

The combustible contents of buildings should be kept to a minimum to prevent fires from starting and spreading. Also, the building should be sited far enough from neighboring buildings to provide maximum separation; the use of incombustible roofs, exterior walls and fire protected structural systems will reduce the threat of ignition from adjacent burning buildings.

The use of fire detectors and automatic sprinklers has become mandatory for the vast majority of buildings; these buildings are therefore equipped with their own fire pump room. For high risk buildings, it is more cautious to have two separate fire pump rooms located far from each other and redundant sprinkler systems. The designers must weigh the costs of these redundancies against the chance that their firefighting system will be destroyed during an attack.

For the case of an emergency, the building should be equipped with graphical circulation patterns as well as exit signage. Also, emergency stairways should be added and made wider to accommodate heavier foot traffic; and they should definitely not end in the building lobby but outside the facility. Redundant fire alarm systems can be provided without a big increase in cost, and the use of multiple speaker currents will ensure that the coverage remains if one of the electric circuits is damaged by the explosion. Finally, fire command centers should be monitored during all hours of the day to ensure the maximum safety for the building's inhabitants.

If our building is monitored by security cameras, the control rooms where the video storage tapes are located should be hardened with fireproof materials since the tapes will definitely be helpful during investigations and more importantly, they will serve as a "learning" tool. In order to satisfy their fire code requirements, some countries such as the United Kingdom, Hong Kong and Canada provide separate elevators for firemen. These high speed elevators are relatively small (accommodating not more than 3 to 4 firemen) and they exit into pressurized vestibules equipped with communication equipment and hose racks.

5. Structural Considerations

A. General (2) (8) (9)

The advantage of increasing the standoff distance of a building will be limited by the charge weight of the bomb. If the charge weight is small, standoff distance will significantly affect the threat; however, if the charge weight is large, the blast forces may demolish the structure despite the maximization of standoff distance, therefore not helping with the survivability of the building's occupants. In order for the damage to remain localized and prevent the overall collapse of the building, structural improvements should be implemented in the design of various members of our structure: atriums, slabs, columns, beams, walls ...

Costs are often the major driver in construction; however bearing in mind that the total cost of the structural frame is about 15 to 20% of the total building costs, the required structural upgrade to meet with blast-engineering requirements may result in an increase of no more than 2 to 3% overall. Compared to the estimated damage incurred in the case of an attack, this increase is relatively negligible.

The major driver for a successful blast protection is designing redundancies into the structure to carry the additional loads imposed by an explosion. In fact, structural members should be designed to carry additional loads such as if one member is severely damaged to the point it cannot function anymore, the load path will change and the load will be evenly distributed to its neighboring members.

B. Atriums (2)

In order to give impressive function spaces and balcony elevator lobbies, atriums are commonly used in prestigious buildings and hotels. These atriums will bring natural light inside the building; however, the broken windows after a blast will give the appearance of extensive damage and many internal structural elements will be exposed to blast waves. The major problem in the case of atriums is the multiple reflections of the waves that will increase damage and injuries. When atriums are extensive, i.e. providing a significant open space relative to the overall size of the structure, blast pressures could split the building apart, causing major damage.

The exterior wall of the atrium should therefore be reinforced and the glass and its framings should be strengthened to withstand small to medium charges. Also on the inside, all structural members of the atrium should be strengthened to support the pressures of the reflected blast waves; these members include balcony parapets, spandrel beams as well as exposed slabs.

C. <u>Slabs</u> (2) (9)

The most commonly used floor slabs are reinforced concrete flat plate structural systems; they provide the most economical solution along with the maximum use of vertical space. Usually, as the building is designed, drop panels and column capitals are not required to satisfy the loading requirements; therefore, the thickness of the slab remains relatively the same since live load requirements are typical throughout the building. When the slab is subjected to a dynamic loading, the ability of the slab to transfer forces to the walls and columns can severely diminish, as the moment-resisting capacity at the columns and walls is lost. As illustrated in **figure 16** below, failure can be of different types:

