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Structural design for the physical security of buildings against blast

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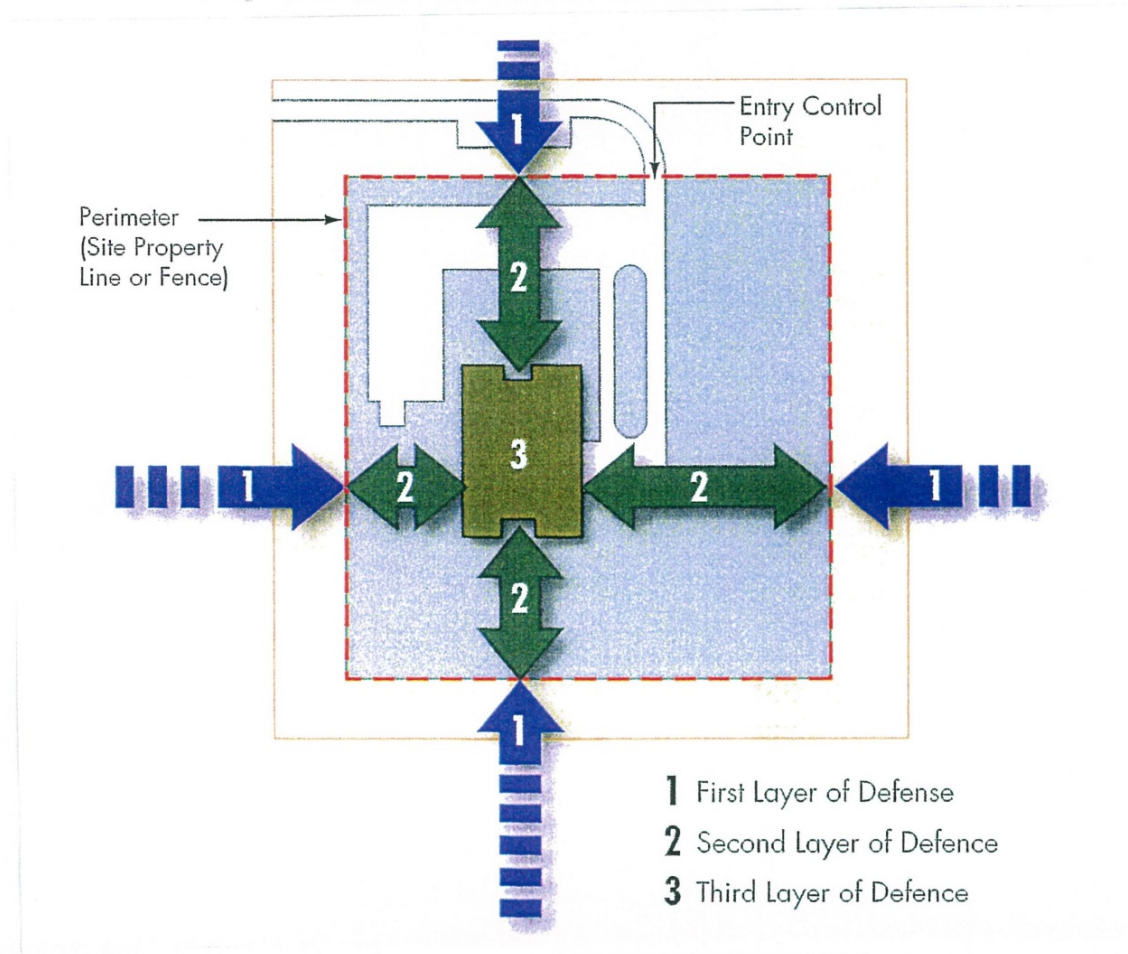


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Physical security of buildings

- Building security issues are about the detection and prevention of intentional threats such as criminal, terrorist, and other malicious acts directed towards the buildings and their occupants.
 - The most obvious protection from the effects of a hostile act is any barrier that can prevent or delay an adversary from reaching a target. A concentric layer of defence system around a specific building is generally adopted to keep the enemies out, delay penetration and buy time for response.
- 1) **First layer of defence:** Walls, fences, and revetments of various kinds as the first layer around the perimeter for the specific site. Guard houses are provided at the entrances and exits of the facility to screen the visitors. Mounting of surveillance cameras / electronic detection devices.
 - 2) **The second layer of defence:** Between the perimeter of the site and the building envelope active and passive barriers should be provided to prevent vehicle penetration.
 - 3) **The third layer of defence:** The building envelope comprising walls, roofs, doors, windows. The building envelope must be able to withstand assaults by an intruder who has overcome the other barriers mentioned above. Besides the building envelope the interior walls and doors should also be hardened as necessary (example- bank vault with a massive door to further delay the progress of the intruder)

