Unit VII

COURSE TITLE	Building Design for Homeland Security	**TIME**	75 minutes
UNIT TITLE	Explosive Blast		

OBJECTIVES

1. Explain the basic physics involved during an explosive blast event, whether by terrorism or technological accident
2. Explain building damage and personnel injury resulting from the blast effects upon a building
3. Perform an initial prediction of blast loading and effects based upon incident pressure

SCOPE

The following topics will be covered in this unit:

1. Time-pressure regions of a blast event and how these change with distance from the blast
2. Difference between incident pressure and reflected pressure
3. Differences between peak pressure and peak impulse and how these differences affect building components
4. Building damage and personal injuries generated by blast wave effects
5. Levels of protection used by the Department of Defense and the General Services Administration
6. The nominal range-to-effect chart [minimum stand-off in feet versus weapon yield in pounds of TNT-equivalent] for an identified level of damage or injury
7. The benefits of stand-off distance
8. Approaches to predicting blast loads and effects, including one using incident pressure

REFERENCES

1. FEMA 426, *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings*, Chapter 4
2. Case Study – Appendix A: Suburban, Hazardville Information Company or Appendix B: Urban, HazardCorp Building as selected
3. Student Manual, Unit VII
4. Unit VII visuals

REQUIREMENTS

1. FEMA 426, *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings* (one per student)
2. Instructor Guide, Unit VII
3. Student Manual (one per student) as selected
4. Overhead projector or computer display unit
5. Unit VI visuals, including E155_Unit07_Manchester.mpg which must be in the same electronic folder as the Unit VI visuals -- E155_Unit07.ppt
6. Chart paper, easel, and markers

UNIT VII OUTLINE

Preparing To Teach This Unit

- **Tailoring Content to the Local Area:** This is a generic instruction unit that does not have any specific capability for linking to the Local Area. However, Units IX, Site and Layout Design Guidance, and X, Building Design Guidance are excellent opportunities to illustrate the concepts in this instruction unit as applied to the Local Area.

- **Optional Activity:** There are no optional activities in this unit, except Student Activity questions that are applicable to the selected Case Study.

- **Additional Information Suburban Case Study:** Figures 8, 9, and 10 in Appendix A: Suburban, Hazardville Information Company use the following information to obtain the radius (in feet) of the rings. Using FEMA 426, Figure 4-5, page 4-11, the structural damage is taken from the Threshold, Concrete Columns Fail curve, the probable lethal injuries are taken from the Potentially Lethal Injuries curve, and the severe injuries from glass are taken from the Glass with Fragment Retention Film – Severe Wounds curve. Approximate Weapon Yield used are Figure 8 – 135 pounds TNT equivalent, Figure 9 – 20,000 pounds TNT-equivalent, and Figure 10 – 1,000 pounds TNT equivalent.

- **Additional Information Urban Case Study:** Figures 10, 11, and 12 in Appendix B: Urban, HazardCorp Building use the following information to obtain the radius (in feet) of the rings. Using FEMA 426, Figure 4-5, page 4-11, the structural damage is taken from the Threshold, Concrete Columns Fail curve, the probable lethal injuries are taken from the Potentially Lethal Injuries curve, and the severe injuries from glass are taken from the Glass with Fragment Retention Film – Severe Wounds curve. Approximate Weapon Yield used are Figure 10 – 500 pounds TNT equivalent, however Figures 11 and 12 are composites – 40,000 pounds TNT equivalent for Threshold Concrete Column Fail, 10,000 pounds TNT equivalent for Potentially Lethal Injuries, and 500 pound for Glass – Severe Wounds (no .Fragment Retention Film)

- **Activity:** The students will answer questions in the Student Activity exercises the Case Study to identify the Design Basis Threat and using the range-to-effects chart and estimated pressures chart in FEMA 426 to evaluate stand-off distances and expected damage for selected questions.

- Refer students to their Student Manuals for worksheets and activities.

- Direct students to the appropriate page in the Student Manual.

- Instruct the students to read the activity instructions found in the Student Manual.

- Tell students how long they have to work on the requirements.

- While students are working, all instructors should closely observe the groups' process and progress. If any groups are struggling, immediately assist them by clarifying the assignment and providing as much help as is necessary for the groups to complete the requirement in the allotted time.

- At the end of the working period, reconvene the class.

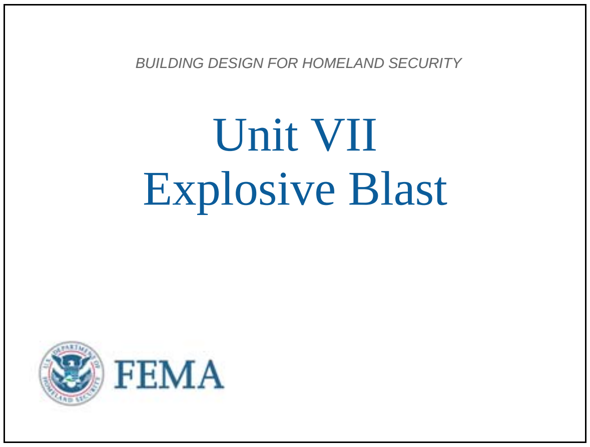
- After the students have completed the assignment, "walk through" the activity with the students during the plenary session. Call a different student forward to the screen to answer the questions associated with each chart, including the Case Study values if time permits.

- If time is short, simply provide the "school solution" and ask for questions. Do not end the activity without ensuring that students know if their answers are correct or at least on the right track.

- Ask for and answer questions.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

VISUAL VII-1



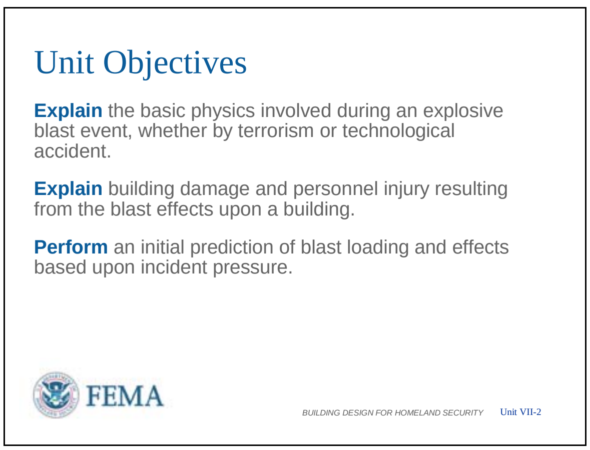
Introduction and Unit Overview

This is Unit VII Explosive Blast. Note that we are covering **pages 4-1 to 4-20 in FEMA 426** during this unit.

In the previous units, we determined the various initial ratings during the assessment process.

In this unit, we will examine how explosive blast impacts buildings and people to better understand the design recommendations and mitigation options presented in later units.

VISUAL VII-2

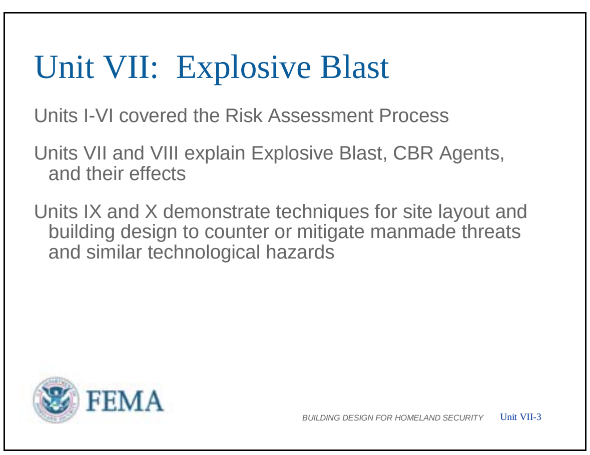


Unit Objectives

At the end of this unit, the students should be able to:

1. Explain the basic physics involved during an explosive blast event, whether by terrorism or technological accident.
2. Explain building damage and personnel injury resulting from the blast effects upon a building.
3. Perform an initial prediction of blast loading and effects based upon incident pressure.