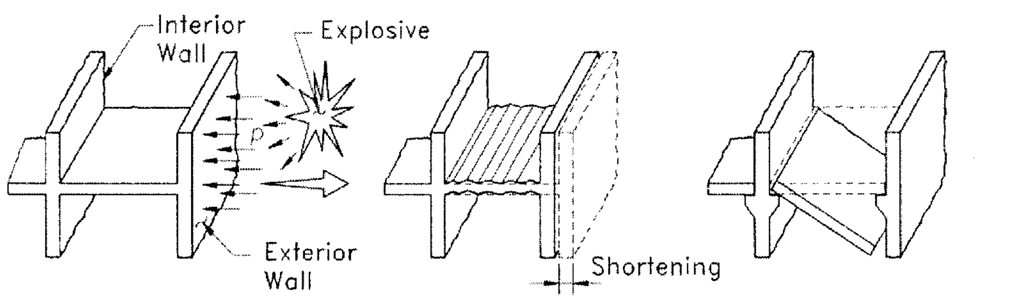
1. The slab might experience *localized failure*.
2. Also shown in **figure 17** below, *punching shear* failure could occur which will increase the unsupported length of the columns and probably buckling of these columns.
3. *Crushing failure* is due to an excessive load transmitted from the edges of the slab. For well connected slabs, failure will only be local; however, for slabs with inadequate connections catastrophic failure might occur. The whole building might lose its lateral stability if the lateral load transfer system consisting of shear walls, columns and slabs is weakened enough.

(a) Global bending/membrane failure

(b) Global shear failure

(c) Local bending/membrane failure

(d) Local shear or breaching



Original structure

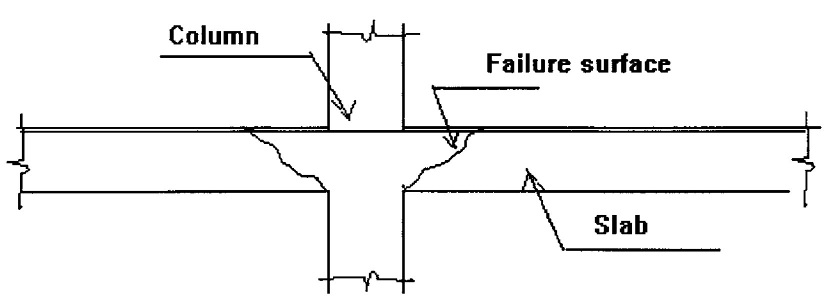
slab well connected to walls

Slab poorly connected with wall (pushed off supports)

(e) Global crushing failure.

Figure 4-12. Principal Failure Mechanisms for Slabs

<u>Figure 16</u>: Principle failure mechanisms for slabs. (9)



<u>Figure 17</u>: Punching shear failure at a column.

To provide the necessary precautions against a blast, the following improvements should be implemented early in the design phase:

- Detailed design of the lower floors of a building should be very thorough since they are the most susceptible to encounter large blast pressures.
- Also in the lower floors, column capitals and drop panels should be provided to reduce the effective slab length as well as to improve the resistance against punching shear failure.
- Although not mandatory, spandrel beams should be included to enhance the response of the slab edge.
- The slab-column connections should be heavily reinforced and closed-hoop stirrups should be properly anchored around flexural bars for additional safety.
- Beams should be included over critical sections of the slab; this will greatly enhance the transmission of lateral loads to the shear wall.
- Bottom reinforcement should be provided continuously through the connection with the columns to prevent brittle failure; for the extreme case where the column has punched through the slab, this reinforcement will allow the shear transfer mechanism not to be inhibited.
- The external perimeter of the building must be hardened especially at all intersecting columns, and reinforcing bars should be anchored at the slab edges and at every discontinuity; **figure 18** illustrates that.