Defence layers



Partial collapse of Alfred P Murrah Building, Oklahoma City, USA, 1995



- A truck bomb of 3200kg exploded outside the building at less than 6.0m from the building
- The blast blew off the front façade and caused progressive collapse of part of the building
- 168 people killed and more than 680 people injured
- The blast destroyed or damaged more than 300 other buildings and shattered the glazing in more than 250 nearby buildings
- **Security design:** (1) First layer of defence- Set back (width of side walk) was inadequate (2) Second layer of defence-No measures taken for the second layer of defence (3) Third layer of defence-Lack of redundancy in the structural system

United States Embassy, Beirut, Lebanon, 1983



- A delivery van with 900kg of explosives parked under the portico at the front of the seven storey building exploded
- Front section of the embassy collapsed killing 63 people
- **Security design:** (1) First layer of defence-No perimeter fences were present (2) Second layer of defence-No defence features provided in this layer and cars were able reach the entrance of the building (3) Third layer of defence- No building hardening against blast, no progressive collapse-worthy design, reinforced concrete connections were inadequate

Bishopgate bombing, London, 1993



- A bomb hidden in a parked truck outside the Hong Kong Shanghai Bank building at Bishopgate, Central London, exploded causing extensive damage to buildings in a 500 metre radius shattering over 500 tonnes of glass from windows
- The bomb was home made with approx. 1000kg of fertilizer
- One person killed and 44 people injured
- Most of the windows on the eastern side of 52-storey National Westminster Tower were shattered
- All the doors in the lift shafts were blown
- Cost of repair was 1 billion Sterling Pounds
- **Security design:** (1) First layer of defence- Urban alleyway needed protection by system of barriers and bollards to provide adequate setback (2) Second layer of defence-Narrow alleys did not offer second layer of defence (3) Third layer of defence-Vulnerability of glazing, cladding, doors, windows etc. to blast.

Arndale Centre, Manchester, UK-1996



- 1500 kg bomb placed in a van on roadside outside the shopping centre
- 212 People injured, no fatalities
- Extensive damage to glazing
- Several buildings near the explosion were damaged beyond repair
- **Security design:** (1) First layer of defence-The van parked along the street kerb and the setback was only the width of the side walk (2) Second layer of defence- No measures for second layer of defence (3) Third layer of defence- The tower was spared from major damage due to setback offered by lower floors, most of the severe damage and injuries caused by failure of the building envelope and shattered glazing, claddings etc.

Australian Embassy bombing in Jakarta 2004

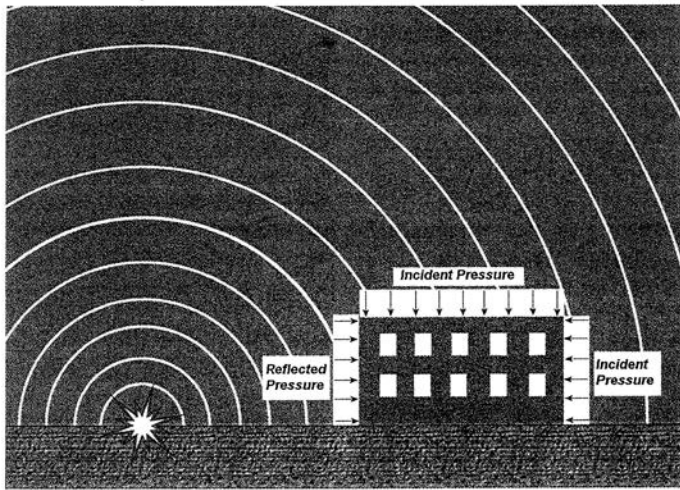


- One-tonne car bomb which was packed into a small Daihatsu delivery van exploded outside the Australian embassy
- 9 people killed and over 150 injured
- Numerous office buildings surrounding the embassy were also damaged by the blast which shattered windows in buildings and injuring many workers inside mostly by broken glass
- **Security design:** (1) First layer of defence-Inadequate setback to building (2) No measures to second layer of defence (3) Most of the injury due to broken glazing