VISUAL VII-3



Explosive Blast

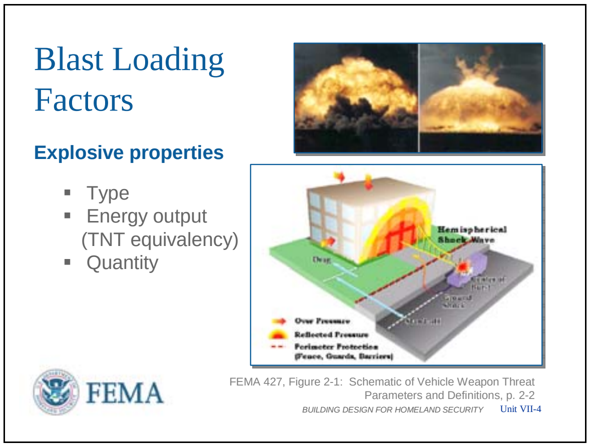
So far we have looked at the risk assessment process with the level of understanding achieved from the instruction yesterday.

Today we go into the technical basics of Explosive Blast and CBR agents to understand their effects and the benefit of their associated mitigation measures.

Then we will look at Site and Layout Design and Building Design mitigation measures for these terrorist tactics and similar technological hazards.

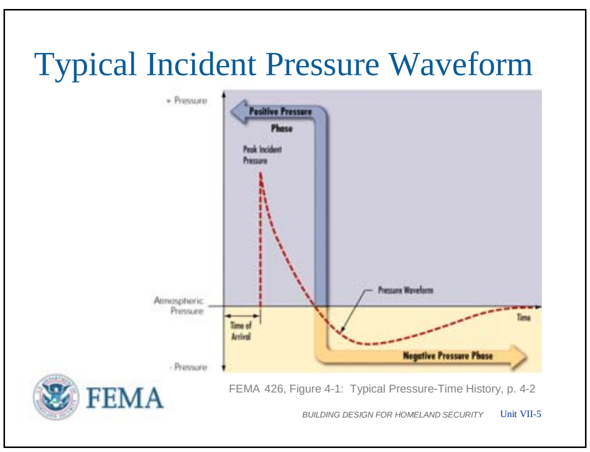
INSTRUCTOR NOTES

VISUAL VII-4



Pressure TNT equivalency can generally range from 0.14 to 1.7. If the pressure TNT equivalency is above 1.0, this means the explosive achieves a higher pressure (pressure equivalency) than TNT.

VISUAL VII-5



Exam Questions #A8 and B6

CONTENT/ACTIVITY

Blast Loading Factors

Explosive properties types – Is it a high explosive or low-order explosive?

Is it specifically designed for the purpose – military grade explosive (C4, landmine, etc.) or a combination of generally available materials (ANFO, black powder)?

The energy output of explosives can be related by TNT (trinitrotoluene) equivalency. TNT equivalency is usually considered to be the relative pressure achieved by the explosive compared to what TNT can achieve.

Aside from TNT equivalency, the larger the quantity of an explosive, the higher the pressures and the larger the impulse.

Typical Incident Pressure Waveform

The explosive detonation generates a bubble of air moving at supersonic speed from the bomb location. About one-third of the explosive material contributes to the detonation.

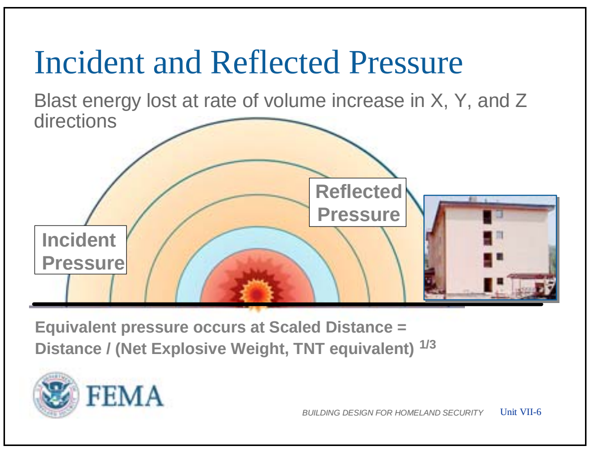
As it reaches a point in space, such as a person or building, the pressure goes rapidly from atmospheric to peak pressure in very little time. The pressure at this point decays rapidly as the supersonic bubble moves on, its pressure reducing exponentially as the surface area of the bubble increases, expending energy over an ever increasing area. The pressure also drops off due to the completion of the chemical reaction of the explosive mixture (burning of the remaining two-thirds of the material). If the explosion occurs within a confined space, the gases generated by the burning of the explosive are contained and keep the pressure elevated over a longer

INSTRUCTOR NOTES	CONTENT/ACTIVITY

period of time. [Indicate a longer tail off of the positive phase to illustrate the confined space variation.] Design is typically based on positive pressures.

The negative phase of the blast wave is the ambient air rushing in behind the blast wave to return to a stable pressure. Although the negative phase has much less energy than the positive phase, it can hit the structure at the most inopportune moment in its vibration, resulting in unexpected consequences – increased damage or having windows blow OUT of the building rather than into it.

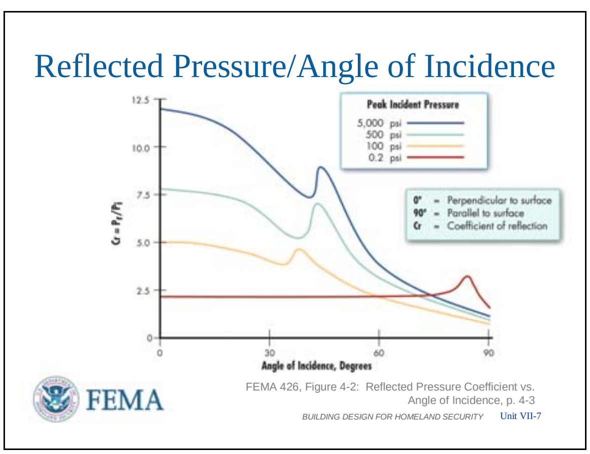
VISUAL VII-6



Incident and Reflected Pressure

When the incident pressure wave impinges on a structure that is not parallel to the direction of the wave's travel, it is reflected and reinforced. The reflected pressure is always greater than the incident pressure at the same distance from the explosion, and varies with the incident angle.

VISUAL VII-7



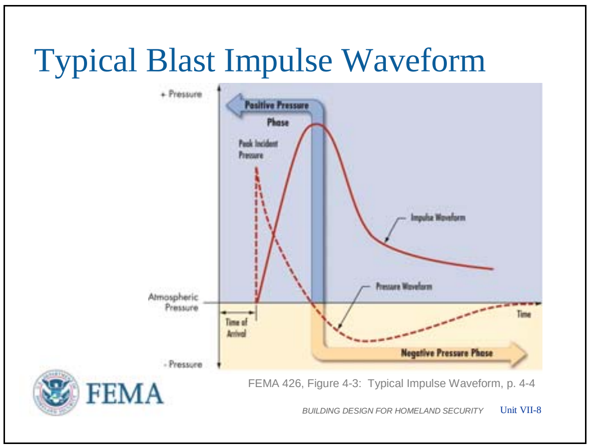
Reflected Pressure versus Angle of Incident

When the blast wave strikes an immovable surface, the wave reflects off the surface, resulting in an increase in pressure. This reflected pressure actually causes the damage to the building. A very high reflected pressure may punch a hole in a wall or cause a column to fail, while a low reflected pressure will try to push over the whole building.

