Blast Resistant Design
A Primer for Architects

AIAPDH230
3 HSW/LU Hours

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FINAL EXAM
BLAST RESISTANT DESIGN

1. **A “blast” event refers to:**
   a. An entertainment event that gets beyond the capability of the building where it is being held
   b. Any type of force that causes a building to move
   c. A shockwave of compressed air that spreads outwards from an explosion
   d. A military action using live ammunition

2. **For Blast buildings that are used in forward military positions, which one of the following is an important characteristic?**
   a. Air conditioning
   b. Easily transported and erected
   c. Must be yellow and red in color
   d. Use solar energy for power

3. **Which of the following types of Architecture have potential for requiring blast resistant design:**
   a. Industrial buildings
   b. Strategically symbolic buildings
   c. Transportation hubs
   d. All of the above

4. **Many military building installations have a degree of blast design consideration. How many broad categories do these buildings typically fall into?**
   a. 2
   b. 3
   c. 4
   d. 5

5. **The most frequently occurring blast events happen in which type of building?**
   a. Military
   b. Industrial Plants
   c. Federal facility
   d. Residential Buildings

6. **An effective BR design team is composed of which of the following professionals?**
   a. Architect
   a. Structural Engineer
   a. Building Owner
   a. All of the above

7. **The secondary layer of the BR design team consists of which of the following professionals:**
   a. Owner & their QRA/security consultant
   b. Structural engineer and Contractor
   c. MEP consultants and material vendors and manufacturers
   d. Regulators and Association Managers

8. **“Side-On” over pressure is also called:**
   a. Reflected pressure
   b. A force that strikes only the side of a building or structure
   c. Free field overpressure
   d. Low volatility over pressure

9. **The blast “duration” is measured in:**
   a. Impulse units
   b. milliseconds
   c. seconds
   d. hours

10. Deflagration explosions are created by low explosive forces and move at speeds _______ the speed of sound (sub-sonic).

a. Equal

b. Above

c. Below

d. None of the above

11. ______________ results in supersonic (faster than the speed of sound) explosions created by high explosives.

a. A Vapor Cloud

b. Detonation

c. Shock Wave

d. Deflagration

12. Which type of explosion occurs when a cloud of flammable vapor, gas or mist ignites.

a. Shock wave

a. Deflagration

a. Vapor Cloud

a. Thermal Radiation

13. Which of the following terms comes from the military and is used in reference to attacks from the air, specifically for damage that can be caused by bombs that are designed to explode above a target?

a. HOB (Height of Burst)

b. Stand-Off Distance

c. Building Damage Levels

d. Progressive Collapse

14. Increasing the "Stand-Off Distance" does which of the following?

a. Increases the impact of the blast

b. Eliminates the blast wave

c. Creates an observation point for monitoring blasts

d. Reduces the damage risk from a blast

15. This type of overpressure is on the side "facing" the blast when a blast wave propagates in a rigid surface. This type of overpressure is always higher than the pressures on the other faces.

a. Reflected Overpressure

b. Incident Overpressure

c. Back face Overpressure

d. All of the above

16. This type of overpressure is sometimes called the "free field" overpressure and is the undisturbed blast wave pressure that impacts the overall building.

a. Reflected Overpressure

a. Incident Overpressure

a. Back Face Overpressure

a. Impulse Pressure

17. Per ASCE, how many Building damage levels are there?

a. 3

b. 4

c. 5

d. 6

18. When a building is designed to a Low BDL, which of the following is not true:

a. Building is usable after an event

b. Only minor repairs are needed

c. Cost of repairs approaches replacement cost of the building

d. Building design is robust and repair costs are moderate.

19. Who sets the BR design criteria?

a. The Architect

b. IBC codes

c. The structural engineer

d. The Owner and their QRA consultant

20. On a typical Overpressure / Impulse curve, low pressure and low impulse values mean?

a. Nothing
b. Less damage
c. More damage
d. A region of negative impulse

21. Which of the following are relevant BR design issues that need to be addressed during the building programming?

a. Does the Building need to be designed for BR?
b. Who will determine BR design criteria?
c. Should the design team hold or proceed on an assumed basis as directed by Owner?
d. All of the above

22. When designing for BR, Architects have primary responsibility for all of following except:

a. Exterior wall components and details.
b. Foundation design
c. Exterior doors and hardware.
d. Window systems and glazing.

23. Which of the following are favorable characteristics of prefabricated BR buildings?

a. Speed of transport and erection
b. Standardization
c. Deployment in remote areas
d. All of the above

24. If structural strengthening of a building is not feasible or insufficient to address blast impact, what is a technique that can mitigate the shockwave?

a. Employ slopes, or berms around the building
b. The use of "blast walls"
c. The use of heavy blast rated fabric and similar tensile structures
d. All of the above

25. Buildings designed for ___________ psi require specialized components.

a. <1
b. 3-7
c. 8-10
d. None of the above

Blast Resistant Design - A Primer for Architects

The course on Blast resistant Design is a three-part course broken down as follows:

PART 1 – Introduction to Blast Resistant Design

PART 2 – Technical Issues and Considerations

PART 3 – Implications for Blast Resistant Design for Architects

PART 1 – INTRODUCTION TO BLAST RESISTANT DESIGN

In an age of mega industrial and commercial projects and evolving threats of urban terrorism, requirements for and responses to designing buildings for varying degrees of blast resistance have become more relevant for Architects across the design spectrum. For many the terminology and science involved can seem overwhelming. This course will demystify the terms and concepts to enable participants to create better design responses and interact with their consulting engineers and clients with greater confidence.

The objectives of the course are 3-fold:

1. Provide Architects an understanding of the emerging trends in Blast Resistant (BR) Design as these requirements enter into mainstream design.
2. Explain the science behind BR design and lift the veil from the complex sounding terminology and remove common misunderstandings that lead to inhibitive design responses. By demystifying the concepts, architects will be better positioned to work with their structural engineers and clients. The course will address terms such as Blast-Proof vs Blast Resistant; Overpressures and impulses; 3-part curves; Blast contours; Inherent protective properties of common construction systems and active vs passive responses.
3. Share rules of thumb and experience-based guidelines from the perspectives of Architect and Owner. These will provide valuable concept takeaways without being burdened by the math.

LEARNING OBJECTIVES

- Relevance of Blast Resistant (BR) design to Architects
- Explain the key terms in Blast Resistant Design
- Understand the principles of Blast Resistant design
- Impact of factors such as building shape, profile, geography
- Explain what a QRA approach to building design is
- Is Blast Resistant design inherently Ugly?
- How BR design implications are going beyond industrial, military and offshore settings

Disclaimer Notice:

This course is intended to provide information as an educational benefit for architects and design professionals. The author has attempted to present a summation of the concepts and published data in a manner that intended to clarify these for architects. While the Information contained in this course has been reviewed and presented with all due care, the author does not warrant or represent that the Information is free from errors or omission. The author accepts no liability whatsoever for, or in respect of any use or reliance upon this publication by any party. Author: Muhammad Siddiqui.

WHAT IS BLAST RESISTANT DESIGN?

A “blast” in the context of Blast Resistant (BR) design refers to a shockwave of highly compressed air that spreads outwards from an explosion source. When that wave strikes a building, the building experiences tremendous pressures, measured in psi, but for very short durations, measured in milliseconds. It is this characteristic of blast impacts that requires specialized treatment of building structures and envelopes beyond the types of protection that are more common, such as wind forces or seismic considerations. Those are more sustained in duration and impose different forces on a structure.

Blast Resistant design, as addressed in this course, involves design requirements to be considered to enable a building to provide the required level of protection to an anticipated blast event. The “event” trigger can be an accidental explosion due to a chemical process in an industrial setting, some form of terrorist attack using explosives or any number of accidental explosion scenarios which can occur in an increasingly urbanized society with its complex infrastructure demands.

It is not practical to plan for all accidental scenarios but where there is some likelihood of a potentially predictable explosion based on either the arrangement of an industrial plant or the strategic vulnerability of a facility (as in a potential target for a terrorist attack), then the buildings in these settings have to be designed to mitigate the impacts of the potential threat. This design response is executed using Blast Resistant design concepts.

BRIEF HISTORICAL BACKGROUND

Awareness of the threat that explosive blasts pose to structures has been around from the time explosives were invented and used in warfare. As such it was in the military realm that design of buildings to resist blast impacts was first developed. The early responses were derived from the impact resistance philosophies of earlier warfare. Basically, this meant resistance through brute strength – the bunker approach. While this can be an effective solution, it is generally very expensive and very limited in function. This solution was, and continues to be, a valid consideration in specific military situations. It is also a baseline approach to nuclear facility design.

However, following the industrial revolution and the proliferation of factories, pipelines and complex chemical process plants and increased use of hydrocarbon-based processes, the non-military threat of accidental industrial blasts became an ever-growing real possibility. These fears were brought to realization in several smaller scale accidents in Europe and the United States in the early part of the 20th century. As the awareness and potential consequences of these processes became more understood, engineers began to analyze the forces created by different types of blasts and then develop responses to mitigate these to protect people and critical equipment. Almost in parallel, the invention of dynamite in 1867, unleashed a new era of the use of high explosives, initially for mining, but quickly into the arena of weaponry. The use of explosives for military purposes generated a series of powerful threats and this led to an awareness that infrastructure and buildings needed to be protected from the effects of these new forces. The US War Department had started to investigate the science of blast impacts on buildings prior to World War 2 but it was the development of nuclear weapons that triggered highly focused and detailed study of the impact of blast forces on structures. Much of the foundational research for blast resistant design was done in the 1940s and 1950s by the US Department of Defense as part of the nuclear weapons program. (NOTE: This course is not intended to cover design for nuclear facilities as these are designed to respond to different criteria and conditions than industrial explosions or terrorism attacks.)

Below is a timeline of some notable blast events, their magnitude and resulting loss as measured in fatalities:

[It is worth noting that when losses are discussed in the context of blast resistant design, the unit of measure is generally human fatalities. It is difficult to ascertain why this has become so, but one possibility is that while material costs and zone of destruction can vary enormously based on the location and type of facility damaged, the purpose of blast resistant design is, first and foremost, to protect as much human life as possible, followed by the most critical operating infrastructure. Hence, it follows that the success or failure of blast resistance be measured in how many lives are saved or lost. By extension, human fatalities can be inferred as a measure of the severity of a blast on society.]

