Section 7: STANDOFF WEAPONS HARDENING

7.1 Introduction. This section begins with a description of the threat from a standoff Rocket Propelled Grenade (RPG) type of attack, followed by the general mechanisms by which RPGs can be stopped, and ends with hardening design options available for both new and retrofit construction. An RPG attack is a very high-severity level attack directed primarily toward killing or injuring personnel inside a building, although some critical assets might also be subject to destruction. An RPG is not used to gain entrance or cause significant damage to a building. A high-velocity jet of material is created by the RPG which penetrates significant distances and kills or injures by direct impact and spallation. The jet itself creates only a small hole.

7.2 The RPG Threat

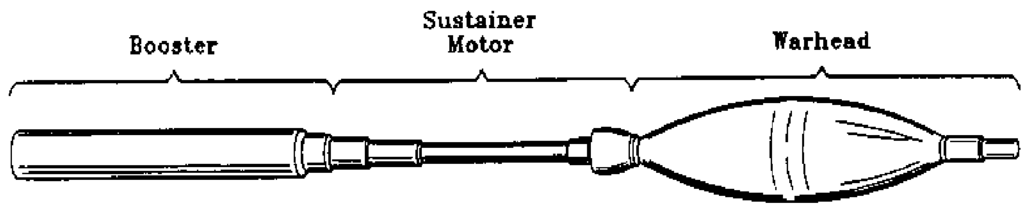
7.2.1 RPG Characteristics. An RPG, like the Soviet built RPG-7 antitank grenade, is a rocket-assisted projectile fired from light hand-held launchers (see Figure 68). The grenade is first ejected from the launcher at a velocity of about 390 feet (120 m) per second by a small strip powder charge. Approximately 36 feet (11 m) from the launcher a sustainer rocket ignites and boosts the rocket to a maximum velocity of about 980 to 1310 feet (300 to 400 m) per second. The general characteristics of the weapon are summarized in Table 51. The RPG warhead consists of a conical-shaped charge within an outer steel casing called the ogive. On detonation, the material of the inner lining of the cone of the shaped charge collapses and forms a metallic jet having a very high velocity. The following gives a brief summary of the jet formation and target penetration mechanisms associated with a shaped charge of this type as background.

7.2.2 RPG Jet Formation. On detonation of the shaped charge, the metal jet is initially in a continuous stretching condition similar to a wire-drawing process. Because there is more explosive near the tip of the conical liner than around the base, there is an inherent variation in the velocity of each element of the jet. This results in stretching of the jet along its length until it eventually breaks up and separates into a column of small rod-like particles aligned one after another in tandem fashion.

7.2.3 RPG Jet Penetration. When the jet is in its early continuous state, it can penetrate virtually any material regardless of the hardness of that material. The density of the target material is its most significant protective property. However, once the jet is broken into discrete particles, the penetration mechanism changes, and factors such as target hardness become more important to the penetration process. Maximum depth of penetration is achieved when the jet is absolutely straight with each element exactly following its predecessor. As the jet impinges on a target material, the pressure exerted by the jet tip pushes the material away in all directions. The tip is used up continuously and converted into a high-temperature liquid with possibly some vapor formed and pressure generated at the contact point. New jet material continuously comes into contact at the rapidly moving "working face" as the jet drives through the material. The penetration process continues until either all the jet particles are consumed, the energy of the unused jet particles is insufficient to overcome the target's own strength, the target material rebounds on the jet reducing its effective length, or the particles otherwise impact the side of the penetration cavity due to axial misalignment of the jet.