The worst case is when the direction of travel for the blast wave is perpendicular to the surface of the structure and the incident pressure is very high. The Coefficient of

INSTRUCTOR NOTES

VISUAL VII-8



There is also a TNT equivalency based upon impulse and that ranges from 0.5 to 1.8. If the impulse TNT equivalency is above 1.0, then the explosive has a longer push (impulse equivalency) than TNT.

CONTENT/ACTIVITY

Reflection can be greater than 12 for high incident pressures.

By keeping the incident pressure low (by limiting the size of the explosive, maintaining a large distance between the explosive and the building, or both), the reflected pressure can be kept low. Keeping the Coefficient of Reflection below 2.5 by keeping the peak incident pressure below 5 psi (pounds per square inch) is a desirable goal.

Typical Blast Impulse Waveform

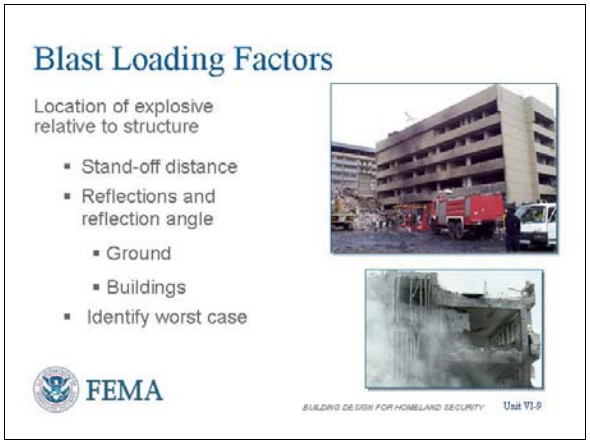
Another consideration is the impulse of the blast wave, which is the integration of the peak incident pressure (both positive phase and negative phase) at the point in question over time.

A general rule of thumb:

- Brittle materials (like glass) respond to peak incident pressure and are less affected by impulse. Thus a high order explosive with high incident pressure will easily damage glass.
- Ductile materials (like most building structures), on the other hand, respond more to impulse (the total push) rather than peak incident pressure (the maximum hit). Thus, a low order explosive with a large impulse that pushes for a longer time will cause more damage to buildings.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

VISUAL VII-9



Blast Loading Factors

Location Relative to Structure: Stand-off distance is your best friend. The larger the distance between the explosive and the structure:

- The lower the incident pressure and
- The lower the resultant reflected pressure.

We will investigate this in more detail later.

As we have already seen, the reflection angle at which the blast wave strikes the structure also affects the value of reflected pressure.

The ground is also a reflection surface to consider.

- If the bomb is placed close to the ground, the ground reflection adds a small amount of incident pressure to the situation.
- If the bomb is elevated (a more difficult task), the ground reflection can become significant, but the reflection off the building surface diminishes.

Identifying the worst case situation begins by finding the:

  - Closest approach (stand-off distance) between the explosive and the building
  - Then consider the angle of reflection.

Or put another way – place the explosive directly perpendicular to the largest face of the building, with the explosive centered upon the building's face as close as you can get.

INSTRUCTOR NOTES

VISUAL VII-10

Blast Compared to Natural Hazards

Higher incident pressures and relatively low impulse

- High explosive (C-4)
- Low-order explosive (ANFO)
- Aircraft or vehicle crash combines kinetic energy (velocity, mass), explosive loads, and fuel/fire
- 200 mph hurricane generates only 0.8 psi, but with very large impulse

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BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-10

CONTENT/ACTIVITY

Blast Compared to Natural Hazards

There are a number of similarities between blast loading and building response in comparison to building response from earthquake, flood, or wind loading, but there are also significant differences.

- Low-order explosives generate less pressure than high-order explosives, but the low-order impulse lasts longer than high-order (in the range of hundreds of milliseconds versus tens of milliseconds).
- Blast loads are high amplitude, low duration (milliseconds) events that create an air pressure wave that acts over the entire building envelope. They have relatively low impulse whether high or low order compared to natural hazards.
- Earthquake loads are usually low amplitude, high-energy, long-duration (seconds) events that are transferred through the foundation.
- Flood loading has high-energy, relatively high amplitude, and very long duration loading (minutes) that impact everything in its path with increased reflected pressures and extensive damage. The higher the velocity of the flood waters coupled with the increased mass of water results in extensive damage.
- High winds are dynamic and typically affect the envelope, but are of low amplitude compared to blast. However, they push for a very long time (in the range of seconds or longer) and, thus, have very large impulse. (Note: wind gusts are rated for 3 seconds duration minimum, but sustained winds can push for minutes.).
- A nuclear blast or millions of pounds of high explosives would generate high pressures AND long duration impulse (in the range of seconds).

INSTRUCTOR NOTES

VISUAL VII-11

Many of the mitigation options for seismic and hurricane retrofit such as moment connections, elimination of progressive collapse, laminated glass, and strengthened architectural elements mitigate many explosive blast vulnerabilities.

CONTENT/ACTIVITY

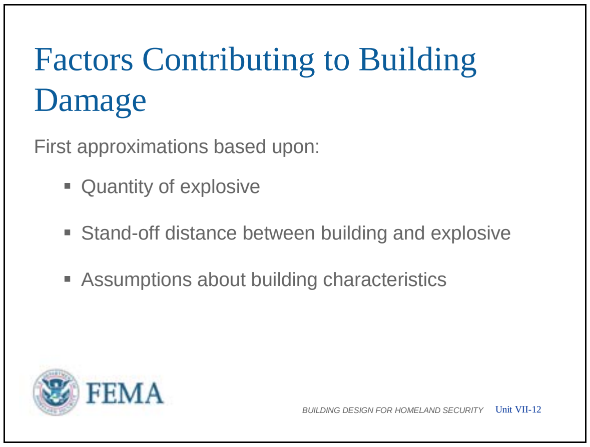
Blast Compared to Natural Hazards

Explosive blast tends to cause localized damage compared to other hazards that may destroy the whole building.

- The first building surface struck will get the greatest pressures, and expect it to receive the greatest damage. The blast may break a building component by punching through it (window or wall) or shearing it (column).
- The other side of the building, due to its greater distance from the explosion, will see lower pressures, unless there are nearby buildings that will reflect the blast wave back to the building in question.
- Reflections can increase damage to the building, but are hard to quantify.
- Greater mass has usually been the design of choice to protect against explosive blast. The inertia of the mass slows the structural reactions to the point that the impulse is over before the building tends to move.
- Conversely, additional mass is usually undesirable during an earthquake due to the long duration, low frequency forces that can get the mass moving. Earthquake design usually concentrates on lighter structures with great ductility and additional reinforcement at weak points.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

VISUAL VII-12

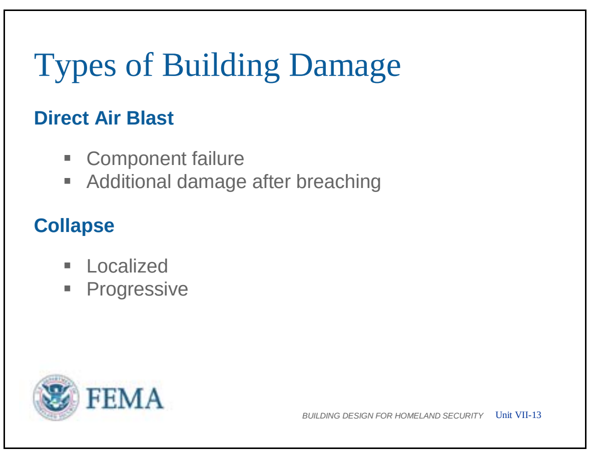


Factors Contributing to Building Damage

Certain prediction of damage to buildings and people during an explosive event is beyond the scope of the reference manual. There are too many variables that would have to be considered and modeling would take many months for analysis by supercomputer. Thus, as in standard building design, we use approaches with safety factors that provide adequate first approximations to estimate response based upon the:

- The amount of explosive usually expressed as TNT equivalent weight.
- The stand-off distance between the explosive and the building or person.
- Assumptions about building characteristics – the exterior envelope construction (walls and windows) and the framing or load-bearing system used.
- The building characteristics provide insight into weaknesses and allow general predictions about how the building will respond.