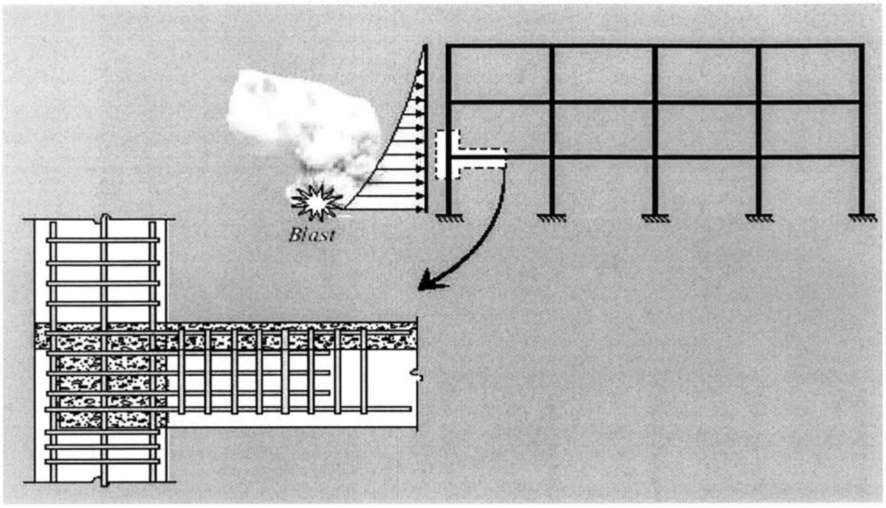


Figure 18: Reinforcement along the perimeter of the building. (2)

- Reinforcing bars should span in both directions to develop tensile forces; special care should be taken at the splices to make sure that the membrane action in maintained in the slab (**Figure 19**). Finally, slabs might be subjected to uplift forces in the case of an internal explosion or of a severe exterior explosion; the slab should therefore be reinforced to resist these loads.

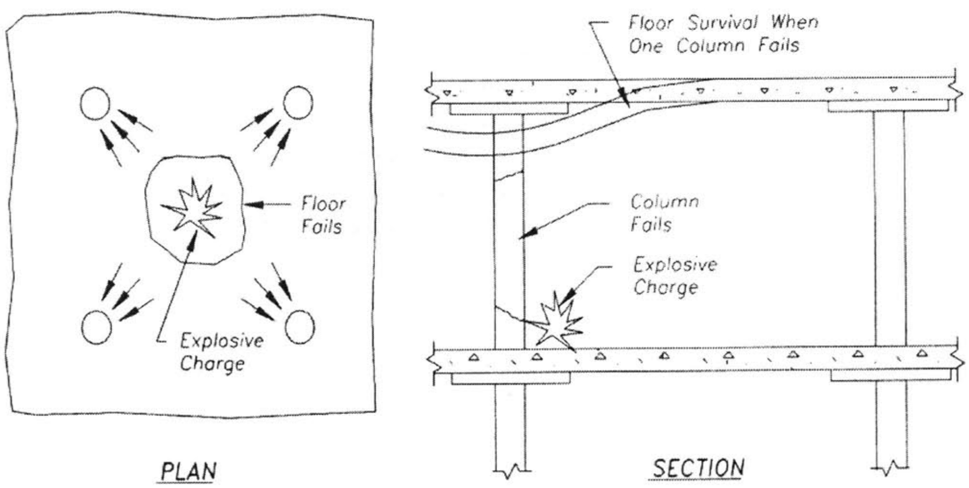


Figure 4-6. Flat Slab Construction

Figure 19: Membrane action maintaining the slab from collapsing. (9)

If the majority of these guidelines are carefully followed, the slab should be able to act as a safety net for the damaged structure; even in the case of punching shear failure, no progressive collapse should develop. Although slabs without good connections or enough ductility will behave poorly, providing large amounts of lethal debris, they could stop the propagation of the blast waves.

Slab deformations interact will blast waves to relieve the pressure on structures; this was the main driver of researchers at *Weidlinger Associates* who are suggesting retrofitting the slabs with openings, deliberately increasing their frangibility; this venting will equalize the pressures applied to the slabs.

D. Columns (2) (9)

In typical structures, columns are designed to resist gravity loads, and ductility is not taken into account as a major parameter. This is definitely not the case for blast-resistant design since columns will be subjected to severe bending in the case they are directly exposed to blast waves; ductility will therefore become a major parameter for the combined effect of the axial loads due to gravity and to the lateral displacement due to the blast waves.

In order for the damage to our structure to remain localized, these are some recommendations to improve the columns' responses:

- The lower floors' columns as well as the perimeter columns should receive somewhat more attention since they are more liable to encounter blast waves; they should be designed with adequate ductility for bending requirements, as well as maximum strength for blast pressures and impact of flying debris. To achieve added ductility and strength, these columns could be encased in steel jackets for example or steel columns could be embedded in reinforced concrete columns or wall sections.
- As slabs may be subjected to uplift forces, tensile forces might briefly develop and the combined effect of bending and tension

might damage the column considerably. For this worse case scenario, the columns could be reinforced to handle a transient tensile force.

- Finally, spiral reinforcement will greatly enhance the lateral response of columns in case of a blast by confining its core.