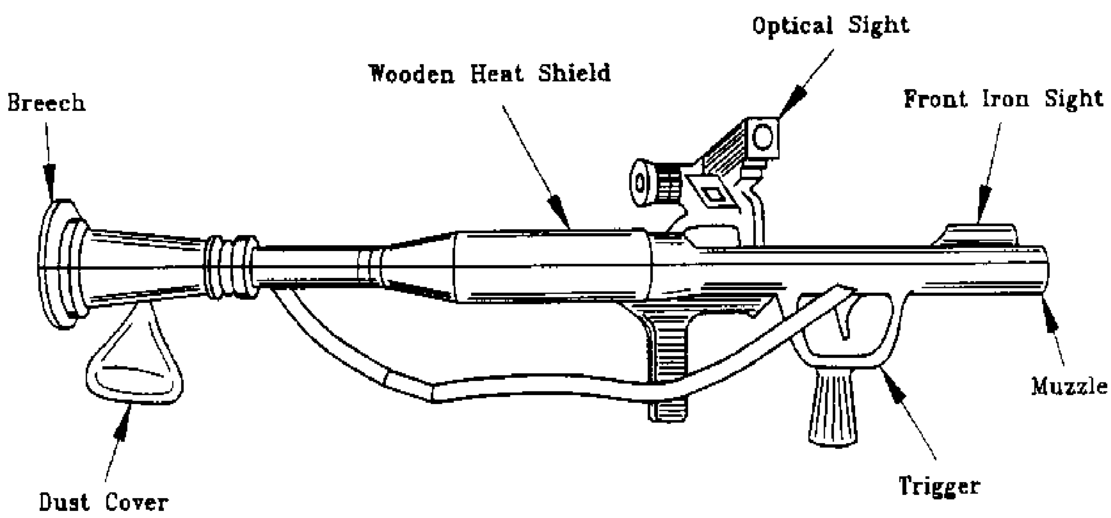
Table 51
Example Operational Characteristics of an RPG (Soviet RPG-7)

Characteristic	Value
Launcher Length	
Unloaded	37.8 inches (960 mm)
Loaded	52.6 inches (1340 mm)
Launcher Weight	
Unloaded	14.5 pounds (32 kg)
Loaded	19.0 pounds (42 kg)
Caliber	
Tube	1.57 inches (40 mm)
Round	3.35 inches (81 mm)
Rate of Fire	4.6 rounds per minute
Grenade	
Length	36.61 inches (930 mm)
Weight	4.6 pounds (10 kg)
Fuse	Point impact with base detonator
Propellant	Smokeless powder
Range	
Arming	16.4 feet (5 m)
Sighting Range (Max)	1,640 feet (500 m)
Maximum Range	2,950 feet (900 m)
	Self destructs
Velocity	
Initial	384 ft/s (117 m/s)
Rocket Assist	965 ft/s (294 m/s)
Type Warhead	HEAT
Lead Capability	20 mph (32 km/h)



The grenade is carried in two parts: (1) warhead and sustainer motor and (2) booster charge. The two must be screwed together before the grenade is ready to fire.

A. Grenade -- Prelaunch Configuration



B. Launcher

Figure 68
Example Antitank Grenade Launcher Weapon—the Soviet RPG-7

7.3 RPG Defeat Mechanism. Important characteristics that limit the penetration of an RPG jet are primarily material density, strength, and the tendency of certain materials to rebound on the jet. In addition, predetonation of the RPG at a standoff distance from the material or creating an oblique line of attack can limit RPG effects.

7.3.1 Material Density. In general, the amount of penetration achieved by a continuous jet is approximately inversely proportional to the square root of the density of the material. Consequently, materials with greater density have a greater stopping capability.

7.3.2 Material Strength. Material strength becomes increasingly important as the jet slows down and/or becomes particulated, i.e., when the pressure exerted by the jet is no longer large compared to the strength of the target. An approximate indicator of strength is the Brinell Hardness Number (BHN) of the material. In general, materials with higher BHN have better stopping ability.

7.3.3 Rebound Defeat Mechanisms. Rebound or hole "closure" is a phenomena where target material moves back into the cavity caused by a jet and interferes with subsequent portions of the jet, reducing its effective length and penetrating capability. Only certain materials like steel, ceramics, aluminum, and glass-reinforced plastics exhibit rebound. In general, this phenomenon effects jets that have particulated. Rebound occurs when the material flows back toward the cavity axis and closes the hole behind each particle. Thus, the next particle must penetrate the closed cavity before impacting the cavity bottom.

7.3.4 Oblique Attack Effects. Barrier surfaces that are at some angle to the line of attack of the jet create a thicker material cross section for the jet to penetrate.

7.3.5 RPG Defeat By Predetonation and Standoff. Screens can be used to predetonate an RPG at a standoff distance away from the barrier. At large standoffs the jet particulates and slows down before hitting the target and consequently is easier to stop.

7.4 Hardening Design Options. This section provides guidelines for hardening both new construction (par. 7.4.1), as well as the retrofit of existing construction (par. 7.4.2) against an RPG attack.