VISUAL VII-13



Exam Questions #A9 and B10

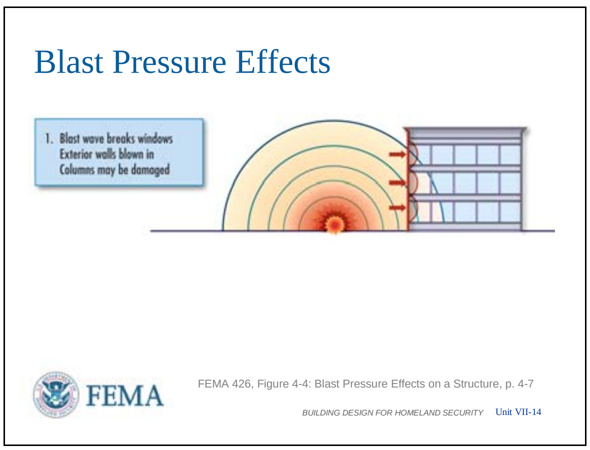
Types of Building Damage

- Direct air blast, especially from close-in explosions, results in component failure of walls, windows, columns, and beams / girders.
- The pressures experienced by the building can far exceed the building's original design and can occur in directions that were not part of the original design.
- Once the exterior envelope is breached, the blast wave causes additional structural and non-structural damage inside the building.
- Collapse, which is covered in more detail in **Chapter 3 of FEMA 426**, is a primary cause of death and injury in an explosive blast if it occurs.

INSTRUCTOR NOTES	CONTENT/ACTIVITY

- Localized collapse may have a load-bearing wall, or portion thereof, on one side of the building fall to the ground or a single column fails and the surrounding floors fall with it.
- Progressive collapse is more disastrous as a single component failure, like a wall or column, results in the failure of more walls and columns so that more of the building falls to the ground than what the explosive initially affected.

VISUAL VII-14

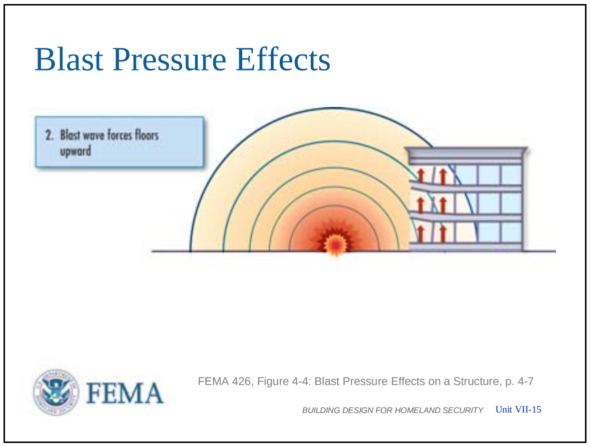


Blast Pressure Effects

- The air blast strikes the exterior wall and the weakest component will fail first – usually the windows, which saves the walls and columns, but causes much non-structural damage inside the building.
- Note that unreinforced masonry walls can be weaker than windows, especially if they are non-load bearing.
- If the explosive is close enough, the walls can breach and one or more columns can fail in addition to the windows.
- Based upon the reflection angle, one can expect the lowest or lower floors (1 to 3) to receive the greatest damage.
- If the blast wave strikes the whole surface of the exposed side simultaneously, this is called a laminar situation, and breaching (puncture) of walls and failure of columns is less likely. This is what is sought by achieving a large stand-off distance.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

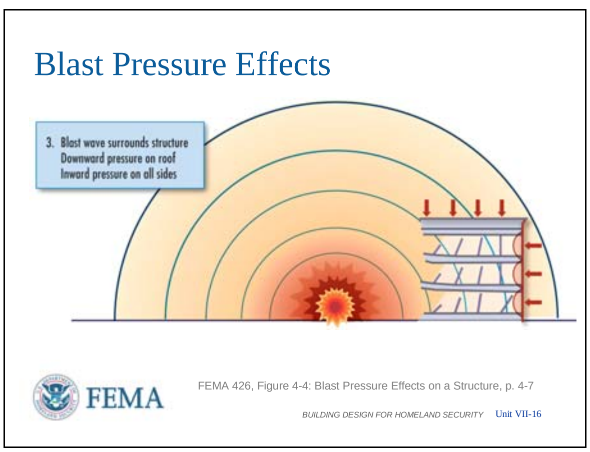
VISUAL VII-15



Blast Pressure Effects

- Once the blast wave enters the building, it is trapped and more air enters the building, further increasing the pressure. Structural components like flooring and shear walls now are moving in directions for which they were not designed.
- Floor failure can result in three effects:
  - o Concrete chunks raining down, causing injury and possibly death
  - o Whole floor gives way and pancakes downward with obviously more serious consequences
  - o If flat slab construction is present (thickened floors act as beams in the framing system), the floors can disconnect from the columns, resulting in floor AND column failure.

VISUAL VII-16

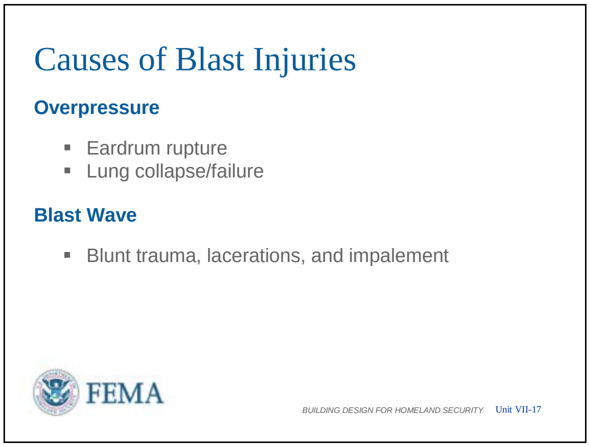


Blast Pressure Effects

- The blast wave continues to engulf the building. Any building component that traps the blast wave, like an overhanging roof, can expect increased damage, based upon how it is constructed and attached.
- The roof and sides parallel to the blast wave movement will see incident pressure only, which should result in little or no damage.
- Once the blast wave has passed the building, the far side (opposite the side first experiencing the blast wave) will see increased pressure as a slight vacuum forms and the ambient air rushes back in to achieve equilibrium. Reflections of the blast wave off other buildings behind this one can also increase the pressure impinging the far side.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

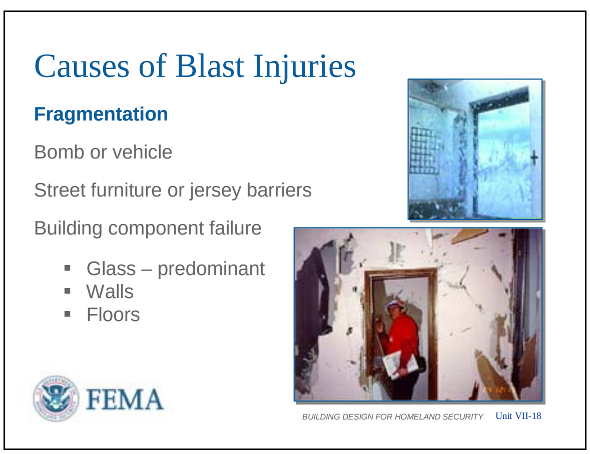
VISUAL VII-17



Causes of Blast Injuries

- Injuries and casualties occur in three ways during explosive blast by:
    - o Overpressure
    - o Motion of person by blast wave
    - o Fragmentation generated by blast wave
- Overpressure causes eardrum rupture first, which is normally not lethal.
- Overpressure can also overdrive the lungs, causing injury or death. The relationship between pressure and impulse is very evident in lung response. An incident pressure of 102 psi for 3 milliseconds is the threshold of lethality as is an incident pressure of 23 psi for 18.5 milliseconds.
- Blunt trauma, lacerations, and impalement injuries occur when the blast wave picks up the person and throws them against a surface or object (translation), or glass and wall fragments cause lacerations or blunt trauma on impact. In relative distance terms, death by translation occurs at a greater distance for the same bomb size than death by lung overpressure.