Date	Event / Location	Cause	Explosive Force (TNT equivalent)*	Fatalities
1917	Maritime Accident: Halifax Canada	French Steamer Mont Blanc carrying explosives collided with Norwegian ship Imo	2,900 tons	Over 1,750
1921	Industrial Explosion: Oppau, Germany	Explosion at an ammonium sulfate and nitrate plant	1,000 tons	500 – 600
1947	Industrial Accident: Texas City, USA	Explosion 1: On April 16, 2,300 tons of ammonium nitrate exploded aboard SS Grandcamp; Explosion 2: On April 17, 960 tons of ammonium nitrate exploded on the SS High Flyer	Exp 1: 690 tons Exp 2: 288 tons	Estimates to 567

1974	Industrial Explosion: Flixborough, UK	Chemical explosion following the ignition of a vapor cloud.	unavailable	28
1986	Nuclear Accident: Chernobyl, Ukraine	Melt down and explosion at No 4 reactor during a safety test.	10 tons	Estimates range upwards of 4,000 due to long term effects
1995	Truck Bombing: Oklahoma City, USA	Terrorist attack on a federal building in Oklahoma using ammonium nitrate and other substances.	2.5 tons	168
2013	Industrial Explosion: West, Texas, USA	Ammonium nitrate explosion at fertilizer plant	12.5 tons	15
2015	Industrial Accident: Tianjin, China	A series of explosions at a container storage facility where chemicals were stored.	21 tons	173
2020	Industrial Explosion: Beirut, Lebanon.	Chemicals stored at the Port of Beirut exploded.	300 – 400 tons	218

Source: Wikipedia / Reuters

**** For comparison: The GBU-43B (nicknamed MOAB – Mother of All Bombs), the most powerful non-nuclear bomb in the US arsenal has explosive power of 11 tons. A Tomahawk missile is 0.5 tons and the "Little Boy" (The nuclear bomb dropped on Hiroshima Japan) was about 15,000 tons.***

BLAST RESISTANCE VS BLAST PROOF

If you have ever noticed that many watches will note they are "water resistant" and then specify a depth to which that resistance is applicable. There was a time when the term "waterproof" was used but that is no longer the case. The reason is that "something proof" implies that it provides complete protection from whatever it is "proofing" from. That is an absolute condition that is not practical in real world scenarios. Protection from moisture intrusion can be resisted to a certain depth based on the design but at some level, the pressure will exceed the level of design protection and damage will occur. Hence the term resistance is used, and its limits identified. The concept of protection for buildings from blasts follows the watch analogy. To blast "proof" a building, it would have to emerge completely unscathed after being subjected to any blast. The military comes closest to creating bunkers that are sometimes called blast proof. But even these brutes have a limit beyond which they cannot resist. For example, a bunker that can resist a 500 lb. bomb impact will not escape damage from a 2,000 lb. bomb. In most industrial, commercial, or public facilities where blast impacts are a concern for designers, a level of blast resistance is determined by a detailed QRA (Quantitative Risk Assessment) performed by specialized engineering and Risk consultancy firms. The QRA study will analyze the types of blast threats, among other risks, to a facility and provide a guide to designers about the levels of blast impact and the likelihood of their occurrence. Based on this information, a facility owner determines the level of risk and mitigation they want. That establishes the level of blast resistance for which the building is to be designed. In all cases, the blast design, no matter how heavy or light, represents a level of Resistance to a specified blast magnitude. In no cases can a building be termed completely blast proof. Blast Proof and Blast Resistant are not interchangeable terms. Architects need to be wary if a client asks for a "blast proof" design. This is generally the result of either lack of familiarity with the concepts of BR design or simply a common confusion of the terms. Regardless, it is important to ensure that any contractual language or Scope of Work clearly define the term as "Blast Resistance" rather than "Blast Proof". In addition, is advisable to state the limits and criteria of the Blast Resistance. If this is not known at the time, language stating an assumed criteria should be stated with the condition that these limits of BR design will be updated when specific information is provided by the Owner. Since that timing may be an unknown, there should be a clause to allow for adjustment in design fees to accommodate the BR design effort if it exceeds a minimum level stated in the Scope of Work.

WHY SHOULD ARCHITECTS CARE ABOUT THIS?

For most architects, concern for Blast Resistant design is not a routine consideration and it is not even a category in building codes such as the IBC.

This area of design has generally been relegated to a highly specialized niche of architects who practice within the military or industrial domain. However, due to the rise in urban terrorism from the 1980s onwards, the advent of car and truck bombings targeting pubic and politically symbolic buildings has become a sad but real concern. It is also not an issue that we can ignore as a threat in far away locations. In 1995 the bombing of the Alfred P. Murrah Federal Building in Oklahoma City using an explosive laden truck brought the reality of such events to the United States heartland. Since then, credible threats to various buildings of high visibility within and outside the United States have caused many facilities to actively incorporate blast resistant design into their requirements. As a result, more and more architects and engineers involved with mainstream commercial, institutional and public architecture are having to consider elements of blast resistance. While the structural integrity of the design is a role that structural engineers fulfill using complex dynamic analyses, architects must be knowledgeable about the constraints on their design freedom and the costs of mitigation. In addition, all building connection details, exterior doors, glazing, penetrations and overall envelope design are affected to some degree depending on the Blast design criteria. Architects who become familiar with the terminology and reasons for the limitations are better positioned to collaborate with their engineers and owners to offer workable designs that do not have to be "Bunkeresque". In commercial and public settings this knowledge becomes invaluable in designing effective blast resistant buildings that can otherwise look "normal".

WHERE DOES BR DESIGN HAVE RELEVANCE? – BUILDING TYPES, LOCATIONS, INDUSTRIES, ENVIRONMENTS

As has been mentioned, blast resistant buildings are now being developed in almost all typologies. Still, the main areas where this is a key programming question are:

a) **Military**: Many military installations have a degree of blast design consideration. The Department of Defense (DoD) in the US has very detailed criteria for buildings and blast responses based on the use, location and criticality of the building. Typically, the buildings fall into two broad categories:

   I. Those located in permanent bases and installations. These are more conventional buildings with levels of protection dictated by DoD protocols.

   II. Those located in forward military positions or bases. These involve an element of mobility to the buildings, requiring them to be modular and flexible in terms of erection, removal, and transportation.

b) **Industrial Plants**: The examples in the Historical Background section above cited many industrial accidents. These remain the most frequently occurring events and as such the use of blast resistant design is an essential part of the programming for these facilities. In recent years, with better siting and the use of more BR buildings, the number of fatalities is declining. While improved processes and greater focus on safe work practices are contributors, when an accident does happen, the resistance of the building is the last measure of protection. Often it is the difference between life and death.

c) **Politically or Strategically Sensitive Facilities:** In current times, with the proliferation of technology and availability of explosives, the ability of a few disaffected individuals to cause great damage is a real risk. To protect the users and make these facilities as accessible as possible to the public in a free society, considerations for blast resistance are an increasing priority. In these cases, there are two elements: Passive and Active design. The passive protection involves perimeter protections such as bollards, walls, hardscape elements with the aim of deterring approach of potential threats from getting close enough to the building to cause real damage. The protection of structures by hardening or designing for Blast resistance is another element of passive measures. Active measures involve security monitoring, guards, preemptive surveillance and similar techniques. The challenge for architects is to facilitate both objectives in a way that does not create a brutal design or convey a sense of siege or fear. An excellent case study to understand how this balance can be achieved is in the enhancements made around the National Mall in Washington DC in the years after 2001. Many of the protective measures are imperceptible to visitors but some, such as the retaining wall around the Washington Monument are very visible but beautifully integrated into the landscape such that it becomes a welcoming feature rather than an intimidating symbol of fear. It is such integration of soft and hard landscape, urban space planning and surveillance technology that come together as part of a cohesive design response to safeguard sensitive symbolic facilities without creating an overtly oppressive feel. Of course, there are some governmental and sensitive scientific facilities where a measured degree of "in your face" intimidation in the design is part of the "stay away" message that the design deliberately conveys. But even here, the while the scare factor succeeds in deterring the casual threat, other, more discreet, and robust design measures have to be taken to protect from the more serious dangers.

d) **Public Facilities:** Beyond the likely political or military targets, we must recognize the unfortunate reality that terrorists around the world target many public buildings. For this reason, new facilities such as schools, museums, sports and entertainment venues, transportation hubs and other places of assembly are increasingly adopting some of these principles. In all cases, the likelihood risks and costs are weighed and a balance regarding the level of protection is determined. These become the design criteria for the design team. Just as for the politically or nationally symbolic structures, public facilities also need to strike a balance between the degree of visible "protection" that conveys security against design measures that border on penal architecture. Here too, landscape and careful traffic circulation plays a significant part in softening the public face of the blast protection elements.

e) **Federal Facilities:** This category can be considered part of both Public Facilities and Politically or Strategically Sensitive facilities. However, this deserves a special mention and unique category because all Federal facilities are now subject to some level of protective design consideration that includes a level Blast Resistance. This requirement also includes any existing facilities that are expanded or undergo a major renovation. For all these Federal building categories, the General Services Administration (GSA) of the US Federal government establishes design guidelines that are de-facto codes.

f) **Residential:** This may seem an odd category but there is an emerging trend among many prominent people (whether due to fame or wealth) to seek protective design elements for their residences. In some ways, this is no different from other times in history when feudal lords, aristocrats and others from the ruling classes took measures in the design of their homes (castles) to create a protective barrier from not only external attack but also from rebellious elements within their own domains. It is just that in current times, the class of prominent targets and their potential enemies is more numerous, and the types of threats are more sophisticated and deadly when explosives are used. The most challenging of these can be homes built in urban areas. The design considerations remain the same, but applications differ depending on the circumstances. For example, the protection of a home set in a sub-urban lot with surrounding acreage will be different from the response to protect a penthouse apartment in a high-rise tower. The application of BR design for private residences is a very specialized category where the schemes are often unique and coordinated with security consultants. The details of tactics applied are, understandably, kept confidential and rarely, if ever, published.

WHO MAKES UP AN EFFECTIVE BR DESIGN TEAM? – ARCHITECT, STRUCTURAL ENGINEER, OWNER, REGULATORS:

To arrive at the optimal blast protection level for a facility, it has to be a collaboration between the Owner, QRA assessment consultants, architect, structural engineer, and in the case of public or commercial settings, the landscape designers. Since there are no adopted building codes that provide mandated requirements for blast design, it is the owner and the QRA / security consultant who determine the criteria for the design. This lays out the level of threat (risk) that they want to mitigate. These criteria provide the structural engineer the basis to determine the forces for which they need to design the foundation and structure. The Architect uses the criteria to detail the connections and exterior envelope of the building. The electrical and MEP engineers have to ensure protection of their service feeds and penetrations of conduits and pipes into the building. They also must consider their design for recirculating air if the exterior air intakes are damaged and provide contingency for power failures using UPS (Uninterrupted Power Supply) and backup generator systems. The degree to which any of these considerations are implemented is based on the level of building functionality and redundancy that the Owner wants to retain following a blast event.