7.4.1 New Construction. In designing a new building against an RPG attack, one or more of the following should be considered: (1) proper site layout to minimize attack line-of-sight; (2) the use of building sacrificial areas; and (3) appropriately designed barriers with or without predetonation screens.

7.4.1.1 Site Layout. Since the RPG is a line-of-sight (LOS) weapon, the facility should be sited to limit, or preferably block, RPG attack sightlines from potential vantage points. Options include: (1) the use of natural or manmade obstructions such as trees, fences, land-forms, or buildings to obscure sight paths; (2) siting the facility at a high point, if possible, to force aggressors to fire up toward the target; and (3) causing the RPG to strike protective surfaces at an angle, reducing the effectiveness.

7.4.1.2 Sacrificial Areas. Sacrificial areas in the building can be employed above, below, and around the critical area in the building to be protected. The walls, doors, etc., of this sacrificial area may be damaged, but will provide a standoff region to reduce the effectiveness of the RPG jet for the critical area. In general, to facilitate this the critical area should be low and internal to the building and well away from exterior walls.

7.4.1.3 Barrier Construction and Predetonation Screens

1) Walls. The only practical wall construction material to stop a direct RPG attack is the use of massive concrete in combination with sand and a predetonation screen. The design tradeoffs are shown in Figure 69. In general, the use of sand is more appropriate to a temporary situation where the function of the facility may change and the sand can be removed later. If an RPG threat against the building is likely to be permanent, the use of concrete by itself or in combination with a predetonation screen is more appropriate.

a) Predetonation screens. Predetonation screens may consist of wood fences, chain-link fencing, expanded metal mesh, or heavy woven-fiber fabric. Wood fences can be made of wood slats or plywood panels a minimum of 3/8 inch (9.4 mm) thick. If they are made of slats, the slats should be spaced no more than 1/4 inch (6.4 mm) apart. Spaces in metal fabric screens must be 2 inches (50 mm) by 2 inches (50 mm) maximum and the fabric a minimum of 9 gauge (3.8 mm). The effectiveness of screens of various sizes is shown in Table 52. This data suggests that 2-inch (50-mm) chain link presents the minimum risk of an RPG passing through the screen with no effect. An RPG which strikes a predetonation screen either detonates on impact or is dudded. Dudded refers to a round being damaged so that it will not detonate. The residual effects of a predetonated round on a building are more severe than the effects of a dudded round. Therefore, in the design one need be concerned only with predetonated rounds. After predetonation, the RPG jet and the spent rocket engine from the RPG continue past the screen. The screen should be located away from the wall a standoff distance appropriate to the concrete wall construction (see Figure 68). For other materials allow a minimum of 40 feet (10 m).

b) Predetonation walls. Solid walls constructed of CMU or other material can also be used if they can be constructed at the proper height and location. These are 100 percent effective in predetonating RPGs.