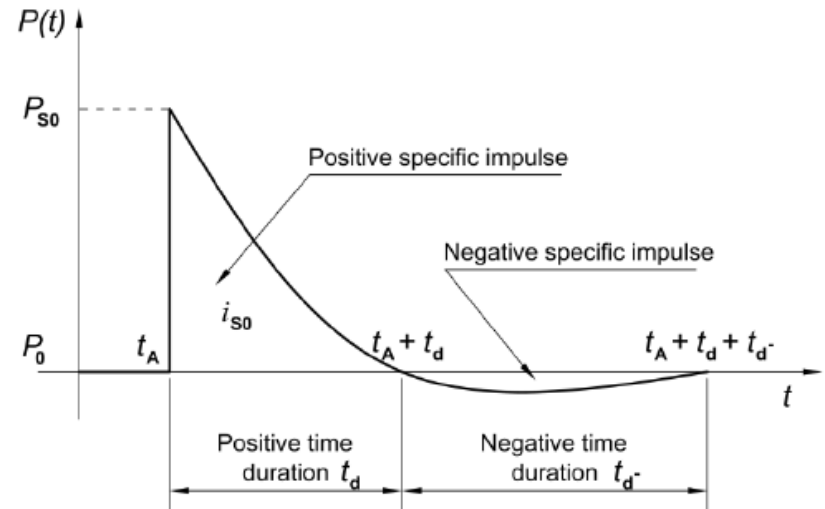
Blast effects on people and buildings

- People and buildings are becoming vulnerable to blast effects
- Explosives planted within or adjacent to buildings accessed by the public is of great concern
- Very limited body of design documentation exists currently to provide engineers with the technical data necessary to design building structures for enhanced security
- As the effects of terrorist attack could be catastrophic, it is prudent to incorporate measures that may save lives and minimise business interruption
- **Structurally this could be achieved by preventing progressive collapse of the building to reduce the number of occupants that become trapped under the structural debris**
- **Maintaining the structural integrity of non-structural building elements can also help to protect the occupants from flying debris and air-blast pressures**

Blast basics



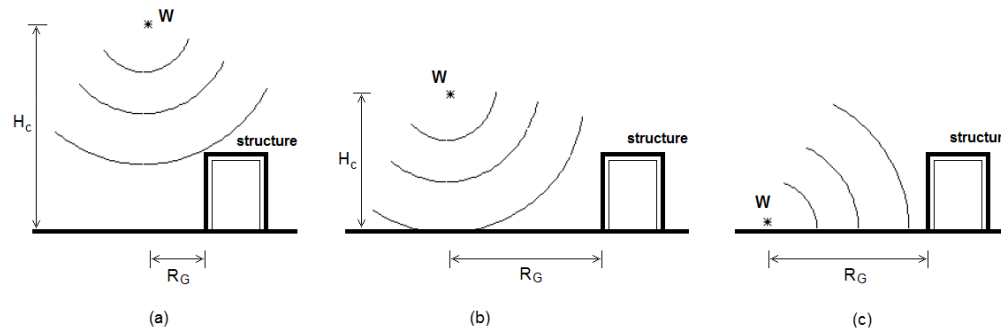
Incident and reflected pressures on building.



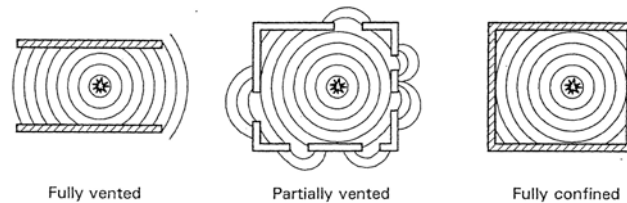
- W - Charge mass expressed in kilograms of TNT
- R - Distance from the centre of the spherical charge in metres

Peak overpressure, $P_{s0} \propto W / R^3$ (Approximately)