In addition to the above, there is an increasing role that governmental regulators are starting to play in influencing BR design. In some industries such as nuclear or military, there are now established design regulations (effectively codes) that govern most aspects of BR design. However, in commercial, industrial, and public settings, a body of opinions and guidelines are emerging from various academic and industry groups. Similarly, more and more lessons and consequent recommendations emerge from investigations of accidents or near misses that occur. So, while there are currently no BR building codes, it is likely that at some point in the future some requirements will be adopted as the demand for BR protection becomes more prevalent. For this reason, even architects who may not actively practice in BR design, may find it useful to at least be versed in the terminology and basic concepts just as most architects are generally familiar with the basics of seismic or wind design even if they do not practice in an earthquake or hurricane prone region. Sometimes, it is mistakenly assumed that seismic design is the same as BR design. In part 2 of the course, the relationship between wind, seismic and BR will be explored.

One emerging group in the BR design space is the multitude of manufacturers and construction trade groups who have recognized the growth of BR design applications across multiple building types. These vendors and trade groups have, over the last decade (2010s) taken initiatives to test, research and innovate solutions for BR design. While the primary objectives have been commercial, the benefits of these actions have encouraged competitors to also join the band wagon. The result has been that there are now many studies, white papers and new products that provide designers with many options and supporting data and testing validation for their design components. Industry groups and trade associations also sponsor academic research that further advances BR design flexibility. Some trade associations such as the PCI (Pre-Cast Concrete Institute) have published not only research data but also provide extensive construction detail guidance for architects and engineers. Similarly, the AISC (American Institute of Steel Construction) publishes a Steel Design Guide for the Design of Blast Resistant Structures. Other manufacturers from prefabricated building BRB (Blast Resistant Building) vendors like Hunter and Red Guard to companies like *Roxtec* that specialize in protecting BR penetrations and numerous door, window and hardware suppliers are all now sources of products and design information.

Based on the above discussion, it should be evident that a good BR design team starts with a knowledgeable Owner and their QRA / security consultant who understand their industry and the project's societal risk exposure. On that basis they can provide the appropriate design criteria. The next group is the design team. This includes a primary and secondary layer. The primary layer is the Architect and Structural engineer. They jointly establish the tactical design response for the building, establishing the structural frame type and building envelope materials and construction type. The secondary layer of the design team consists of the MEP consultants and material vendors and manufacturers whose engagement and infusion of information for timely design decisions helps to ensure an integrated design and avoids re-work which can lead to gaps in design integrity. Lastly, depending on the project, there may be regulatory requirements or even official design "rules" that must be followed. While these regulators are separate from the design and Owner team, a good practice is to engage them early and consider them and their guidelines as consultative de-facto team members. This is similar to the way architects approach building code officials. One can choose to see them as adversaries or as guides. It should not be expected that they will necessarily go easy due to early engagement, but it is certain that upfront coordination will reveal any critical areas of concern soon enough to maintain design pace and avoid late inconvenient adjustments.

This concludes Part 1 of the course. Part 2 will focus on technical terms, considerations and design responses.

SECTION 1 REVIEW QUESTIONS:

1. **In non-military situations, which types of buildings are most frequently impacted by blasts**
   a. Tall skyscrapers
   b. Residential subdivisions
   c. Industrial facilities
   d. Schools

2. **QRA is the acronym for:**
   a. Quality Research Analysis
   b. Quotient of Risk Assessment
   c. Qualitative Review Approach
   d. Quantitative Risk Assessment

3. **Which of the following codes has extensive guidelines for Blast Resistant Buildings?**
   a. IBC 2009
   b. NFPA 101
   c. UBC
   d. None of the above

4. **In developing a house for a famous client with security concerns, who would advise the architect on the criteria for any blast resistant design requirements?**
   a. The owner's security consultants
   b. The local building official
   c. The Department of Defense
   d. The structural engineer

5. **Which of the following are building elements affected by BR design?**
   a. Exterior doors & hardware
   b. Wall and roof penetrations
   c. Exterior Windows
   d. All of the above

PART 2 – BLAST RESISTANT DESIGN – TECHNICAL CONSIDERATIONS

Part 1 of this course covered a basic introduction to Blast Resistant (BR) design, some fundamental concepts, and its applicability and relevance for Architects.

This part will review the main technical terms and considerations that Architects should be familiar with if their project requires a BR design. In this part we will address the following items:

4. Blast Resistant technological development
5. Technical terms explained
   - Overpressure
   - Deflagration vs Detonation
   - Impulse & Duration
   - Positive and Negative phases
   - HOB
   - Stand-Off distance
   - "psi" rating
   - Building Damage Levels
   - Progressive Collapse
   - Ductile and Robust structures
   - Frequency / Risk Analysis
6. Pressure Impulse Curves
7. "Blast Radius" and "Blast Contour"
8. Seismic vs Blast Resistant design
9. BR Building components
10. Blast Design Tools

BLAST RESISTANT DESIGN TECHNOLOGY

Over the past century the technology to support and enhance Blast Resistant (BR) design has developed significantly to a point where it is now possible to design almost any style of building and still meet the BR requirements for most applications. Of course, the more architecturally sophisticated the design, the higher the cost to provide BR features. The point is that while in decades past, technology was a limitation, it is not so much anymore. Budgets and functionality are now the main drivers.

The initial technological developments for BR design started to take shape based on the analyses conducted during the development of the US atomic bomb program. As part of this program, extensive studies were undertaken to understand the impact of blasts on structures. Based on the reaction of the buildings to blast forces, a science of Blast Resistant design started to emerge. Forces were better understood and categorized, and the resistance of structural and other building elements was documented. This provided engineers with the knowledge and criteria to design and reinforce structures to withstand the forces. Beyond the structure, building cladding, doors, windows, roofs, and all exposed elements started to be studied and manufacturers began to develop, test and market products to support these designs. Initially, the limited applications meant that very few vendors supported BR design and when these products were offered, the price tags were very high. Much of this was due to expensive testing to prove the BR capabilities. Over time, especially after security concerns like terrorism, urban threats and industrial accidents made BR responses more mainstream, product manufacturers were able to increase the variety and capabilities of many affected architectural products. By the mid-2010s, BR variants for most types of architectural building products could be found or existing products upgraded. It should be noted that this is true for the lower-level BR requirements. The reason is that it was determined that all products and building systems have an inherent blast resistance to a certain level of impact simply by virtue of their design characteristics such as wind loading, and other design forces routinely applied due to building codes. By testing existing products for varying levels of blast conditions, many products could be used “as is” and some needed only minor modifications. In other situations, depending on application, entirely new products were developed.

With the constant advances in building technology, development of lighter and stronger materials and more refined, flexible engineered connections and virtual testing, more and better design options are becoming available for architects.

BR DESIGN TERMINOLOGY

There are some common terms used in the context of BR design. Most of these have specialized engineering depth. However, it is useful for Architects in general but especially those involved with BR design to be familiar with the terms and what they conceptually mean. This allows an Architect to have more meaningful discussions with their structural and MEP engineers, product vendors and clients.

- **Explosion**

According to Merriman-Webster dictionary, an explosion means “ to burst forth with sudden violence or noise from internal energy: *such as : to undergo a rapid chemical or nuclear reaction with the production of noise, heat, and violent expansion of gases dynamite explodes.”* In technical terms, as relevant to BR design, an explosion is a “*is a rapid expansion in volume associated with an extremely vigorous outward release of energy, usually with the generation of high temperatures and release of high-pressure gases” [Wikipedia].* This is accompanied with a bright flash and an audible blast. Depending on where the explosion happens, the portion of the energy is released as part of the flash that is characteristic of explosions. This is the result of the thermal radiation. Some more of the energy is absorbed into the soil and results in ground shock. Most of the remaining energy releases through the air as a shock wave. Both the ground and air shock waves expand radially from the explosion epicenter.

- **Deflagration and Detonation**

Explosions that are created by low explosive forces and move at speeds below the speed of sound (sub-sonic) are called deflagration. Examples would be an open fuel fire or the burning of gasoline in a car engine. Detonation results in supersonic (faster than the speed of sound) explosions created by high explosives. These travel through shock waves. It is these types of explosions resulting from detonations (or industrial accidents that are in effect unintended detonations) that BR design deals with. A point of note here is that explosions of one type can morph into the other. For example, a vapor cloud explosion (starts as a detonation) followed by a fire is one of the worst-case scenarios for a petrochemical plant. Conversely, when a deflagration escalates into a detonation, the rapid increase in speed and the resulting shock wave can have consequences that several fold more dangerous than a deflagration only events.

[TIP: To see examples of the various types of explosions listed here, there are many samples of actual videos or animations on YouTube that can illustrate the force and rapidity with which these events can unfold]

- **Vapor Cloud**

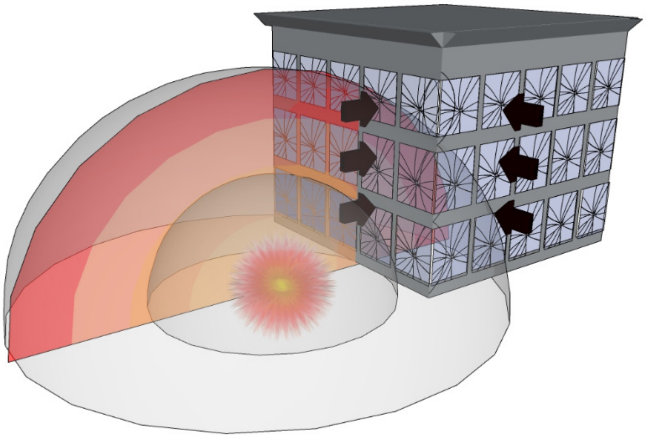
This is an explosion that results when a cloud of flammable vapor, gas or mist ignites. These types of explosions generate very high over pressures and cause catastrophic damage. This type of risk is very high in industrial settings where flammable gasses are used, and a risk of leakage is present along with potential ignition sources. Buildings that are built within potential risk zones are always designed for Blast Resistance.

- **Shock Wave**

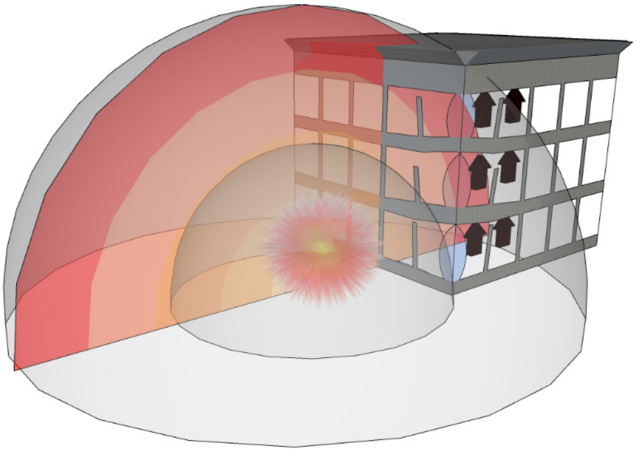
This is the compression wave resulting from an explosion that travels through the air, dissipating the energy released by the explosion. The pressure in the front of the wave is called the "Peak Pressure" and this decreases as the wave moves out from the origin of the explosion. The part of the wave front where the pressure is greater than the atmospheric (normal) pressure is called the "Positive Phase". This is followed immediately by a portion of the wave where the pressure is actually drops lower than atmospheric pressure. This is called the "Negative Phase" (see Figure 2.2). It tends to have a "suction" effect. This dynamic of a powerful high-pressure impact on a building, immediately followed by a negative pressure suction force is critical to understanding how the structure and building components should be designed so they can address both forces. It's like designing to mitigate effects of whiplash on a building.