VISUAL VII-18



Exam Questions #A10 and B9

Causes of Blast Injuries

- Fragmentation from any source can result in blunt trauma, impact, and penetration, or laceration injuries.
- The fragments can come from around the bomb or from parts of the vehicle.
- They can be picked up either intact or damaged by the blast wave as it travels along – street furniture or jersey barriers.
- Building component failure also causes material fragments with sufficient velocity to injure or kill. Note that upward of 80 percent of all injuries from explosive blast can be attributed to lacerations caused by broken glass. The most effective way to reduce injuries during explosive blast is harden the glass and window frame system and/or reduce the amount of glass.

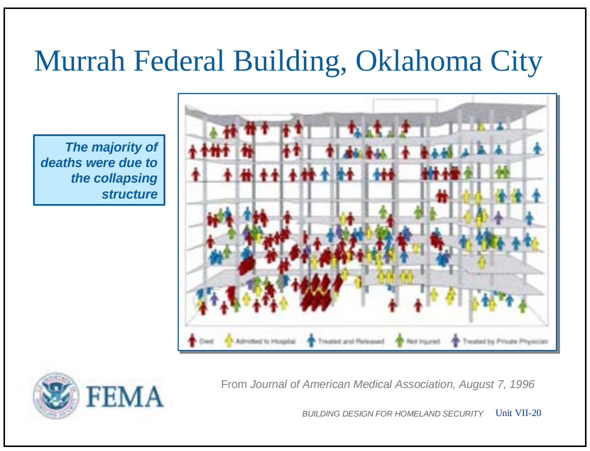
INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

VISUAL VII-19

Murrah Federal Building

The Murrah Federal Building is typical of many commercial properties in the current inventory. The bomb was designed as a shape charge and detonated in the drop-off area, destroying two primary columns and causing the spandrel beam to rotate. The floors above failed in progressive collapse and the blast wave penetrated deeply into the interior.

VISUAL VII-20

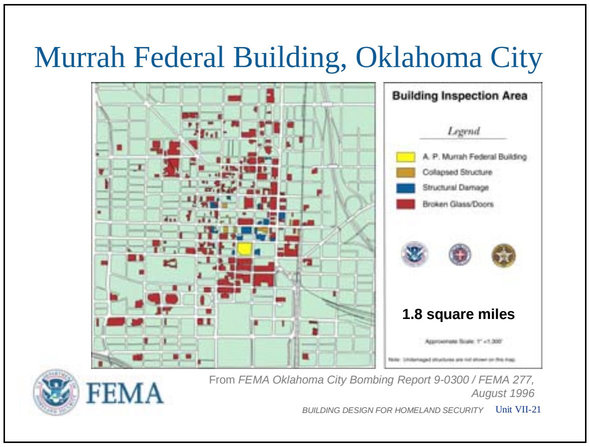


Murrah Federal Building

The majority of deaths were caused by the collapsing structure.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

VISUAL VII-21



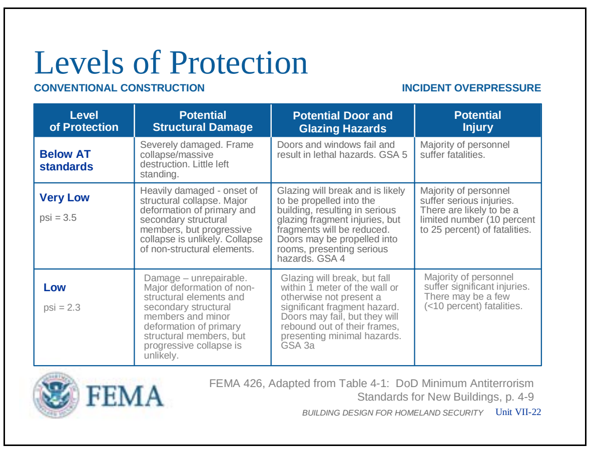
The map is approximately 1.35 miles on a side.

Murrah Federal Building

The collateral damage zone extended out several thousand feet, with extensive glass and debris injuries.

Glass was broken as far as 0.9 miles away.

VISUAL VII-22



Levels of Protection

CONVENTIONAL CONSTRUCTION — INCIDENT OVERPRESSURE

Level of Protection	Potential Structural Damage	Potential Door and Glazing Hazards	Potential Injury
Below AT standards	Severely damaged. Frame collapse/massive destruction. Little left standing.	Doors and windows fail and result in lethal hazards. GSA 5	Majority of personnel suffer fatalities.
Very Low psi = 3.5	Heavily damaged - onset of structural collapse. Major deformation of primary and secondary structural members, but progressive collapse is unlikely. Collapse of non-structural elements.	Glazing will break and is likely to be propelled into the building, resulting in serious glazing fragment injuries, but fragments will be reduced. Doors may be propelled into rooms, presenting serious hazards. GSA 4	Majority of personnel suffer serious injuries. There are likely to be a limited number (10 percent to 25 percent) of fatalities.
Low psi = 2.3	Damage – unrepairable. Major deformation of non-structural elements and secondary structural members and minor deformation of primary structural members, but progressive collapse is unlikely.	Glazing will break, but fall within 1 meter of the wall or otherwise not present a significant fragment hazard. Doors may fail, but they will rebound out of their frames, presenting minimal hazards. GSA 3a	Majority of personnel suffer significant injuries. There may be a few (<10 percent) fatalities.

FEMA

FEMA 426, Adapted from Table 4-1: DoD Minimum Antiterrorism Standards for New Buildings, p. 4-9

BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-22

Levels of Protection

- The Department of Defense (DoD) and the General Services Administration (GSA) call out similar levels of protection that relate building damage and potential injury. This slide and the next summarize these perspectives.
- **NOTE:** The GSA glass ratings and estimated incident pressure levels are added to the DoD UFC criteria as best meet the description for comparison.
- This slide represents the conventional construction found in most buildings.
- Note the relatively low values for incident pressure for each level of protection.
- The Low Level of Protection can be interpreted as the threshold of lethality and is a desirable minimum design goal to achieve. If the risk, such as the likelihood, of experiencing an explosive blast is high, consideration for use of a higher level of protection would be in order.

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

VISUAL VII-23

Levels of Protection

CONVENTIONAL CONSTRUCTION — INCIDENT OVERPRESSURE

Level of Protection	Potential Structural Damage	Potential Door and Glazing Hazards	Potential Injury
Medium psi = 1.8	Damaged – repairable. Minor deformations of non-structural elements and secondary structural members and no permanent deformation in primary structural members.	Glazing will break, but will remain in the window frame. Doors will stay in frames, but will not be reusable. GSA 2	Some minor injuries, but fatalities are unlikely.
High psi = 1.1	Superficially damaged. No permanent deformation of primary and secondary structural members or non-structural elements.	Glazing will not break. Doors will be reusable. GSA 1	Only superficial injuries are likely.