Again, following one or more of these guidelines will improve significantly the blast-resistant mechanism of columns. Redundancy is very critical for columns to prevent the overall collapse of our structure since the loss of a lower floor column can effectively damage neighboring columns; thus with a "domino" effect, the localized damage will propagate into overall collapse.

Figure 20 shows a picture taken after an explosion in a reinforced concrete structure where there was insufficient ties provided in the column and poor detailing at the column/slab joint.

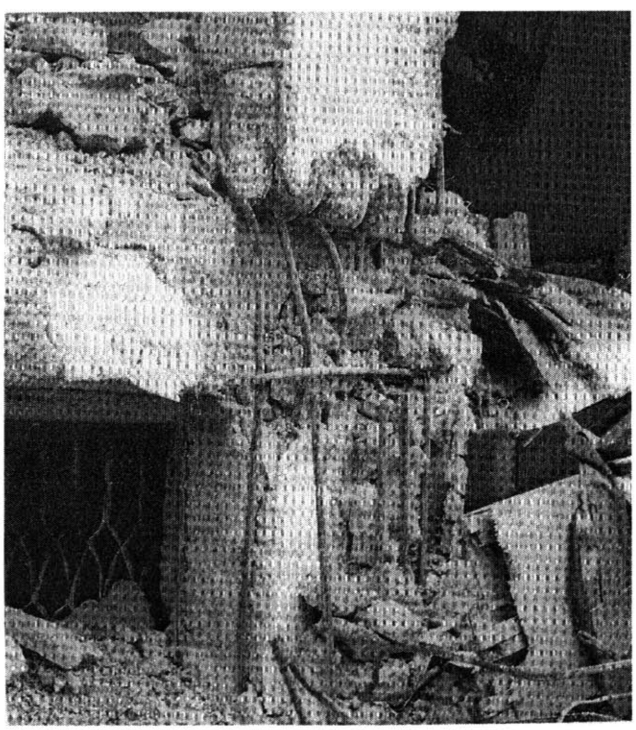


Figure 20: Failure due to insufficient ties and poor detailing of the joint. (11)

E. **Beams** (9)

Just like column and slabs, the beams should be properly detailed: development lengths, bar laps, ties and splices and the materials used are reinforced concrete or steel. The only failure types considered will be those associated with the ductility response. **Figure 21** below illustrates three types of failures for beams:

1. *Membrane failure*: Supports provide enough strength and stiffness to resist displacement at the edges however producing in-place forces (edges will have an inward motion). Failure will occur because the steel's strain will reach rupture strain.
2. *Shear failure*: There are several types of shear failures that should be taken into account during the design process: diagonal tension and diagonal compression failures which are flexural; punching failure which is a local shear failure (these 3 types of failure are not very important when associated with blast effects but they shouldn't be neglected); finally, the direct shear failure which is relatively severe in the case of short-duration dynamic loads. This last failure response is usually localized to regions of geometric or loading discontinuities and is not flexural; failure occurs very early in the structural response, within a few milliseconds from the blast, and the beam undergoes almost no bending prior to failure. Depending on the charge weight of the bomb, the dynamic shear force can many times the shear force associated with the diagonal and punching failures.
3. *Bending failure*: Occurs only when a sufficient plastic hinges form on the beam: "1" is sufficient for a simply supported beam, "3" for a continuous beam. Failure will occur by slipping of the beam from its supports; a lower load than those required for membrane or shear failures will be necessary to fail the beam. This failure can easily be ruled out when beam connections are well designed.