The effects of a blast wave on a building are illustrated below:

1. Blast wave breaks windows, exterior walls are blown in and columns may sustain damage. (*Figure 2.0a*)



2. Blast wave forces floors upwards. Structure buckles. (*Figure 2.0b*)



3. Blast wave surrounds structure, there is downward pressure on the roof and inward

pressure on all sides. Structural members fail with risk of progressive collapse. (*Figure 2.0c*)

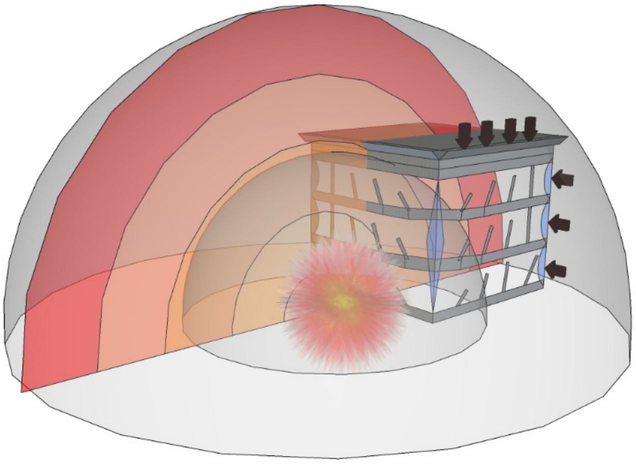


Figure 2.0: Blast Pressure Effects on a Structure

Source: Adapted from Naval Facilities Engineering Center, "User's Guide on Protection Against Terrorist Vehicle Bombs," May 1998. Graphics modified by Author

- **Overpressure**

For the purpose of building design, this is the pressure that impacts the building and is measured in psi (metric = bars). The higher the value the more potential damage will be caused. Since blast shockwaves tend to be spherical in nature, the overpressures do not only impact the façade where they strike, but also the sides and top of the building. As has been noted, the shockwave also has a negative phase and as such the rear façade is also impacted. There are three major types of overpressures impacts to a building. (See Figure 2.1):

- ○ Reflected over pressure is on the side "facing" the blast when a blast wave propagates into a rigid surface. The "reflected" overpressure is always higher than the pressures on the other faces (The incident pressures). This enhanced "reflected" overpressure can be about twice the incident pressure for incident pressures under 15 psi but can increase to over 12 X the pressure for stronger values.
- ○ Incident, or "Side-On", also sometimes called the "free field" overpressure is the undisturbed blast wave pressure that impacts the overall building. Simplistically, these are the pressures on all sides that are not "facing" the blast wave.
- ○ Back (Rear) face overpressure is the pressure on the façade of the building on the back side of the shockwave facing façade. Often this is treated the same as the other incident side-on facades for the purpose of design. It is noted only to emphasize that all facades of a building experience some level of impact from a blast wave and so have to be considered in BR design, even if the risk is unidirectional.

After considering the above, engineers design for the reflected pressure which is higher than the side-on pressure.

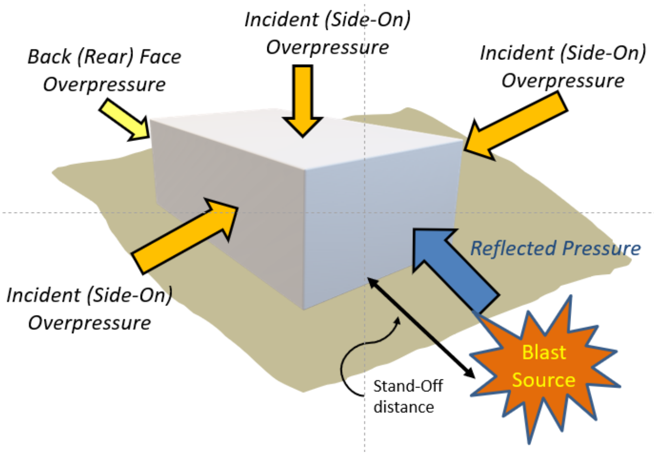


Figure 2.1 – Reflected & Incident (Side On) Overpressure (Simplified). Source: (c) muhammad a. siddiqui.

- **Impulse & Duration**

While over-pressure defines the magnitude of the blast impact, the duration is the length of time the blast wave acts on the building. Unlike hurricanes, earthquakes, or even tornadoes, that can act on a building for several seconds, minutes or longer, blast waves are very rapid and literally pass in the blink of an eye. They are measured in milliseconds since blasts tend to be very powerful impacts for a very brief time. As a result, the true impact of a blast wave on a building is a function of both the overpressure and the duration that the blast acts on the building.

Many times, impulse and duration get used interchangeably but they are not the same. Put simplistically, duration is time and impulse is a result of force applied over a period of time, i.e: change in momentum. For BR design, it is the impulse that is used by engineers. It is represented by the area under the pressure/duration curve. See Figure 2.2. This also illustrated how the blast wave creates a positive and negative impulse. Generally, the negative phase is ignored for design response because it has a smaller effect of the building design response required than the effects of the positive impulse phase.

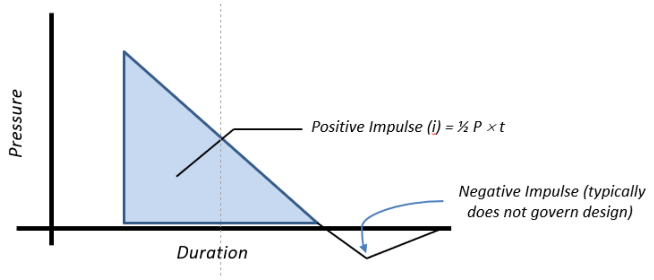


Figure 2.2 – Pressure / Duration Curve and Impulse (Simplified). Source: Author

- **HOB (Height of Burst)**

The term HOB comes from the military in terms of attacks from the air, specifically for damage that can be caused by bombs that are designed to explode above a target. By exploding above a target, the level of damage caused can be much greater than an impact explosion. This is because the blast wave coverage is expanded. Weapon designers develop the optimum heights for detonation based on maximizing the destructive consequences. A non-military application from this concept is in assessing the blast impacts from aerial vapor cloud explosions where the expected elevation of leaked gases can be modelled, and the resulting explosions simulated similar to the way the military evaluates impacts of bombs. In this case, the roof of the building bears the brunt of the reflected overpressure.

- **Stand-Off Distance**

The term stand-off distance comes from security and is the distance between the source of an explosion threat and the potential target building. This distance is adjusted to minimize damage level depending on the risk-based assessment of the level of threat. This distance is determined interactively by law enforcement, building owners and engineers for a given threat type and risk. Architects then use the established distance to create physical elements around the building to restrict access within the standoff distance. This is done in conjunction with other security and control measures. There are no civilian code-based guidelines for stand-off distances. However, FEMA, in its Reference manual to Mitigate Potential Terrorist Attacks (publication FEMA 426) provides guidelines and charts that define incident overpressures in psi as a function of stand-off distance and explosive force based on pounds of TNT. The FEMA charts illustrate that the stand off distance can range from less than 100 feet for a small car bomb of less that 100 lbs. of TNT to 2,000 feet for a large truck bomb with tens of thousands of pounds of TNT.

- **“psi” Rating**

It is common to hear many people using the term “psi rating” to describe a BR building. This refers to the peak overpressure for which the building is being designed. While it is a convenient way to understand how much one BR building may be more or less resistant than another, it is important to understand that overpressure is NOT the sole determining factor on the degree to which a building must be reinforced. The impulse and duration are equally important. A building with a low psi rating but a long duration may require more design enhancement than a building with a higher psi impact but a very short duration. So, while a “psi rating” may be used in layman discussions, there is no such standard within the engineering community. That said, it should be noted that while there is no “rating”, the overpressure psi is a valid and widely used measure as a starting point for evaluating various design elements, guidelines and products. The final selection for the building BR structural design must include the impulse factor.

- **Building Damage Levels**

Once a criterion for the expected threat level is defined, the next step is to determine the response that the building design must provide. This can range from the ability to completely withstand the blast to only maintaining sufficient structural integrity to allow occupants to survive while the building may sustain irreparable damage. This is a very important consideration since designing a building to withstand a blast unscathed can be a very expensive proposition. According to the

ASCE (American Society of Civil Engineers) there are three Building Damage Levels (BDL) – High Medium and Low. For most projects, owners tend to set design response to the Medium level. This means that the designers must design a building to a level that after an event it only suffers damage to the medium level – repairable for reuse at a lower cost than replacement. See table below:

Building Damage Level	Description
High	Key components may have lost structural integrity; building may collapse due to environmental conditions (i.e. wind, rain, snow); and total cost of repairs approaches replacement cost of building.
Medium	Significant repairs needed from widespread building damage; building cannot be used until repaired; and cost of repairs is likely significant.
Low	Minor repairs from damage needed but building can be used; and cost of repairs may be moderate to low.

Table 2.1. Source: ASCE

The US Department of Defense (DoD) provides a table that correlates conventional construction without any blast resistant hardening against incident pressures.

Level of Protection	Incident Pressure (psi)
High	1.1
Medium	1.8
Low	2.3

Table 2.2. Correlation of DoD level of Protection to Incident Pressure. Source: DoD

This is a useful proxy for what some call "inherent" level of BR protection for conventional construction. However, design professionals should be cautious in how they use the above information. The term "conventional" construction is very broad and likely to vary from location to location and building type. It is always necessary to evaluate the design with the structural engineers to validate whether a proposed design without special BR consideration is adequate for the required BR pressures and impulse. If the pressures are low enough, it is possible that no further modifications may be necessary.

In considering damage levels and levels of protection, Architects are often asked about how much damage occurs for a given "psi" blast for a "normal" building. There is a widely used table that provides a useful response to this question. The table is compiled from a combination of studies and is provided below:

Damage	Incident Pressure (psi)
Typical window glass breakage	0.15 – 0.22
Minor damage to some buildings	0.5 – 1.1
Panels of sheet metal buckled	0.1 – 1.8
Failure of concrete block walls	1.8 – 2.9
Collapse of wood framed buildings	Over 5.0
Serious damage to steel framed buildings	4 – 7
Severe damage to reinforced concrete structures	6 – 9
Probable total destruction of most buildings	10 – 12

Table 2.3. Damage Approximations Due to Blast. Source: EXPLOSIVE SHOCKS IN AIR, Kinney & Graham, 1985; FACILITY DAMAGE AND PERSONNEL INJURY FROM EXPLOSIVE BLAST, Montgomery & Ward, 1993; THE EFFECTS OF NUCLEAR WEAPONS, 3rd EDITION, Glasstone & Dolan, 1977.