Types of external explosions



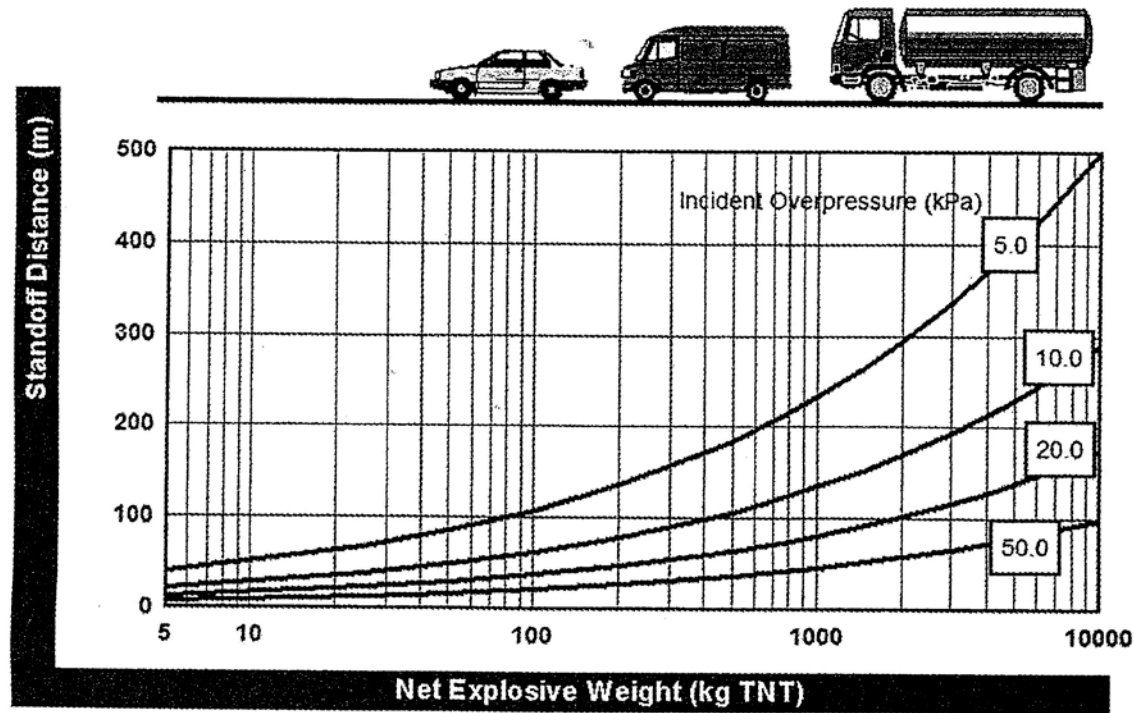
Types of external explosions and blast loadings; (a) Free-air bursts, (b) Air bursts, and (c) Surface bursts.



Fully-vented, partially-vented, and fully-confined explosions

Types of internal explosions

Incident pressure as a function of stand-off distance and explosive weight



Incident pressure as a function of distance and explosive weight.

Protective measures for critical buildings

- The use of standoff distance is the most effective protection measure as the shock wave pressure decrease by a factor of 8 every time the standoff distance is doubled.
- Best way to increase the standoff distance is to provide continuous line of security along the perimeter of the critical facility to keep all vehicles as far as possible.
- The areas within the perimeter can be partitioned into exclusive and non-exclusive zones as follows:
 1. The exclusive zone provide high level of protection. Using the concept that vehicles are able to carry significantly more explosives than a person with a hand carry packages, the exclusive zone would be limited to pedestrian traffic only.
 2. The non-exclusive zone standoff zone would permit entry and parking of cars and trucks, after an initial search at the entry control point
- In urban environment if unable to achieve adequate standoff distance, critical buildings need to be hardened to give the necessary protection. Street closures could be considered to prevent vehicles from approaching the target building
- U.S Department of Defence has adopted a 25 metre standoff distance for primary gathering buildings, from parking and roadways, without a controlled perimeter. It is reduced to 10 metres for similar facilities inside a controlled perimeter.

Protective barriers

- There are two categories of anti-ram barriers
 - Passive or fixed barriers
 - Active or operable barriers