FEMA

FEMA 426, Adapted from Table 4-1: DoD Minimum Antiterrorism Standards for New Buildings, p. 4-9

BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-23

Exam Questions #A11 and B11

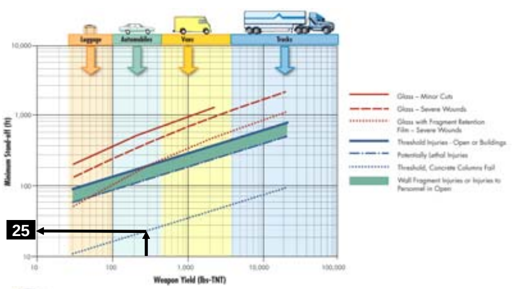
Levels of Protection

- When greater protection resulting in less damage and injury is desired, this slide indicates that the pressures must be kept low for conventional construction.
- Alternately, the building must be hardened to achieve these lower levels of damage and resultant injury. This is especially necessary when the incident pressure is higher due to the design basis threat explosive quantity being at a closer stand-off distance than conventional construction can handle.

<u>The building owner selects the Level of Protection and the Design Basis Threat, which in turn determines the stand-off distance required.</u>

VISUAL VII-24

Nominal Range-to-Effect Chart



FEMA

FEMA 426, Figure 4-5: Explosive Environments – Blast Range to Effects, p. 4-11

BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-24

Direct students' attention to **Figure 4-5 on page 4-11 of FEMA 426**.

Nominal Range-to-Effect Chart

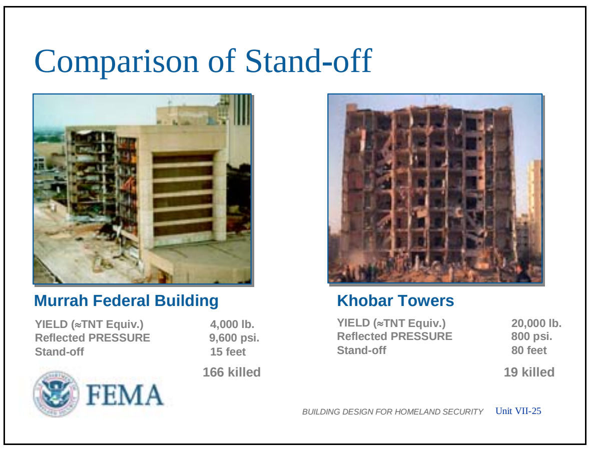
- The Nominal Range-to-Effect Chart is a handy way to represent the stand-off distance at which a given bomb size produces a given effect.
- If you are below the curve for the given effect, that effect has the potential to occur. The further below the curve, the more likely it will happen and the greater the expected damage.
- Conversely, an intersection point between range or stand-off distance and weapon yield or bomb size in TNT equivalent weight that is above the curve for the given effect indicates that there is a good chance that that effect will not occur. However, many variables can alter these curves, such as reflections, resulting in damage at a point above the curve.
- The chart also concentrates upon the two prominent concerns during explosive blast – glass injury and progressive building collapse. In most, but not all cases, the glass is the weakest component of the

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

building envelope. Conversely, the columns, whether concrete or steel, are usually the strongest components of the building envelope. [A workable rule of thumb is that steel columns require about twice the stand-off distance compared to concrete columns for the same weapon yield.]

- **Question:** Ask what stand-off distance for a 300-pound (TNT-equivalent) bomb is needed to just exceed the threshold of concrete column failure?
  - **Answer:** Approximately 25 feet.

VISUAL VII-25



Comparison of Stand-off

The Murrah Federal Building and Khobar Towers vividly illustrate the response of a building to a blast event.

The Murrah Federal Building had less than 20 feet of stand-off and was not designed to prevent progressive collapse.

Khobar Towers was designed using British code to prevent progressive collapse and had approximately 80 feet of stand-off distance.

Notice the size of the weapons.

The Murrah Federal Building was unsalvageable and demolished, while Khobar Towers only lost the front façade and was restored and placed back into service.

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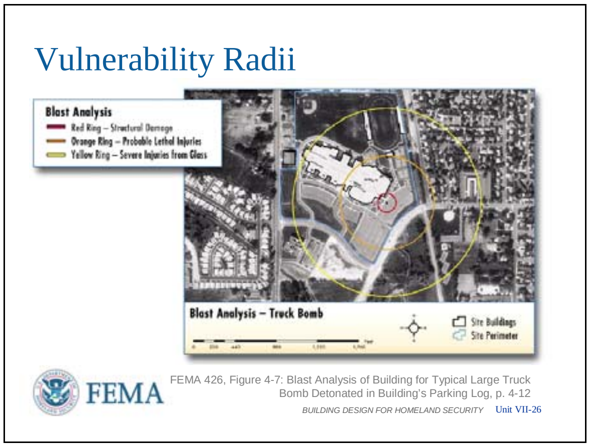
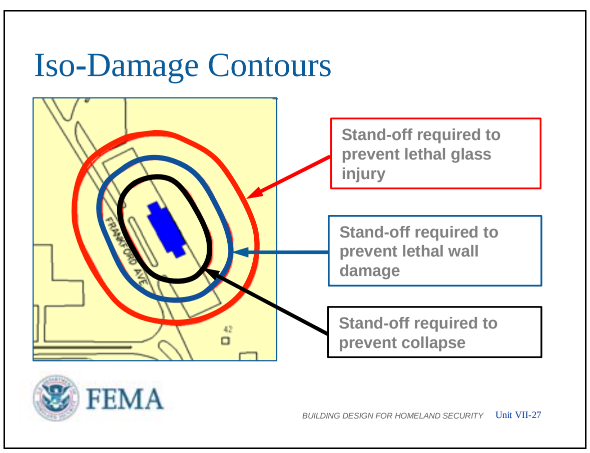
VISUAL VII-26



Vulnerability Radii

- Graphically portraying the information from the Nominal Range-to-Effect Chart can be done in two ways. As shown in **Figures 4-6 and 4-7 in FEMA 426 (page 4-12)**, vulnerability radii show how far a given type of damage will extend from a bomb location for a given weapon yield upon the building of interest for which the blast analysis was performed.
  - o The rings indicate where that level of damage starts and whatever is inside the ring will experience that damage.
  - o The expected damage increases as you move from the ring to the explosion.
  - o Hardening and other mitigation measures can be compared using this representation (for example, existing glass, glass with fragment-retention film installed, or upgraded glass).
- This representation works well when showing the effects of different bomb locations and the extent of the building affected by that bomb.

VISUAL VII-27



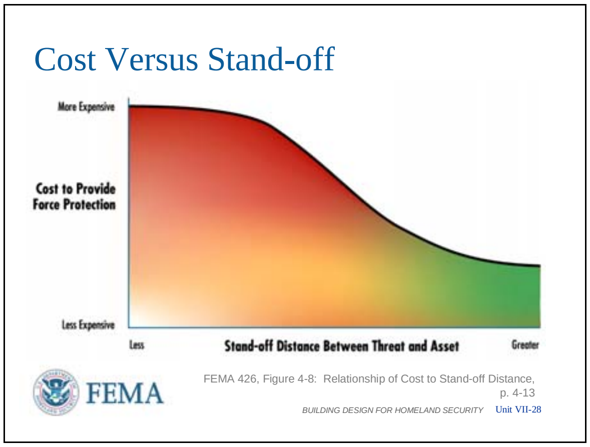
Iso-Damage Contours

- Alternately, the nominal range-to-effect information can be graphically represented as iso-damage contours. For a given weapon yield against a building of known construction, the contour indicates how far the bomb or vehicle must be kept away to prevent the damage indicated in this slide.
  - o The intent here is to focus on the required stand-off distance to prevent or reduce the weapon effect portrayed by the contour.
  - o Thus, to prevent structural collapse, vehicle parking should be eliminated or tightly restricted inside the black contour.
  - o Likewise, to prevent lethal glass

INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

injury, the vehicle parking should be outside the red contour.