A caveat in using the above table is that the studies from which it is compiled, are quite dated. For broad based discussion the information is valid. However, while many basics have stayed the same, there have been significant changes in many materials and construction techniques during the intervening decades which should be considered before passing final judgement. If an Owner is asking for an opinion on an existing building's capabilities, the table may start the discussion, but a proper analysis should be done before drawing a conclusion.

- **Progressive Collapse**

When a primary structural element of a building structure fails and there is resulting failure of adjoining structural elements, the result is a progressive collapse. This can result from accidents like fires that weaken structures or the result of impacts from blasts that "take out" main structural members. One of the most dramatic examples of a progressive collapse was the destruction of the Alfred P. Murrah Federal Building in Oklahoma City. A deliberate use of progressive collapse is employed in the demolition of large or tall buildings through use of controlled detonations resulting in an implosion of the structure.

- **Ductile and Robust Structures**

Two of the techniques to provide resistance to blasts are to make the buildings robust and / or make them ductile. As a principle, the greater the ductility of the structure, the greater its ability to resist failure. This is the “bend but not break” philosophy. The structure is designed to provide an elastic response. Steel frames are effective in providing this property. On the other hand, the robustness of a building is its strength in resisting excessive loads. This is the brutish approach. Usually, materials such as concrete are used but a steel frame with redundant members can also be robust. In fact, redundancy of structural members is used to provide additional strength to older buildings where concern for additional threats is identified. However, it should be noted that adding redundancy or strengthening existing buildings is an expensive and complicated endeavor that is frequently not worth the economic investment.

- **Frequency / Risk Analysis**

In part 1 of the course, the concept of a QRA (Quantitative Risk Analysis) was introduced. The application of this methodology to BR design results in a recommendation from the QRA consultant (in concert with the building owner) for the design overpressures and durations for the buildings in the project based on their location relative to the threat source. The analysis involves extensive scenario modelling. The analytical tools and models are almost always proprietary to the QRA firms. The models evaluate the likelihood and frequency of an event occurring. The building owner and the QRA consultant determine the risk level that the owner is willing to accept for a given frequency of the threat. These are evaluated in terms of the statistical chances of an event occurring and represented by values such as 1 x 10-6 (meaning that at the given location, there is a once in a million chance of the overpressure exceeding the modeled value). In some cases, the results are presented in terms of the number of fatalities resulting from an event.

In industrial settings, the owners often set the acceptable risk levels in coordination with their insurance carriers. In public and governmental projects, the levels are set by guidelines published by agencies (such as GSA, FEMA, DoD, DoE and others) as there are currently no building codes that establish BR design criteria. The division of risk responsibilities are illustrated below:

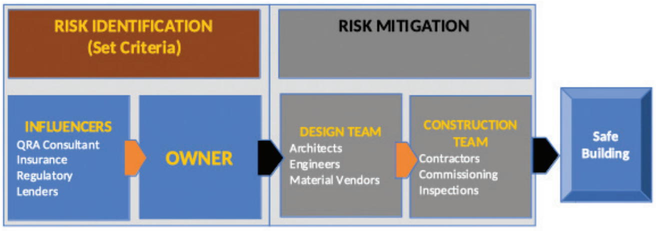


Figure 2.3 – Risk Identification & Mitigation. Source: Author

STAKEHOLDER LEVELS OF ENGAGEMENT

In the absence of established codes for BR design, the defining of the need, extent of BR required, and the level of architectural design are all either given by the Owner or determined by a collaborative consensus between the Owner, QRA consultant, engineers and architects. The level of engagement is particularly high on the part of the owners who must set the criteria and assume the risks resulting from those decisions. The owners are aided in this effort by the QRA consultants who identify the types of risks and their likelihood. In non-industrial settings where security is the driver for BR design, the owners consult with law enforcement and federal agencies to help establish design criteria. For governmental buildings, the relevant agencies establish the criteria and provide design guidelines or requirements.

Once the criteria are established, the architects and engineers (structural, HVAC and electrical) work collaboratively to develop a design that meets the owner’s functional and BR design requirements.

OVERPRESSURE / IMPULSE CURVES

Given the strong relationship between overpressure and impulse in influencing BR design, it is useful for Architects to have a high-level understanding of what the Overpressure / Impulse curves look like and what they mean.

An Overpressure / Impulse curve plots the pressure on the Y axis and the impulse of the blast on the X axis. The curves for constant Building Damage Levels for a given blast scenario are then plotted.

The building design characteristics and location criteria are then modeled, and the resulting response is plotted. It will show where a design falls on the curve. The design can then be modified until it is in the region that has been established as acceptable to the project team.

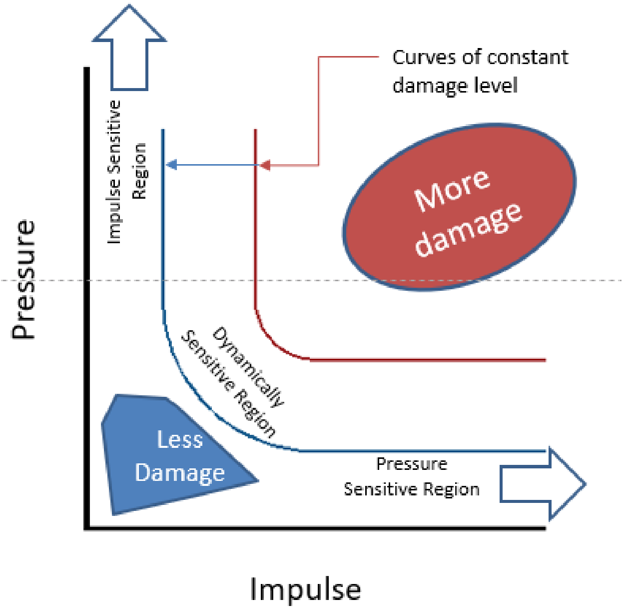


Figure 2.4 – Pressure / Impulse curve showing damage level and sensitivity zones. Source: Author

BLAST RADIUS AND BLAST CONTOURS

Another term that designers encounter from QRA consultants is the "Blast Radius" or "Blast Contours". These are simply modeled points of equal blast pressure radiating from the point of the explosion. Like map contours that represent points of equal elevation, these "blast contours" do the same for blast pressure. The contours closer to the origin of the explosion represent higher pressures and lines further out represent lower pressures. By plotting the location of the proposed building, a target overpressure design basis can be developed. The term "Blast radius" is more commonly used when the blast wave is more likely to be uniform (circular). The term "Blast contour" is used when the blast dissipation is more likely to be irregular. In concept and application, they are used the same way. The example below shows a sample of blast contours.

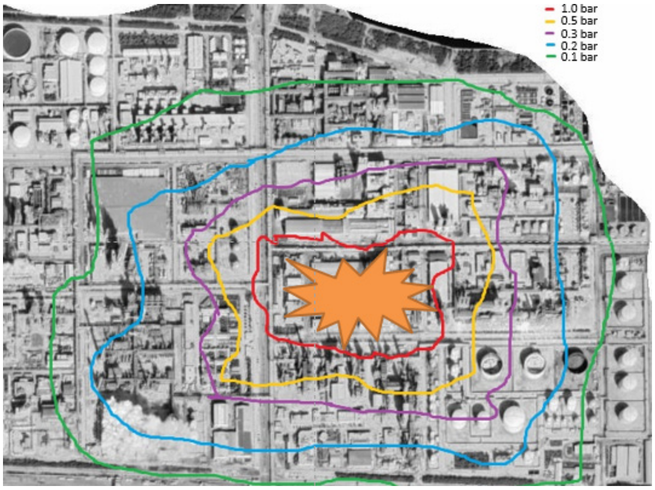


Figure 2.5 – "Blast Contours"; Source: Author (Not a real location or situation but for illustrative purposes only)

SEISMIC VS BLAST RESISTANT DESIGN

It is tempting to equate Blast Resistant design with Seismic design. But the two involve different types of forces acting differently on a structure. Hence, the responses are also different. An earthquake causes ground movements in wanes that shake the building from the foundation upwards. As we have discussed, a blast generates a shockwave that primarily hits the building through the air, although there is a ground component to the blast wave as well that is similar to an earthquake, but it is much lower in intensity. The other major difference is the time involved. Blasts have durations of milliseconds whereas an earthquake can last for several seconds and minutes. Other differences that affect buildings are that earthquakes are almost always followed by multiple aftershocks of diminishing intensity. Earthquakes also tend to affect the entire building at the foundation fairly uniformly and the shaking causes the upper structure to respond. Blasts do not affect the structure uniformly. They are most severe on the façade and elements closest to the path of the blast wave. So, while the theory of addressing seismic and blast resistance have common roots, the tactical applications and responses are different and diverge depending on the severity of each threat.

BR BUILDING COMPONENTS

A common misconception among design professionals is that BR design only affects the building structure and exterior walls. While those are indeed the most sensitive areas, there are several other components of a building that must be addressed to provide a BR design. The following are the major components that are affected:

- **Foundations**

Foundations are inherently part of the building structure, but they are listed separately here to emphasize that BR design is not solely a function of lateral design. The miniscule time that the severe blast overpressures impact a building place very powerful stresses on the building foundation and the connections between the foundation and the superstructure.

- **Exterior Doors and Hardware**

Depending on the expected overpressure and BDL criteria, specialized doors have to be used. The frames and hardware are similarly specialized. For lower ratings, many available heavy-duty doors and hardware provide adequate resistance, but this should always be verified. Some Owners will specifically require "blast rated" components (meaning they have been tested and certified). Blast rated doors are not usually readily available "stock" items. They are fabricated for each project so lead times must be factored. Similarly, the availability and lead times for blast rated hardware should also be a consideration for early specification and procurement.

- **Exterior Windows**

Until relatively recently, BR window systems were generally unavailable, and the use of bullet resistant vision panels was the closest substitute. However, there are now BR window systems and glazing options that can provide both large surface and high-pressure resistance. Laminated annealed glass with structural sealant at the inside perimeter is generally the preferred option. In industrial settings, windows are avoided but this is not generally feasible be in civilian or government facilities. As a result, FEMA, in its publication FEMA 427 has provided performance conditions for windows that provide a useful basis for BR design:

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glass cracks. Fragments enter space and land on floor no further than 1 meter (3.3 feet) from window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 3 meters (10 feet) from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 3 m (10 feet) from the window at a height no greater than 2 feet above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 3 meters (10 feet) from the window at a height greater than 0.6 meters (2 feet) above the floor.