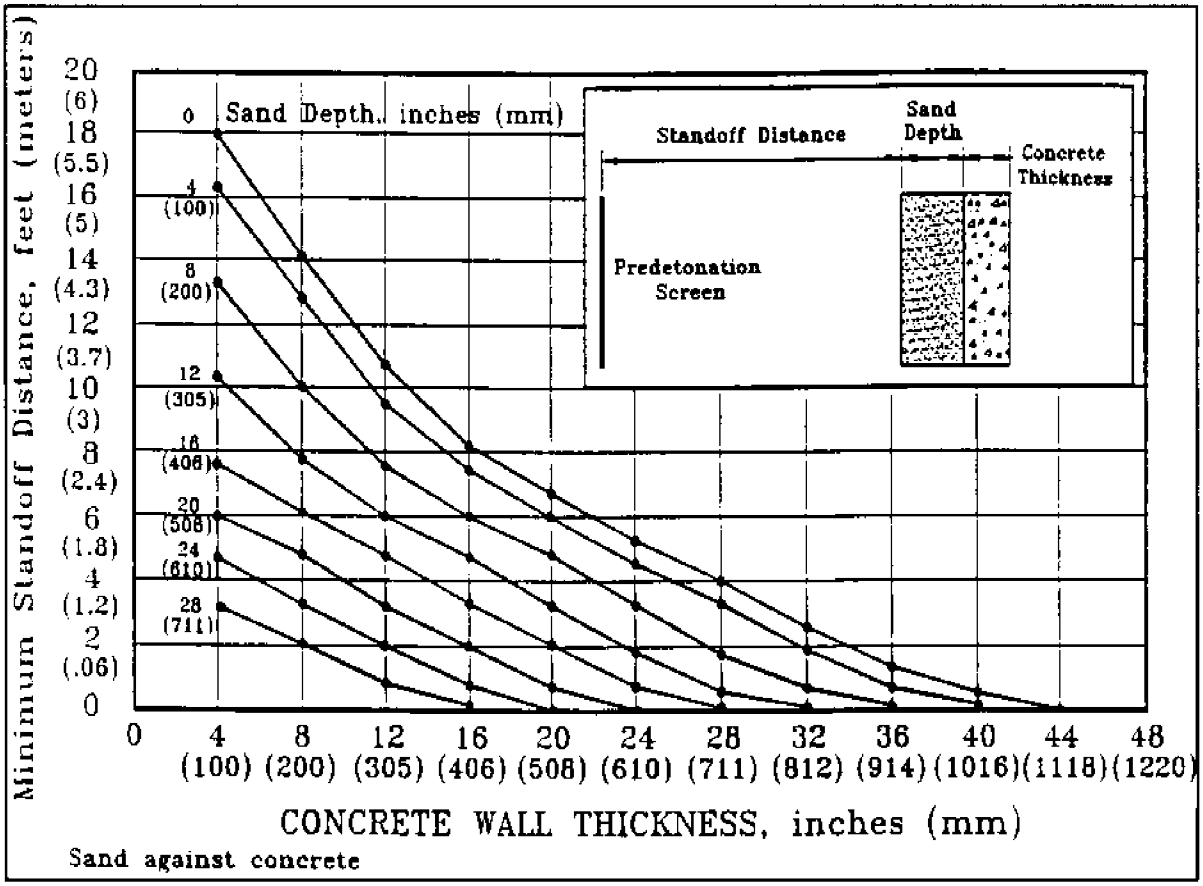


Figure 69
RPG Hardening—Concrete/Sand Thickness Verses Standoff Distance

Table 52
Predetonation Screen Effectiveness

Screen Size	No Effect	Detonating
2-inch (50-mm) Chain Link	36%	64%
3- by 3- by 0.2-inch (76- by 76- by 5-mm) Weld Mesh	48%	52%
3- by 6- by 0.2-inch (76- by 152- by 5-mm) Weld Mesh	58%	42%
3- by 12- by 0.2-inch (76- by 305- by 5-mm) Weld Mesh	62%	38%

c) Wall construction. New construction options for walls include concrete/sand combinations as shown in Figure 69. This figure shows the concrete wall thickness required versus standoff distance for sand depths (if used) ranging from 0 to 28 inches (700 mm). An example of the use of this figure is as follows. If no sand and no predetonation screen are used, about 44 inches (1.1 m) of concrete are required. If the concrete wall thickness is limited to 12 inches (300 mm) and no sand is used, the minimum standoff distance required for the predetonation screen is about 11 feet (3.3 m). If 16 inches (400 mm) of sand is employed, the standoff distance is reduced to 5 feet (1.5 m). These combinations of depths of sand and concrete used with an effective predetonation screen have been found adequate to stop the penetration of the predetonated RPG.

Another wall concept is the 32-inch (810-mm) sandwich ASP Walling design shown in Figure 70. The ASP Walling system consists of formed metal sheets joined together to constitute both the permanent formwork, while at the same time acting as antispalling plates to contain fragments. The basic component of the ASP Walling system is a wall element consisting of interlocked external sheets. The two faces are tied to each other by diagonal lacing panels which, in zig-zag fashion, form a rigid permanent formwork into which 1.5-inch (40-mm) hard stones are placed (see Figure 70).

2) Roofs and Floors. Because of the large quantities of material required to stop an RPG jet, structural considerations will likely preclude their application to roofs or floors open from above and below. In this case, critical assets may only be protected from above and below using sacrificial areas as discussed in par. 7.4.1.2.

3) Windows. Areas to be protected against an RPG attack should be free of any windows.

4) Doors. Foyers should be provided at protected entrances or door openings should be offset so that each door is opposite a solid wall construction associated with a sacrificial area. Examples of possible configurations are illustrated in Figures 71, 72, and 73. The design of exterior concrete walls should be of the same construction as other protected walls. Predetonation screens at the proper standoff can also be provided if necessary (see Figure 69).