VISUAL VII-28



Cost versus Stand-off

- As in any design for new construction or renovation, there are trade-offs that must be considered. Although increasing the distance between the closest approaches of a vehicle bomb to the building is highly desirable, it is not without a cost.
- The increased distance means more land is needed, which may require considerable time and expense to acquire. The increased land also means a larger perimeter boundary that then requires more perimeter fencing, landscaping, vehicle barriers, lighting, closed-circuit television, etc. Thus, while the increased stand-off allows a less expensive building to be constructed, there are other costs that must be considered in the overall project.
- Where stand-off distance cannot be increased, building hardening is usually necessary to achieve the same level of protection against the Design Basis Threat weapon yield. As the stand-off distance decreases, the cost of hardening significantly increases because the building must now withstand damage that it would not experience at higher stand-off.
- Consider progressive collapse. At large stand-off distance, the design of the building framing and columns should meet basic design to prevent progressive collapse. This would be for the loss of one column, for example. At smaller stand-off distances, the columns may require additional hardening to prevent the failure of more than one column during an explosive blast event.

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VISUAL VII-29

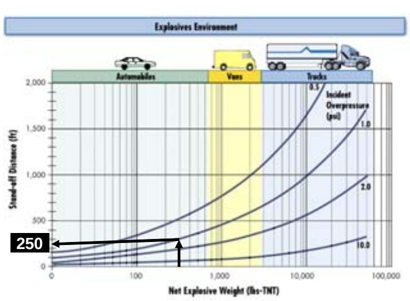
> **Blast Load Predictions**
>
> Incident and reflected pressure and impulse
>
> - Software
>   - Computational Fluid Dynamics
>   - ATBLAST (GSA)
>   - CONWEP (US Army)
> - Tables and charts of predetermined values
>
> FEMA — BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-29

Blast Load Predictions

- The first step in designing a building for explosive blast is to understand the pressures and impulses the building may experience during the potential blast event.
  - o If reflections are a concern, then high-level software, such as Computational Fluid Dynamics (CFD), may be in order.
  - o Defense Threat Reduction Agency software (not CFD) – Vulnerability Assessment and Protection Option (VAPO) can handle reflections, but modeling takes much longer than simpler models and reflection analysis takes hours of computation time on a laptop.
  - o As a first effort, simpler software, such as ATBLAST and CONWEP, can give a prediction of incident blast loading values and a prediction for reflected pressure and impulse using simplifying assumptions.
- Pressure versus distance **(Figure 4-10 in FEMA 426, page 4-17)** is another method for predicting the incident pressure as shown in the next slide.

VISUAL VII-30

> **Pressure versus Distance**



FEMA 426, Figure 4-10: Incident Overpressure Measured in Pounds Per Sq. Inch, as a Function of Stand-Off Distance and Net Explosive Weight, p. 4-17

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Pressure versus Distance

- Figure 4-10 breaks the blast load estimate into the essential elements of weapon yield or explosive weight in TNT equivalent on the x-axis and stand-off distance on the y-axis to give an incident pressure value that a building can experience.
- Note that the x-axis is logarithmic and the y-axis is linear. If both axes were logarithmic as used on the range-to-effect chart presented earlier, the curves of this chart would be straight lines. In other words, on a log-log scale of explosive weight and stand-off distance, a straight line indicates a pressure relationship (not

INSTRUCTOR NOTES

Direct students' attention to **Figure 4-10, page 4-17 of FEMA 426.**

VISUAL VII-31

Blast Damage Estimates

Assumptions - pressure and material

- Software - SDOF
  - AT Planner (U.S. Army)
  - BEEM (TSWG)
  - BlastFX (FAA)
- Software - FEM
- Tables and charts of predetermined values

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BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-31

VISUAL VII-32

Blast Damage Estimates

Damage	Incident Pressure (psi)
Typical window glass breakage (1)	0.15 – 0.22
Minor damage to some buildings (1)	0.5 – 1.1
Panels of sheet metal buckled (1)	1.1 – 1.8
Failure of unreinforced concrete blocks walls (1)	1.8 – 2.9
Collapse of wood frame buildings (2)	Over 5.0
Serious damage to steel framed buildings (1)	4 – 7
Severe damage to reinforced concrete structures (1)	6 – 9
Probable total destruction of most buildings (1)	10 – 12

FEMA 426, Table 4-3: Damage Approximations, p. 4-19

Level of Protection	Incident Pressure (psi)
High	1.2
Medium	1.9
Low	2.3
Very Low	3.5
Below AT Standards	> 3.5

FEMA

BUILDING DESIGN FOR HOMELAND SECURITY Unit VII-32

CONTENT/ACTIVITY

impulse).

- **Question**: Ask what stand-off distance is required for a 300-pound bomb to keep the incident pressure at 1.0 psi or lower.
  - o **Answer:** Approximately 250 feet.

Blast Damage Estimates

- Whereas normal design usually uses constant loading and linear response, blast loading is very dynamic, as you have seen, and damage of building components enters its nonlinear material range prior to failure.
- Conversely, higher level modeling may result in reduced construction costs due to a better understanding of how the building components will respond during a blast for the given site, layout, and building design parameters selected. This is balanced by the additional cost of the higher level modeling.

Blast Damage Estimates

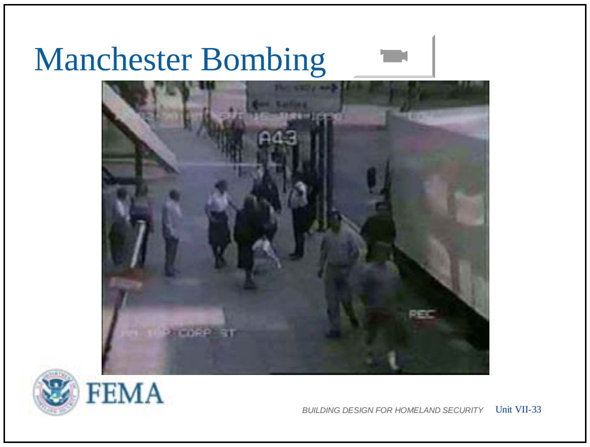
- In this slide, you see Damage Approximations for different types of damage and a range of incident pressures at which this damage is expected to occur.
- Note that, logically, higher pressure results in greater damage and the range of incident pressure indicates the construction variation that may be found.

Instructor Note: **Table 4-3 on page 4-19 of FEMA 426** is based upon information from the following publications:

- "*Explosive Shocks in Air*" Kinney and Grahm, 1985
- *"Facility Damage and Personnel Injury from Explosive Blast"* Montgomery and Ward, 1993
- *"The Effects of Nuclear Weapons, 3rd Edition"*, Glasstone and Dolan, 1977

INSTRUCTOR NOTES

VISUAL VII-33



Instructor Note: Ensure the video file (**E155_Unit07_Manchester.mpg**) is in the same folder as the PowerPoint presentation to have the camera link after the slide title to work.

QUESTION: Ask students -- How big do you think this bomb was?
Answer: Reported to be <u>3,300 pounds</u> but not stated as either actual weight or TNT equivalent. The bomb smashed almost every window in a half-mile radius.

Even with the advance notification Manchester's ambulance services counted <u>206 injured people (NO DEATHS)</u>. Most injuries were sustained from falling glass and building debris. In the immediately ensuing chaos, ambulances and private cars were used to shuttle victims to local and regional hospitals.