Table 2.4. Performance Conditions for Windows.
Source: Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks, FEMA 427

As with all guidelines, these serve as a baseline and must be validated for the project's applications. In the case of windows, architects should consult with their structural engineers to make sure the openings and frame anchoring systems are integrated into the design. For glazing, the manufacturer of the framing and glass should be actively consulted and testing data for their products meets the project criteria.

Finally, it should be noted that for BR design, the costs increase exponentially as the window size and/or the overpressures increase.

- **Interior Studs and Wall / Roof Connections**

Even though the blast impacts the exterior of the building, the impact, even if for a few milliseconds, causes a momentary shift in the building. Therefore, all connections to the exterior envelope have to be flexible to withstand the movements. This is similar in concept to earthquake design. Current engineering advances allow structures to be more dynamic (less bunker like) and that increases movement. That in turn requires all connecting elements to be similarly designed.

- **Penetrations**

Any element that penetrates the exterior envelope of a BR building should be designed to meet the movement criteria of the BR design. These include electrical, mechanical and other types of penetrations. Generally, it is advisable to minimize through-wall or through-roof penetrations but that is not always practical. In these cases, there are special sleeves designed specifically to address BR needs. All the engineering disciplines involved should have familiarity with BR design options for their own area of specialty.

The above capture the most common technical elements that require special focus. The main point to emphasize is that when it comes to BR design, all connections and treatment of the building envelope and its skeleton have to be evaluated. Depending on the risk level and design parameters, the number of items requiring special design and the relationships between the components can be relatively common if the BR requirements are low but as these increase in intensity, the design can get complex.

BR DESIGN TOOLS

The analysis of blast impacts for a given set of criteria is a complex process, the most important and sophisticated of which are the structural predictions for how the structure is likely to behave. Physical testing is expensive and most often not practical. The analysis of a design response to a blast event requires it to be time dependent and non-linear. The techniques involve complex dynamic modeling techniques that evolved from those used for advanced seismic analyses. The elaboration of these is beyond the scope of this course and is really a structural engineering specialization. It is, however, beneficial for Architects to know that their structural engineers have experience using dynamic analysis and employ software that is capable of performing the required calculation. Some of the available computer software programs (per FEMA) are:

- AT Planner (U.S. Army Engineer Research and Development Center)
- BEEM (Technical Support Working Group)
- BLASTFX (Federal Aviation Administration)

In addition to the above, structural engineers use other, sometimes proprietary, software to perform the calculations. There is presently (2022) no specialized software for Architects for blast resistant design.

SECTION 2 REVIEW QUESTIONS

6. **On Blast Contour maps, the irregular concentric "contours" represent:**
   a. Lines of equal pressure
   b. Zones established by FEMA and DoD
   c. Blast duration
   d. All of the above

7. **Which of the following are building elements affected by BR design?**
   a. Exterior doors & hardware
   b. Wall and roof penetrations
   c. Exterior Windows
   d. All of the above

8. **According to some published data as tabulated in this course, collapse of wood framed buildings can occur in blasts over:**
   a. 0.5 psi
   b. 10 psi
   c. 5.0 psi
   d. 1.8 psi

9. **The destruction of the Alfred P. Murrah building in Oklahoma City is a dramatic example of what kind of damage:**
   a. Tornado hit
   b. Bunker busting bomb
   c. Seismic failure
   d. Progressive collapse

10. **Which FEMA publication provides performance conditions for windows??**
   a. FEMA 426
   b. FEMA 427
   c. FEMA 429
   d. FEMA does not provide such a guideline

11. **Which of the following is NOT a software that addresses or supports blast design analysis :**
   a. BEEM
   b. AT Planner
   c. BLASTFX
   d. REVIT

12. **What types of pressure impact a building as a result of a blast shockwave?**
   a. Side-on pressure
   b. Reflected pressure
   c. Back (Rear) face pressure
   d. All of the above

13. **The government agency that establishes design guidelines for Federal building categories:**
   a. GSA
   b. FEMA
   c. The Department of Defense
   d. NSA

PART 3 – BLAST RESISTANT DESIGN – IMPLICATIONS FOR ARCHITECTS

Part 1 of this course covered a basic introduction to Blast Resistant (BR) design, some fundamental concepts, and its applicability and relevance for Architects. Part 2 focused on technical definitions and considerations.

In this last part the following will be examined:

- Programming for BR design – interaction between architects, clients, engineers and vendors
- What Architects need to specify for BR
- Choosing prefabricated, pre-engineered or site built
- Choice of BR forms
- Do BR buildings have to be inherently "ugly" bunkers?
- BR design codes
- Rules of Thumb for Architects

PROGRAMMING FOR BR DESIGN

The need for a BR designed building is not always an upfront "given". In most cases the need for the requirements is extracted during the programming stage of the building. If the question is not raised early, the design impact can be significant. For Architects who work with building types or in industries where BR design is a routine occurrence, the programming questions are standard. However, as has been explained, BR requirements, or at least considerations, are entering into many non-traditional applications. So, it is generally a good idea to ask the question and establish whether BR design will apply or not. In cases where BR design is required, the following are the key elements that need to be addressed during programming:

- Ask the question "Does the Building need to be designed for BR or considerations for blast threats?"
- If so, are the design criteria available?

- If not, who will provide these – QRA consultant or Owner?
- What is the timing to receive the information?
- Should the design team hold or proceed on an assumed or "placeholder" basis as directed by Owner?

The process is illustrated in a flow chart in Figure 3.1.

Blast Resistant (BR) Building Design Programming Flow Chart

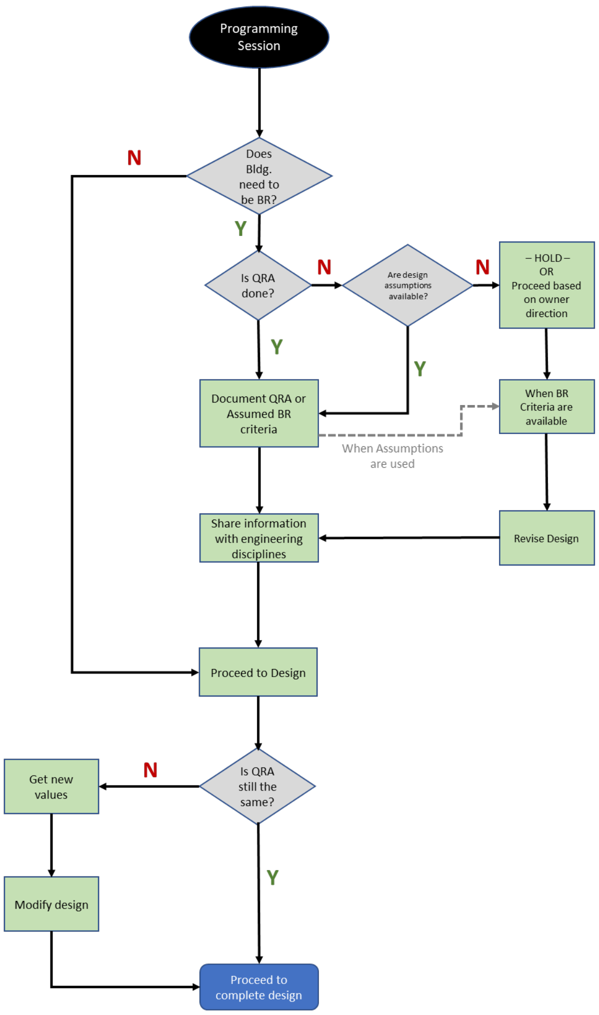


Figure 3.1 – BR Design Programming Flow Chart
Source: Author

WHAT ARCHITECTS NEED TO SPECIFY FOR BR

The typical elements of a BR building which architects have a primary responsibility to specify are:

- Exterior wall components and details.
- Exterior doors and hardware.
- Window systems and glazing.
- Roofing systems.
- Interior wall systems – to have flexibility.
- All connection details between interior building elements and the exterior envelope

In specifying BR "rated" systems and components, architects need to ensure that their specifications state the overpressure requirements that the building is designed for. In cases where the likely source of the blast is known, making the blast direction predictable, there may be different blast resistance requirements for the surfaces with reflected (blast facing side) and side-on (other faces) pressures. In these cases, architects should work closely with structural engineers to ensure the right resistance criteria are applied uniformly across each surface. In practice, generally all sides are designed to the highest value. This helps with uniformity of materials. When products are specified, it is important to request credible testing data from manufacturers. The test reports should specify the criteria for which the test was conducted.

For detailing connections, it is worth checking various industry associations that have published go-byes to assist architects. For example, precast concrete is a popular system for industrial blast resistant building facades. In recognition of this, the Precast Concrete Institute (PCI) has published several blast resistance connection details in the PCI Designer's Notebook series. Another source of good information is the Whole Building Design Guide (WBDG.org) developed by the National Institute of Building Sciences that includes participation from the leading federal agencies involved with BR design (DoD, DoE, GSA, Dept. of Homeland Security, NASA, State Department, Dept. of Veterans Affairs). When using standard details, recommended connections, or other suggested solutions from industry of government sources, architects should always check to see if the solution is prescriptive or a useful starting point. Most are of the latter type, meaning that they need to be adapted to the project specifics. This is not any different from any standard detail application but in the case of BR design, due to the potential consequences of failure, extra care and diligence should be applied.

CHOOSING PREFABRICATED, PRE-ENGINEERED OR SITE BUILT

Depending on the function and location for the BRB (Blast Resistant Building), architects have a variety of choices to address the client's needs. The options include three distinct approaches:

- **Prefabricated BR Buildings**

As demand for BR buildings has increased, much of the need is in industrial settings where functionality and speed are the key drivers. For these applications, many mobile building fabricators have developed prefabricated BR buildings that can be quickly transported and erected on locations. Most of these systems are modularized based on the size of a container for truck transport. The BRBs can be a single container for small applications such as local control rooms or instrument enclosures in industrial applications where quick installation is needed or where access to the site is physically restricted. For uses where more space is needed, multiple modules can be combined to create larger BR complexes.

The main advantages of the prefabricated BRB options are speed, standardization, ability to be deployed in remote areas, and the outfitting of equipment, finishes, and utilities at the shop. These buildings can also be erected in remote and challenging site locations with minimal labor and erection time (if a setting pad or foundation is available with the required service utilities). Prefabricated buildings also tend be lower cost per SF than a field constructed building. The drawbacks are that these solutions offer limited configuration options and are best suited for smaller unit sizes. They are also not very attractive for public buildings or facilities outside of industrial or military settings.

- **Pre-Engineered BR Buildings**

A Pre-Engineered Building (PEB) differs from a Prefabricated (Prefab) building in that a Prefab building is wholly designed and built in a factory and shipped to site (in whole or in sections that are re-assembled at site) whereas a PEB mainly refers to a steel building whose configuration is determined before building components are manufactured. Pre-engineered buildings are often designed to allow greater flexibility by using a prefabricated skeleton to create a framework for the new building.