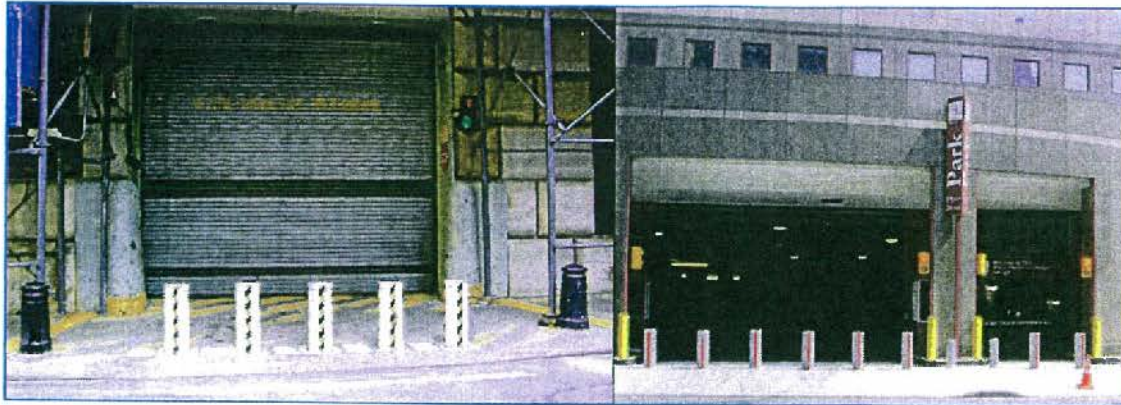
These components enclose the standoff zones

- Passive vehicle barriers are placed along the perimeter of the standoff zone where approach by land vehicle is possible. These barriers have no moving parts and are in a continuous “ready” state at all time. The majority of these are constructed in place.
- Planter boxes and concrete filled steel bollards can be used as passive anti-ram solution. Planters must be embedded at least 500mm into the founding material. Concrete filled steel bollards are generally placed at 500mm spacing to prevent vehicle intrusion. In order for them to provide resistance to impact of a vehicle, the bollards need to be embedded into concrete footing that is about 1.0-1.5 metres.
- The height of the planters and bollards should be as high as a car or a truck bumper

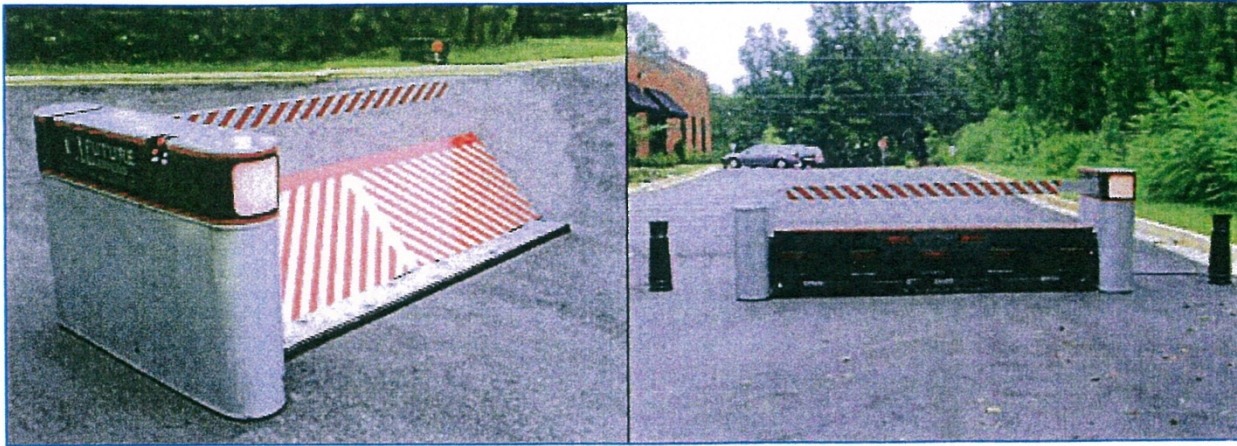
Passive barriers



Active barriers



Active barriers



Preventing progressive collapse

- Provisions in the applicable building codes do not give explicit requirements for the consideration of blast and progressive collapse resistance, except for general statements about structural redundancy, resilience and robustness.
- NCC 2016 BCA performance requirements
 - a) BP1.1 (a) (iii) : A building or structure, during construction and use, must be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage.
 - b) BP 1.1 (a) (iii) is verified for structural robustness by complying with the verification clauses BV2 (a) and (b)
- Because of the catastrophic consequences of progressive collapse, it is prudent to include measures of mitigating the effects of progressive collapse into overall building design. Some measures are summarised as below:
 1. Buildings should be designed using alternative-load-path or specific local-resistance method
 2. Structural damage without collapse of a building is an acceptable strategy
 3. Consider incorporating internal damping into the structural system to absorb the blast impact
 4. Design floor system for uplift in exterior bays
 5. Use ductile details to absorb the energy of a blast
 6. Use two-way floor and roof systems
 7. Avoid the use of masonry when blast is a threat. Masonry breaks up easily and become secondary fragments during blasts
 8. Use non-linear analysis methods for the design of critical structural components