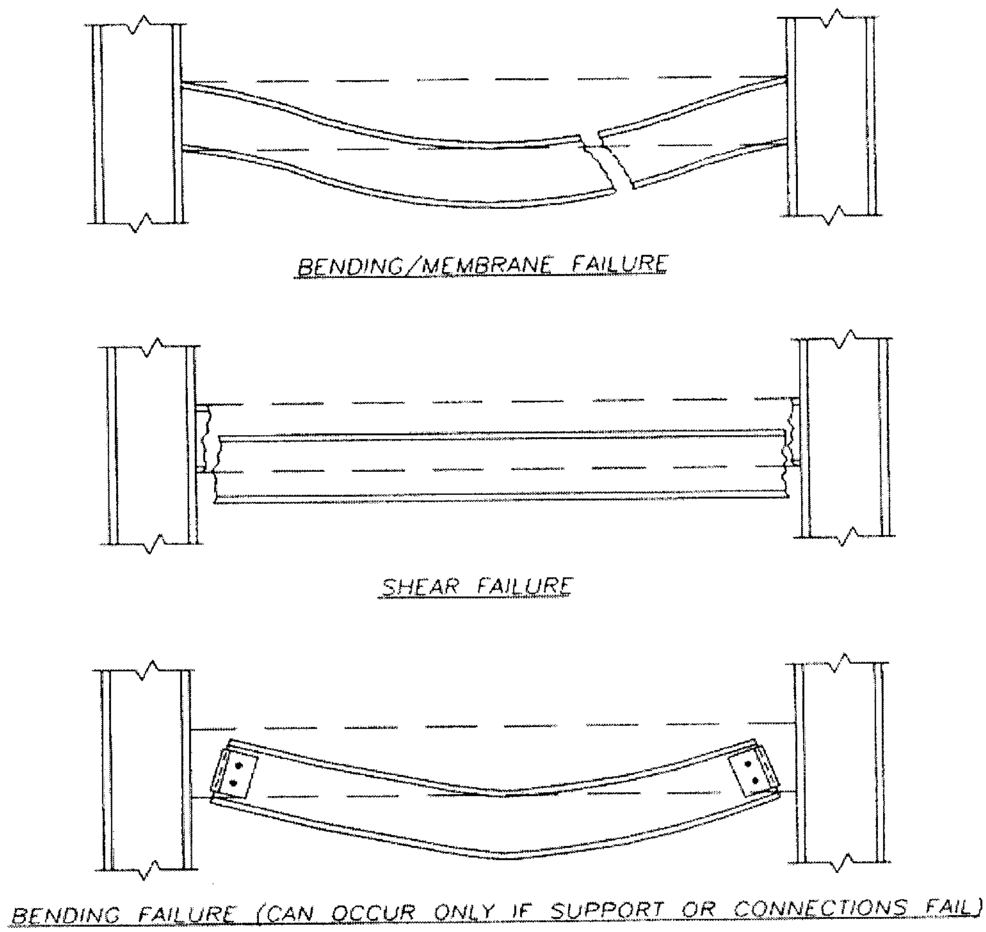


Figure 21: Bending failure types. (9)

F. Load-Bearing Walls (9)

Walls cannot sustain the combined effect of axial and bending loads. This unstable behavior produces a secondary moment caused by the axial force due to the bending-induced lateral deflection, which enhances the lateral deflection causing collapse of the wall.

Usually buildings having load-bearing walls have cast-in place reinforced concrete walls or reinforced masonry walls. In fact, masonry structures have serious blast-resistance limitations for obvious reasons and their use is not desirable. Also, pre-cast concrete construction is not recommended because connection joints will be very difficult to design to satisfy requirements for both strength and ductility.

In order to satisfy the safety requirements for load-bearing walls, reinforcing bars should be continuous into the slab elements as well as in the wall above. For added safety, bar splices should be kept away from the construction joints because heavy debris from the concrete cover might detach after an explosion and the lap splices might fail, cutting the reinforcement and therefore losing the stability.

G. Lateral Shear Resisting Walls (2)

The effect of blast loads is more critical than this of seismic loads since seismic motion is applied over the entire foundation system of the building; blast loads have higher intensities and are concentrated over a smaller region. The total base shear applied in both cases could be the same, but the lateral resisting behavior is definitely not.

In order for our shear walls to resist these localized high-impulse loadings, the slabs, columns and joists should be carefully detailed for ductility of the system, especially for reinforced concrete. The structure will have to deform substantially under extreme loadings and it will absorb large amounts of energy.

The lateral load system should be well distributed throughout the floor plan; shear walls should be located all around the building. This will often satisfy the seismic as well as the wind requirements; **figure 22** below shows a typical shear wall.