The majority (129, 62%) of casualties sustained minor injuries from flying glass. A significant number of casualties (36, 18%) presented with emotional distress or medical problems. A wide age range of casualties was involved. Few patients (19, 9%) required admission to hospital. There were

CONTENT/ACTIVITY

Manchester Bombing

General Points to make as the video runs

- The truck was parked at about 9:20am, and the bomb exploded just under 2 hours later. The blast was audible over 8 miles away.
- Irish Republican Army gave advance notification at about 1 hour prior to detonation to newspapers, radio stations, and at least one hospital
- The police began clearing the street 40 minutes before the blast, but people still walk past the suspected truck at 17 minutes prior to the explosion.
- British Telecom has a special terrorist pager that identifies location and time in order to notify building occupants of the situation and direct evacuation routes
- This is the High Street of Manchester – the center of the city's business district at 10 AM on a Saturday morning just before Father's Day
- Note that the High Street of many British cities are well covered by CCTV
- The double line on the street by the curb means no parking, thus making the truck suspicious -- as nothing was being off-loaded or on-loaded.
- Robot sent in to identify the bomb and possibly disarm it, but without success
- Bomb goes off with a great noise, then the explosion is shown in slow motion – note the 1/3 of the explosive providing the supersonic shock wave followed by the 2/3 of the explosive adding to the blast wave but also supporting the fireball through the conflagration (burning)
- Note the amount of debris, that NO buildings collapsed, that SOME walls remained intact, that ALMOST ALL glass was shattered, with damage being reduced the further the building was from the bomb
- The Post Office box, looks like a single heavy bollard survived the blast and has a

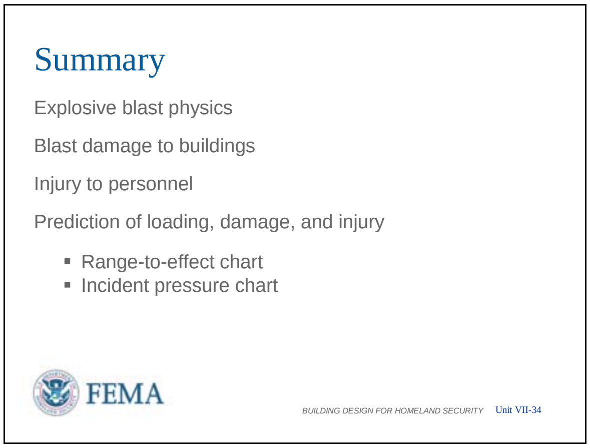
INSTRUCTOR NOTES | **CONTENT/ACTIVITY**

no deaths and no casualties sustained major trauma.

commemorative plaque installed

- Prior to the bombing the Manchester High Street was quickly going down hill, but after the bombing there was a big influx of investment, and after 4 years of reconstruction the High Street is now among the best in Great Britain.

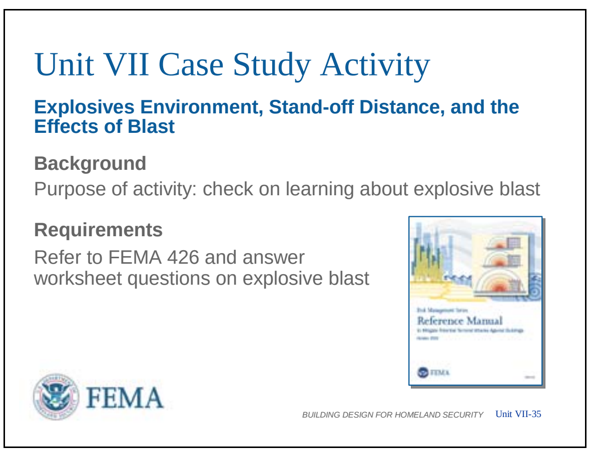
VISUAL VII-34



Summary

- You now have an understanding of the basic physics involved during an explosive blast event.
- You can now explain building damage and injury to people resulting from the blast effects upon a building and injury to people in the open.
- You can perform an initial prediction of blast loading and effects based upon incident pressure using a nominal range-to-effect chart or the incident pressure charts.

VISUAL VII-35



Student Activity

This activity provides a check on learning about explosive blast.

Activity Requirements

Working in small groups, refer to **FEMA 426** and complete the worksheet questions in the Unit VII Case Study activity in the Student Manual.

After 10 minutes, solutions will be reviewed in plenary group. This is a good opportunity to select two members of the class to go to the screen and answer the questions using the charts.

Transition

Unit VIII will cover CBR measures and introduce the basic science needed to

INSTRUCTOR NOTES	CONTENT/ACTIVITY
	understand building protection against chemical, biological, and radiological agents. Unit IX will begin the process of reviewing the site, layout, and building design guidance, further vulnerability assessment, and recommended mitigation options.

UNIT VII CASE STUDY ACTIVITY:
STAND-OFF DISTANCE AND THE EFFECTS OF EXPLOSIVE BLAST

The requirements in this unit's activity are intended to provide a check on learning about explosive blast.

Requirements

1. In the empty cells in the table below, identify whether the adjacent description defines incident pressure or reflected pressure.

Definition	Type of Pressure
Characterized by an almost instantaneous rise from atmospheric pressure to peak overpressure.	***Incident pressure***
When it impinges on a structure that is not parallel to the direction of the wave's travel, the pressure wave is reflected and reinforced.	***Reflective Pressure***

2. Refer to **Figure 4-5 in FEMA 426 (page 4-11)** to answer the following questions regarding the explosives environment:

   - What is the minimum stand-off distance from explosion of a 100-pound (TNT equiv.) bomb to have a level of confidence that severe wounds from glass (without fragment retention film) will not occur? ***270 feet***

   - What damage will be sustained at 400 feet from a 5,000-pound (TNT equiv.) explosion? ***Wall fragment injuries or injuries to personnel in the open and all curves above that point -- glass injuries ranging from minor cuts to severe wounds, with or without fragment retention film.***

3. Refer to **Figure 4-10 and Table 4-3 (pages 4-17 and 4-19, respectively) in FEMA 426** to answer the following questions regarding the explosives environment.

   - What is the minimum stand-off required to limit the incident pressure to under 0.5 psi for a 100-pound (TNT equiv.) bomb? ***Approximately 325 feet***

   - What incident pressure would be expected at 500 feet from a 500-pound (TNT equiv.) bomb and what is the approximate damage? ***Approximately 0.75 psi, minor damage to some buildings or severe wounds from broken glass***

4. Refer to **Figure 4-5 (page 4-11) in FEMA 426** to answer the following questions.

- For the Design Basis Threats of the selected Case Study being used in this course offering, determine the standoff distance for the damage or injury indicated:
  - ________ pounds TNT-equivalent
    - Glass – Severe Wounds – ______ feet
    - Potentially Lethal Injuries – ______ feet
    - Threshold, Concrete Columns Fail – ______ **f**eet
  - ________ pounds TNT-equivalent
    - Glass – Severe Wounds – ______ feet
    - Potentially Lethal Injuries – ______ feet
    - Threshold, Concrete Columns Fail – ______ **f**eet
  - ***250 pounds TNT-equivalent (suburban)***
    - Glass – Severe Wounds ***– 400 feet***
    - Potentially Lethal Injuries ***– 125 feet***
    - Threshold, Concrete Columns Fail ***– 23 feet***
  - ***500 pounds TNT-equivalent (urban)***
    - Glass – Severe Wounds ***– 530 feet***
    - Potentially Lethal Injuries ***– 142 feet***
    - Threshold, Concrete Columns Fail ***– 30 feet***
  - ***5,000 pounds TNT-equivalent (suburban and urban)***
    - Glass – Severe Wounds ***– 1,310 feet***
    - Potentially Lethal Injuries ***– 320 feet***
    - Threshold, Concrete Columns Fail ***– 60 feet***