The pre-engineered building industry now has a sizeable footprint the BR design field. These buildings offer more flexibility of size and form, but they only provide the BR structural frame and, in some cases, the exterior cladding and even doors and hardware. However, as the blast "rating" increases, these systems start to get more complicated, and they lose some of their economic advantages. Unlike prefabricated buildings, the pre-engineered approach is more of a building block approach where components, rather than entire building sections are shipped to site and erected. PEBs also do not facilitate the incorporation of utilities and finishes in the fabrication shop. The most efficient application seems to be the use of these systems to provide a pre-engineered structural frame, thus reducing field time compared to constructing a more traditional steel frame.

- **Site Built BR Buildings**

In many situations, a prefabricated building is not the right solution either due to the functional uniqueness, complexity, or aesthetic requirements for the building. In these situations, the building design follows a conventional design process with BR as an added requirement. This is seen commonly in industrial buildings that fall in a relatively high (over 3 psi) blast risk zone, but their functionality precludes the use of prefabricate buildings. In this case, if there is no significant architectural aesthetics involved, a combination of pre-engineered components and site construction can be employed. In other cases where the building has a special public function (like embassies, schools, public buildings), the buildings are always site constructed in a conventional manner but often with unconventional materials and methods.

CHOICE OF BR FORMS

Blast Resistant building now come in a variety of architectural styles, especially for public and commercial uses. However, there are some basic rules of physics that make some types of shapes and forms more suited to BR design. The most efficient and cost-effective building shapes are those that are regular, preferably rectangular or circular. Other shapes can be made blast resistant but with each irregularity and complexity, the structural design gets complicated, and costs increase rapidly. As a generic guideline, the following shape are a good go by:

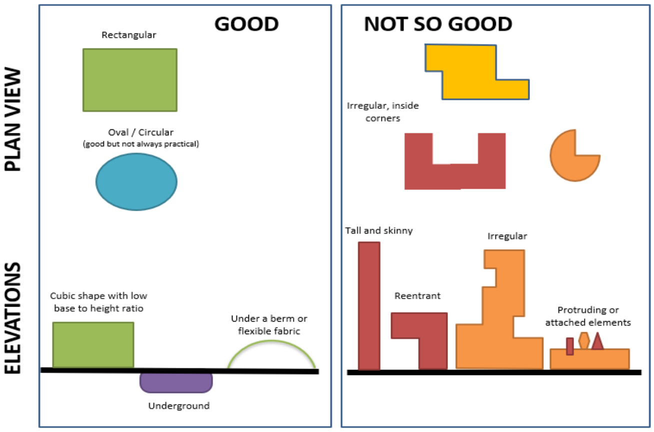


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Figure 3.2 – BR building forms   Source: Author

The diagrammatic representation (Fig. 3.2) illustrates how simplicity and regularity are prime objectives for selection. A few points to note are that shapes that can trap a blast wave (like "U" shapes or inside "reentrant corners) create major design challenges and are best avoided. This applies to both plan and elevations. In the use of underground structures, these are very effective for the airborne portion of a shockwave but are affected by the subsurface portion of the blast wave and so that must be considered by the structural response.

If structural strengthening of the building is not feasible or insufficient to address blast impact, there are techniques that can mitigate the shockwave. One option is to employ slopes, or berms around the building that can be used to shield buildings by absorbing and deflecting the wave. Another frequently used solution is the use of "blast walls" that can be used to block or deflect the impact of a blast, thereby protecting the structure. These types of walls are most commonly used to protect critical equipment in industrial settings where a likely direction of the blast risk is predictable. This is a more cost-effective option than housing the equipment is a fully blast resistant building. It is also a viable consideration when the threat to an existing non-BR building is identified, and modification of the building is not practical. Another popular BR option, often used in temporary BR structures, is the use of heavy blast rated fabric and similar tensile structures, usually inflatable, as these can "bend" with blast waves and quickly regain shape. In the event of failure and collapse, these structures have soft components so are less deadly.

DO BR BUILDINGS HAVE TO BE INHERENTLY "UGLY" BUNKERS?

If one simply does an internet search using the phrase "blast resistant buildings" and looks at the images that show up, there would be no blame in thinking that all BR buildings are container looking, uninviting and "ugly". The reason for that is the most marketed, and hence most tagged websites are those of prefabricated BR building manufacturers. These, as described earlier, tend to be standardized for shipping, modularization, and cost effectiveness, resulting in their bleak and harsh looks. Some vendors try to soften the appearance by using bright colors and/or applying graphics and stripes.

If, however, the internet the search is modified to look for "Blast Resistant Embassies" or "Blast Resistant Courthouses", an entirely different set of buildings can be seen. Even though the sample of photographs is limited because many of these facilities are not publicized for obvious security reasons, the architectural diversity of form and materials is evident. The point is that BR buildings do not need to be inherently "ugly" and "lifeless". That reputation is the result of historical industrial and military use that is entirely driven by cost and "fit for purpose" mentality, not aesthetics or even user comfort. When public image, user friendliness and human factors are factored, more appealing designs are realized – no doubt with a premium cost. One design element that gets special attention is windows. As a rule, BR buildings avoid the use of windows and any type of exterior (and even interior) glazing. However, as discussed in Part 2 of the course, there are glazing products out there that can be used but these can get bulky and expensive. For most uses, it is true to say that windows are discouraged. However, there are creative solutions to liven up windowless spaces. One very successful option is the use of high-resolution display panels framed as windows. These can be either fed live video feeds of the exterior to mimic a true window or they can be used with recorded scenes that create a "mood" for the occupants. This technique, originally developed for underground spaces and medical facilities is seeing more applications in BR buildings.

BR DESIGN CODES

As far as civilian building and life safety codes like the IBC or NFPA are concerned, there are currently (2022) no requirements for BR buildings. These, as has been stated, are owner determined requirements derived by a risk analysis. However, that is not to say that there are no regulatory or scientific based guideline available. Industries such as petrochemicals and several government agencies have published studies, guidelines and even mandatory rules that govern BR buildings. These range from the extreme of the Nuclear Regulatory Commission (NRC) for nuclear plants and associated functional buildings to FEMA guidelines for anti-terrorism across all types of public facilities. Some useful references are:

- ASCE "Design of Blast Resistant Buildings in Petrochemical Facilities" Second Edition,
- UNIFIED FACILITIES CRITERIA (UFC) – UFC 3-340-02 (TM5 -1300) "Structures to resist the effects of accidental explosions".
- US Army Corp of Engineers – PDC-TR-06-08 Rev 1 – "Protective Design Center Technical Report".
- FEMA publications FEMA 426 (Ch., ch.4), FEMA 427, FEMA 428 (ch.4), FEMA 429
- Dept of Defense publications for blast resistant structures.

Even though there are no current building codes addressing BR design, it is likely that at some point in the future, as the scope of BR design expands, codes will take up the subject and it will become more standardized. The road to codification of BR standards is likely to take the following steps, as noted in FEMA 429, Chapter 4:

- Federal preemption
- State mandate or preemption
- Local prerogative
- Model code and voluntary standards

The Federal step is already underway as evidenced by the many agencies that have developed and implemented BR standards, guidelines or mandates. Voluntary standards are limited to some industries like petrochemicals, although to date there is not one universally industry wide set of rules.

The factors that will most affect any broad adoption of a BR design code will depend on the types of mandates proposed and their cost impact relative to the perceived safety benefits for the public at large.

THE "ELEPHANT IN THE ROOM" – COST IMPLICATIONS OF BR DESIGN

As with any aspect of building design, owners always want to know the costs. Architects dealing with BR design are frequently asked what the BR "premium" is. There is, of course, no fixed rule because the "premium" varies wildly depending on the level of protection, building type, and the combination of measures to be taken. The exception to this is when an architect has a history of several similar projects, the delta for BR design can be extrapolated over time and, on that basis, a good estimate can be projected. For example, an architect involved with several similar industrial BR buildings was able to determine that the "premium" for that building type ranged from 20% to 50% depending on the design overpressure. Companies regularly involved with BR buildings have similar data on the cost factors for their designs and building types. This information is usually company confidential and very little is published.

For a new project, cost factors to be considered for BR design fall into the following categories:

- **Level of threat:**

This is the overpressure that the building is to be designed for. This results in enhancements to the building that include:

- ○ The strengthening of the structure.
- ○ Structural measures to prevent progressive collapse in the building is more than one level.
- ○ Utilizing strengthened building envelope elements – walls, roof and any exterior attachments that are not sacrificial.
- ○ Upgrading doors, windows, and hardware to meet the BR design criteria.

- **Location of the building:**

If the location of the building makes it susceptible to the blast threat, mitigation steps can include the following:

- ○ Consider stand-off distance if the threat is from a deliberate attack. This will incur costs in terms of land dedicated to landscape – hard and softscape elements like bollards, retaining walls and planters within the stand-off distance.
- ○ Where stand-off distance is not achievable, blast wave deflection or blocking measures like blast walls or berms can be utilized.
- ○ If the above are not feasible or too costly, relocating the facility may have to be considered.

Finally, the amount an owner is willing to pay for a specific level of BR protection comes down to the degree of damage and loss that is deemed acceptable in the event of an "incident". Depending on the likelihood of the event occurring, an owner may elect to take no measures if the odds are so small as to make it near improbable.

RULES OF THUMB FOR ARCHITECTS

This is the concluding section of the course, and the best take away would be to provide some basic "Rules of Thumb" for Architects that could be applied for BR designs. Ten rules are listed. Not because there are only ten but, in the spirit of the late comedian and philosopher, George Carlin, "Ten sounds official."

(The list below is not in any particular order of precedence)

1. Blast Resistance is NOT Blast Proof. There are resistance limits to every design.
2. Regular, "boring" forms are preferrable to exotic or irregular shapes for BR buildings.
3. For structural frames, moment frames are considered a better choice than braced frames.
4. Avoid windows. If not possible, have a generous budget.
5. A building's "psi" rating is an informal layperson term to describe the relative level of blast threat. (Generally referring to the peak reflected overpressure)
6. Most buildings are designed to achieve a Medium Damage Level. Always confirm with the Owner.
7. Keep Architect and engineering roles clear. Architects are responsible for the BR building envelope and all details that connect to it. Structural engineers design the foundations and the building frame. MEP engineers address all utilities, penetrations, and any emergency backup systems.
8. Buildings designed for <1 psi generally require minimal strengthening beyond the code-based wind loads. Buildings up to 3 psi range can be designed using many commercially available materials. Buildings 3-7 psi require specialized components. Buildings over 8 and 10 psi require significant specialized detailing and customized components. Always confirm with structural consultant.
9. Architects do NOT interpret QRA reports or determine blast resistance criteria. The Owner and QRA consultant provide the design criteria, over pressure and duration values which the design team uses, including any exceptions or variances.
10. Do not attach items to BR buildings and keep roofs clear of equipment and minimize penetrations.