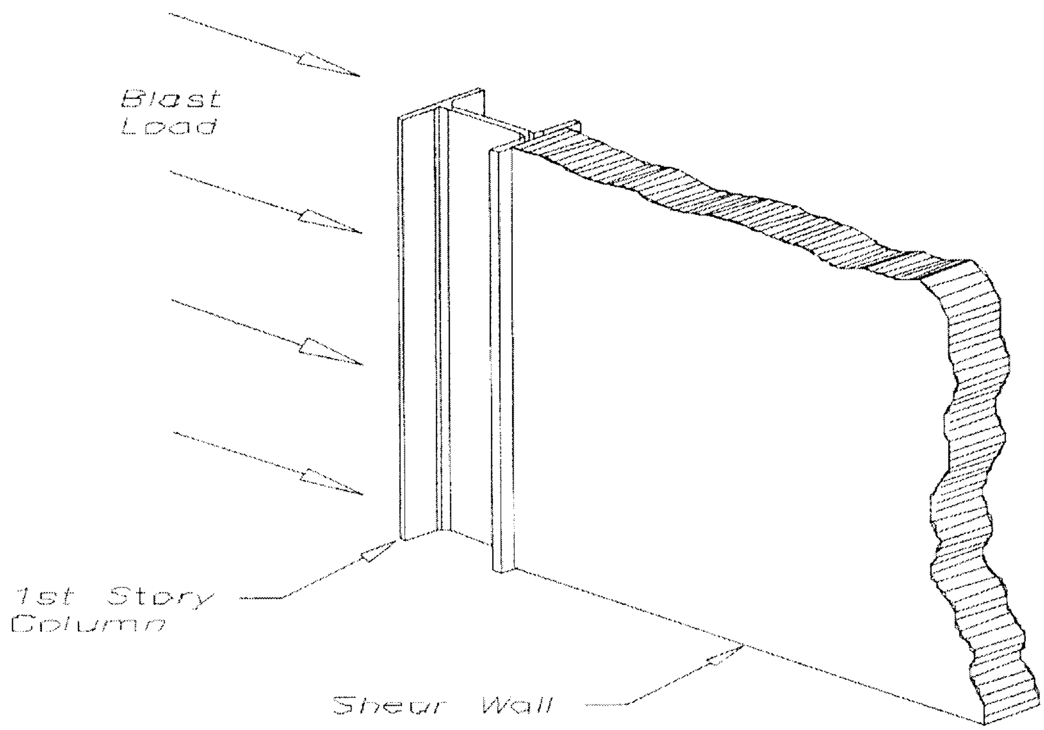


Figure 4-19. Illustration of Situation in Which Shear Wall Behavior is of Interest in Blast-Resistant Designs

<u>Figure 22</u>: Shear wall resisting blast pressure. (9)

"If adding more shear walls is not architecturally feasible, a combined lateral-load resisting mechanism can also be used. A central shear wall and a perimeter moment-resisting frame will provide for a balanced solution. The perimeter moment-resisting frame will require strengthening the spandrel beams and the connections to the outside columns. This will also result in better protection of the outside columns."

(2) By M. Ettouney, R. Smilowitz and T. Rittenhouse.

H. <u>Summary</u> (9)

Most of the structural elements described in the previous sections must have significant amounts of ductility to resist blast loads. Typical strain values can be achieved with appropriate designs; guidelines for ductility designs are shown in the **figure 23** below. The deflection parameter used is "strain" which is the ratio of the critical displacement divided by the member's length: span for beams, height for columns and walls, and thickness for slabs. Shear deformations are separated from flexural ones because failure is more localized; also, reinforced concrete and steel have different strain values because of the higher ductility for steel.

Computer simulation programs can help architects and engineers a lot during the design phase to find the weak points of their designs. These points can easily be corrected without major design changes by adding redundancies. Each new design is then tested under all kinds of severe conditions: strong earthquakes, bomb blasts and high-intensity winds.

Table 4-2. Typical Failure Criteria for Structural Elements

Element Type	Material Type	Type of Failure	Criteria	Light Damage	Moderate Damage	Severe Damage
Beams	Reinforced Concrete (ρ > 0.5%/face)	Global Bending/ Membrane Response	Ratios of Center-line Deflection to Span, δ/L	4%	8%	15%
		Shear	Average Shear Strain Across Section, γ_v	1%	2%	3%
	Steel	Bending/ Membrane	δ/L	5%	12%	25%
		Shear	δ/L	2%	4%	8%
Slabs	Reinforced Concrete (ρ > 0.5%/face)	Bending/ Membrane	δ/L	4%	8%	15%
		Shear	γ_v	1%	2%	3%
Columns	Reinforced Concrete (ρ > 0.5%/face)	Compression	Shortening/ Height	1%	2%	4%
	Steel	Compression	Shortening/ Height	2%	4%	8%
Load-Bearing Walls	Reinforced Concrete (ρ > 0.5%/face)	Compression	Shortening/ Height	1%	2%	4%
Shear Walls	Reinforced Concrete (ρ > 0.5%/face)	Shear	Average Shear Strain Across Section	1%	2%	3%