Glazing

NCC 2016 BCA performance requirements

BP1.3 : Glass installations that are at risk of being subjected to human impact must have glazing that:

- a) If broken on impact, will break in a way that is not likely to cause injury to people; and
- b) Resists a reasonably foreseeable human impact without breaking; and
- c) Is protected or marked in a way that will reduce the likelihood of human impact

Types of glazing and behaviour under blast loading

Annealed glass:

- Annealed (or plain) glass is the common basic glazing material
- It is brittle
- Annealed glass breaks into angular, jagged irregular fragments
- The failure of this glass under blast usually results in sudden and immediately high hazard to building occupants
- Due to the brittle nature of the failure, annealed glass is not recommended where blast resilience is required

Toughened glass:

- Toughened glass is obtained by reheating annealed glass to a plastic state, followed by controlled cooling. This process creates a permanent stress distribution across the thickness with compressive stresses in both outer faces counterbalanced by tensile stresses in the core. Under applied lateral load, the compressive stress in the outer compression zone must be overcome before tensile stresses can set up and cracking initiated.
- The above treatment results in a four to six-fold increase in the effective strength of toughened glass over annealed glass.
- The failure of toughened glass under blast load results in sudden hazard to building occupants
- Due to the brittle nature of failure, toughened glass is also not recommended where blast resilience is required

Types of glazing and behaviour under blast loading

Heat-strengthened glass:

- Heat-strengthened glass is obtained by reheating and cooling annealed glass in a process similar to that for toughened glass, but to a lower temperature.
- Surface pre-compression is therefore lower than in toughened glass
- Its material strength falls between that of annealed and toughened glass range.
- They fail in a brittle manner similar to annealed glass
- Not recommended under blast loading condition

Laminated glass:

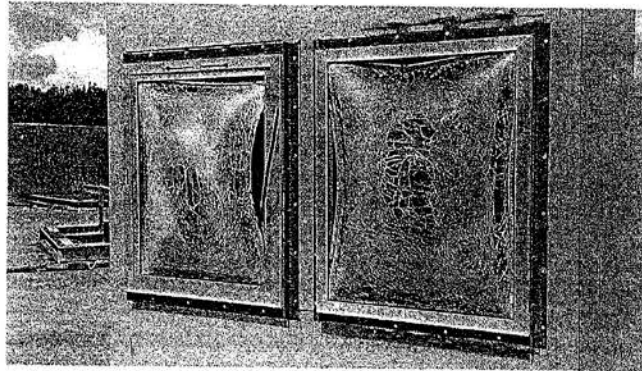
- Laminated glass is a built-up composite of alternating layers of glass and interlayer.
- The interlayer material normally used for blast resistance is polyvinyl butyral (pvb), a plastic which when loaded at high strain rates is highly ductile and has a significant tensile strength.
- It has excellent bonding properties to glass. Upon cracking, the glass fragments remain bonded to the pvb layer. After the glass cracks, the pvb layer behaves as a ductile membrane in catenary action.
- Laminated glass is the preferred material under blast loading conditions

Annealed/ toughened glazing

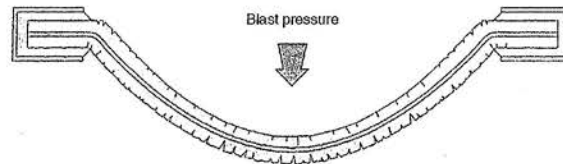


Relative performance of annealed and toughened monolithic glass. Two upper storeys had been glazed using toughened glass while the remainder were annealed, demonstrating the superior flexural strength of toughened glass relative to annealed. Its failure mode, however, remains brittle. The top two storeys had been prepared for reglazing at the time of this photograph

Laminated glazing



Pop-out (on rebound) of laminated glass pane secured with dry gaskets (blast test at limit of pull-out from rebates)



Principles of structural silicone glazing behaviour for resisting in-plane blast loads in laminated glass. Figure courtesy of Arup

Summary

Risk to people and buildings due to explosive attacks can result from:

- Projectiles such as glass, cladding, doors, architectural features etc.
- Blast overpressures and blast wind can cause injuries to human organs and limbs
- Localised structural collapse
- Total collapse

Designing buildings to be fully blast resistant is not an economically feasible option. However engineering knowledge does exist by which new and existing buildings can be enhanced to mitigate the effects of explosion.



Questions?