SECTION 3 REVIEW QUESTIONS

14. If a QRA analysis is not available, the design team asks which question?

a. Stop all work?
b. Which version of IBC should we use?
c. Are design assumptions available?
d. None of the above

15. Which of the following is NOT a characteristic of Pre-engineered BR buildings?

a. Entirely fabricated in the sop and transported to site.
b. Offer flexibility of size and form.
c. Reduce construction time compared with site-built construction.
d. Generally, do not include utilities installed at the shop.

16. Windows in BR buildings can be ____________:

a. provided, but at a premium cost
b. can never be used.
c. easily adapted from any commercial manufacturer.
d. only used above 20 feet.

17. Which of the following provide BR design guidelines for specific situations?

a. IBC
b. NFPA / BOCA
c. FEMA publications FEMA 426 (ch.3, ch.4), FEMA 427, FEMA 428 (ch.4), FEMA 429
d. Institute of Blast Resistant Building Design.

18. PDC-TR-06-08 Rev 1 – "Protective Design Center Technical Report" is issued by __________?

a. FEMA
b. US Coast Guard
c. US Army Corps of Engineers
d. Dept. of Defense

19. Which of the following are some Rules of Thumbs for Architects doing BR design?

a. Regular, "boring" forms are preferrable to exotic or irregular shapes for BR buildings.
b. Avoid windows.
c. Architects do NOT determine Blast resistance criteria. That must come from the owner.
d. All of the above

20. The road to codification of Blast resistance standards is likely to include which of the following steps?

a. Federal Preemption
b. Local Prerogative
c. State mandate or preemption
d. All of the above

RESOURCES & ADDITIONAL READING

"Design of Blast resistant Buildings in Petrochemical Facilities," ASCE task Committee on Blast Resistant Design, 1997

"Blast Considerations," Precast Concrete Institute Designer's Notebook DN-14

"*Building Security Through Design: A Primer for Architects, Design professionals and their Clients,"* November 2001, The American Institute of Architects, Washington, DC.

"Security Design Criteria for New Federal Office Buildings and Major Modernization Projects," Interagency Security Committee ISC (executive agent – GSA), Washington, DC, May 2001

"Structures to Resist the Effects of Accidental Explosions," U.S. Departments of the Army, Navy and Air Force, November 1990

"Blast Resistant design with Structural Steel," Anatole Longinow, PhD and Farid Alfawakhiri, PhD, Modern Steel Construction, October 2003

"Earthquake-Resistant Design Concepts," FEMA P-749, Washington, DC, December 2010

"Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings," FEMA 426, Washington, DC, December 2003

"Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks," FEMA 427, Washington, DC, December 2003

"Insurance, Finance, And Regulation Primer for Terrorism Risk Management In Buildings," FEMA 429, Washington, DC, December 2003

"P100 facilities Standards for the Public Buildings Service," GSA, Washington, DC, October 2021

"The Risk management Process - An Interagency Security Committee Standard," U.S. Department of Homeland security, Cybersecurity and Infrastructure Security Agency, 2021 Edition

REVIEW QUESTION ANSWERS

Section 1

1. **In non-military situations, which types of buildings are most frequently impacted by blasts**
   a. Tall skyscrapers; incorrect, industrial plants have more frequent events then skyscrapers
   b. Residential subdivisions; incorrect, however, interesting enough there is a trend for more protective design elements being applied to residential house plans.
   c. Industrial facilities; Correct, these remain the most frequently occurring events and as such the use of blast resistant design is an essential part of the programming for these facilities
   d. Schools; incorrect, these are not the most frequently impacted by blasts but this is a public place that is increasingly adopting some of the blast resistant design principles do to some current events in history.

2. **QRA is the acronym for:**
   a. Quality Research Analysis; incorrect
   b. Quotient of Risk Assessment; incorrect
   c. Qualitative Review Approach; incorrect
   d. Quantitative Risk Assessment; correct levels of blast resistance are determined by these assessments performed by specialized engineering and Risk consultancy firms

3. **Which of the following codes has extensive guidelines for Blast Resistant Buildings?**
   a. IBC 2009; incorrect
   b. NFPA 101; incorrect
   c. UBC; incorrect
   d. None of the above; correct, As far as civilian building and life safety codes like the IBC or NFPA are concerned, there are currently (2022) no requirements for BR buildings.

4. **In developing a house for a famous client with security concerns, who would advise the architect on the criteria for any blast resistant design requirements?**
   a. The owner's security consultants; correct, The application of BR design for private residences is a very specialized category where the schemes are often unique and coordinated with security consultants.
   b. The local building official; incorrect, they would generally not have the expertise for BR design
   c. The Department of Defense; incorrect, residential is not their focus
   d. The structural engineer; incorrect they generally will not work with home owners about security concerns.

5. **Which of the following are building elements affected by BR design?**
   a. Exterior doors & hardware
   b. Wall and roof penetrations
   c. Exterior Windows
   d. All of the above

Section 2

6. **On Blast Contour maps, the irregular concentric "contours" represent:**
   a. Lines of equal pressure; correct; these model points of equal blast pressure radiating from the point of the explosion.
   b. Zones established by FEMA and DoD; incorrect, these zones do not show on blast contour maps;
   c. Blast duration; incorrect, these contours deal with blast pressure
   d. All of the above; incorrect

7. **Which of the following are building elements affected by BR design?**
   a. Exterior doors & hardware; correct, this is a building element affected by BR design
   b. Wall and roof penetrations; correct, this is a building element affected by BR design
   c. Exterior Windows; correct, this is a building element affected by BR design
   d. All of the above; correct all answers above are correct

8. **According to some published data as tabulated in this course, collapse of wood framed buildings can occur in blasts over:**
   a. 0.5 psi; incorrect, this would typically cause minor damage to buildings
   b. 10 psi; incorrect, this is probable total destruction of most buildings
   c. 5.0 psi; correct, this incident pressure would cause collapse of wood framed buildings
   d. 1.8 psi; incorrect, this would cause panels of sheet metal to buckle

9. **The destruction of the Alfred P. Murrah building in Oklahoma City is a dramatic example of what kind of damage:**
   a. Tornado hit; incorrect, this did not affect the Alfred P. Murrah building in Oklahome City
   b. Bunker busting bomb; incorrect
   c. Seismic failure; incorrect, this is not what caused the destruction of the Alfred P Murrah building.
   d. Progressive collapse; the destruction of the Alred P. Murrah building was one of the most dramatic examples of progressive collapse. The primary structural element of the building structure failed and there was resulting failure of adjoining structural elements.

10. **Which FEMA publication provides performance conditions for windows??**
   a. FEMA 426; incorrect, this provides guidelines and charts that define incident overpressures in psi as a function of stand-off distance and explosive force based on pounds of TNT.
   b. FEMA 427; correct this publication has provided performance conditions for windows that provide useful basis for BR design
   c. FEMA 429; incorrect, this covers steps that will need to be taken to the codification of BR standards, as there are no current building codes addressing BR design at this time.
   d. FEMA does not provide such a guideline; incorrect, they are in FEMA 427

11. **Which of the following is NOT a software that addresses or supports blast design analysis :**
    a. BEEM; incorrect, this is a software that addresses or supports blast design analysis
    b. AT Planner; incorrect, this is a software that addresses or supports blast design analysis
    c. BLASTFX; incorrect, this is a software that addresses or supports blast design analysis
    d. REVIT; correct, this is NOT a software that addresses or support blast design analysis

12. **What types of pressure impact a building as a result of a blast shockwave?**
    a. Side-on pressure; correct
    b. Reflected pressure; correct
    c. Back (Rear) face pressure; correct
    d. All of the above; correct all above are types of pressure impact as a result of a blast shockwave.

13. **The government agency that establishes design guidelines for Federal building categories:**
    a. GSA; correct, the General Services Administration (GSA) of the US Federal government establishes design guidelines that are de-facto codes.
    b. FEMA; incorrect, FEMA does not provide such a guideline
    c. The Department of Defense; incorrect, this department does not provide such a guideline
    d. NSA; incorrect, the National Security Agency does not provide such a guideline

Section 3

14. **If a QRA analysis is not available, the design team asks which question?**
    a. Stop all work?; incorrect, stopping not necessary at this point
    b. Which version of IBC should we use?; incorrect,
    c. Are design assumptions available?; correct, according to Figure 3.1 this is the next step in the Programming Flow Chart
    d. None of the above: incorrect, according to Figure 3.1

15. **Which of the following is NOT a characteristic of Pre-engineered BR buildings?**
    a. Entirely fabricated in the sop and transported to site.; correct, this description fits a pre-fabricated building not a pre-engineered BR building
    b. Offer flexibility of size and form.; incorrect, this does describe a Pre-engineered BR building
    c. Reduce construction time compared with site-built construction.; incorrect, this does describe a Pre-engineered BR building
    d. Generally, do not include utilities installed at the shop.; incorrect, this does describe a Pre-engineered BR building

16. **Windows in BR buildings can be ____________:**
    a. provided, but at a premium cost; correct, BR buildings try to avoid the use of windows, however there are glazing products out there that can get bulky and expensive bur are an option.
    b. can never be used.; incorrect, windows can be used but are expensive
    c. easily adapted from any commercial manufacturer.; incorrect, these windows are specially made
    d. only used above 20 feet.; incorrect, windows are generally discouraged but can be used if willing to pay a premium for a special type of bulky glazing product.

17. **Which of the following provide BR design guidelines for specific situations?**
    a. IBC; incorrect, not the correct guidelines for BR design and specific situations
    b. NFPA / BOCA; incorrect, not the correct guidelines for BR design and specific situations
    c. FEMA publications FEMA 426 (ch.3, ch.4), FEMA 427, FEMA 428 (ch.4), FEMA 429 incorrect, not the correct guidelines for BR design and specific situations
    d. Institute of Blast Resistant Building Design; correct, this does provide BR design guidelines for specific situations

18. **PDC-TR-06-08 Rev 1 – "Protective Design Center Technical Report" is issued by _________?**
    a. FEMA; incorrect FEMA does not issue this report
    b. US Coast Guard; incorrect, FEMA does not issue this report
    c. US Army Corps of Engineers; incorrect, FEMA does not issue this report
    d. Dept. of Defense; correct, this is a report issued by the Dept. of Defense

19. **Which of the following are some Rules of Thumbs for Architects doing BR design?**
    a. Regular, "boring" forms are preferrable to exotic or irregular shapes for BR buildings.; correct
    b. Avoid windows.; correct
    c. Architects do NOT determine Blast resistance criteria. That must come from the owner.; correct
    d. All of the above; correct, all of the above answers are Rules of Thumb for Architects doing BR design.

20. **The road to codification of Blast resistance standards is likely to include which of the following steps?**
    a. Federal Preemption; correct; correct
    b. Local Prerogative; correct
    c. State mandate or preemption; correct
    d. All of the above; correct, all these steps to codification of Blast resistance will likely happen.