Figure 23: Summary table for failure criteria of structural elements. (9)

6. Existing buildings (2) (5) (9) (11)

For existing buildings, the first step also consists of assessing the potential threats of exposure to attacks; then, the most important step consists of evaluating the vulnerability of the structures, which is a difficult and inexact approach compared to new designs. The critical components in the structure should be identified and their capacity should be determined relative to their required resistance; most of the building codes are more stringent than they used to be and significant upgrades have to be done for resisting blast effects. Options should eventually be identified for upgrading the structure; conceptual designs as well as cost estimates will therefore be developed. Finally, the optimal design based on technical feasibility and cost effectiveness will be selected.

Usually, retrofitting is the best solution to meet the new security standards; for example, for reinforced concrete buildings, the most adequate method consists of wrapping the concrete with carbon fiber jackets such as Fiber Reinforced Polymer (FRP) jackets that improve its ductility, shear capacity and augment its flexural strength; steel jackets can also be used for reinforcing columns. For a more exact science, one or more of these general guidelines should be followed to enhance the response of existing buildings to terrorist attacks: (guidelines that differ from those elaborated in the structural upgrade part will be discussed only)

- *Mass increase*: An increase in mass of a component will have a positive effect to overcome impulse loading. Because mass added in a member will increase the dead load on its supporting components, their strength will have to increase too.

- *Increased strength*: It can be achieved by increasing the yield strength (σ_y) of materials or by changing the cross-section of members; selecting of either of these two methods depends on the materials used and the type of problems encountered. For example, **wood** should obviously undergo an increase in section; reinforced **concrete** should also have an increase in section size if plastic response is considered as the higher damage category; for **steel**, an increase in σ_y will reduce ductility but will not affect rotation, however an increase in strength will stiffen the member; but the best solution for steel remains increasing the section depth which has the greatest effect on rotation, the most critical parameter.

- *Boundary conditions modifications*: for example changing a two-side supported wall into a three-side supported system will effectively allow it to sustain more loads before undergoing full plastic response. An alternate load path will also be created increasing the redundancy of the structure.

- *Reduction in span length*: stiffness changes will occur because members in reinforced concrete or steel will have significant plastic deformation at the higher damage levels.

Concerning the **glazing** in existing buildings, the majority of owners prefer installing polyester film coatings which is a relatively inexpensive retrofit solution compared to laminated glazing which provides more resistance but involves replacing every window in the building. Coatings on the inside face of the window will hold the shards together after failure. A new British innovation is blast curtains; it consists of translucent curtains that will hold the glass shrapnel although permitting the blast waves to go through.

Protective measures are always limited by practical considerations, such as the budget, the space available or by the limits of available technology. The major budget issue for the installation of improvements, such as new elements in blast-resistant or fire-resistant materials for example, in a building could cost up to 10 more times the original cost of construction.

Conclusion (3) (10)

Any structure which may be considered as a potential terrorist target should have periodic threat and vulnerability assessments; and new courses of action should be undertaken if new technologies are developed. Other major concerns which are often neglected are the emergency operations and the planning for disasters; these two areas can potentially save many lives. In fact, practice drills should be conducted every once in a while and the emergency procedures should be regularly reviewed since they are essential components of an emergency plan.

Buildings are not the only potential targets of terrorist groups; every mode of transportation is at risk too. For example, bridges are potential targets because of their symbolic significance and trains because they can be easily derailed causing a large number of casualties. For the future, concerned parties are evaluating safety measures for major transportation routes: redundancy in roads to keep a region functional in case of an emergency; two bridges (two crossings) instead of one bridge with many lanes; the ports are upgrading their security with "gamma" ray detection of containers and their main concern will move from drugs to weapons; finally, new airports will have blast resistant parking lots and the setback distance will be increased to 300 feet for terminals and the open areas surrounding the airport will be secured to guarantee that planes will not be shot down during take-off or landing.

Finally, the dissemination of public information on projects is a growing concern; for example, public access to the design plans of a bridge can potentially be very dangerous since its single most vulnerable point can easily be identified. In fact, many companies are now removing sensitive information from their websites.

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