7.4.2 Retrofit Construction. The most cost-effective retrofit concept involves the use of sand and predetonation screens or walls. Sand bags or sand-grids used in combination with properly located predetonation screens can stop an RPG from penetrating into high-security areas constructed of concrete and certain CMU construction.

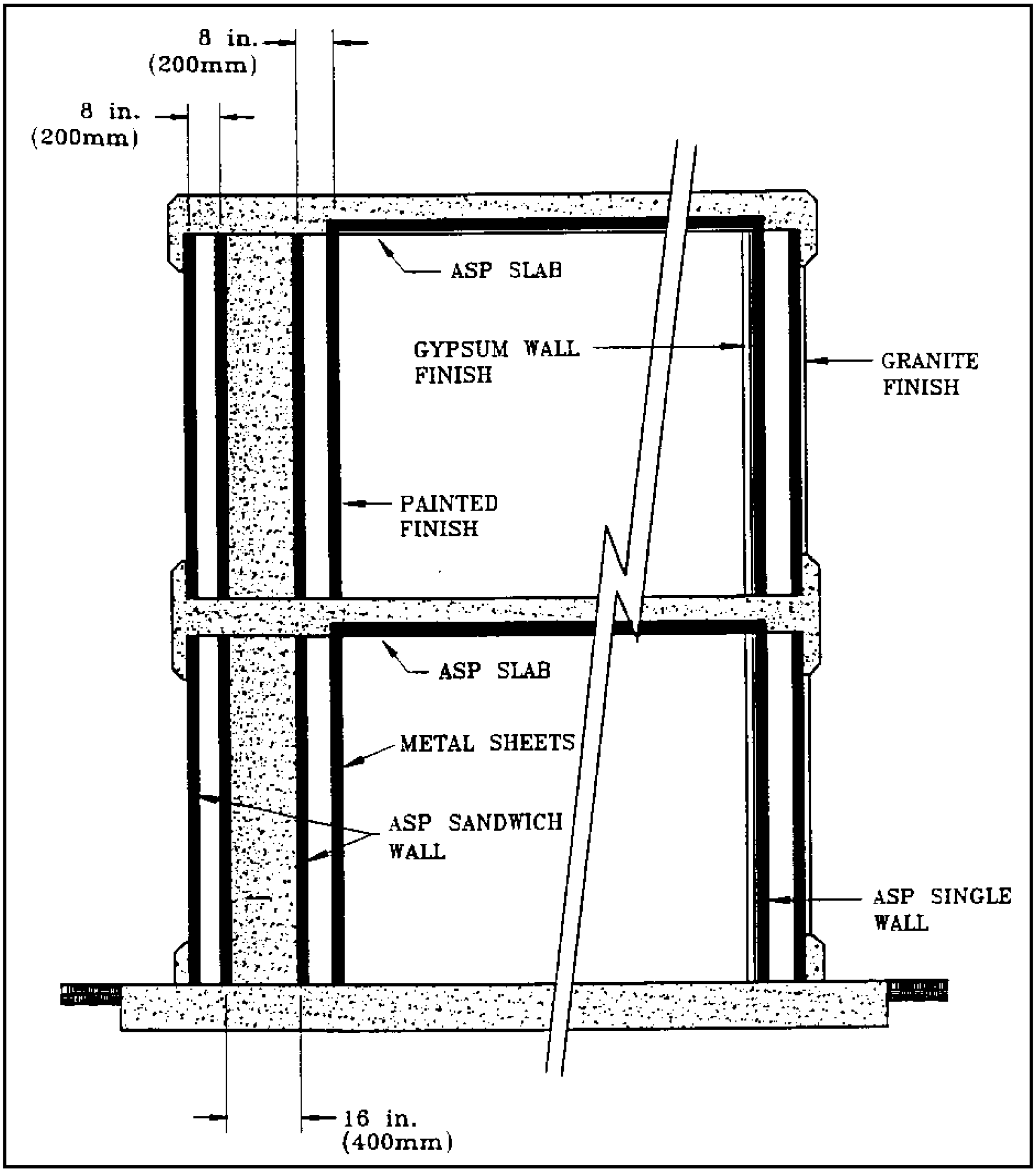


Figure 70
ASP Walling System

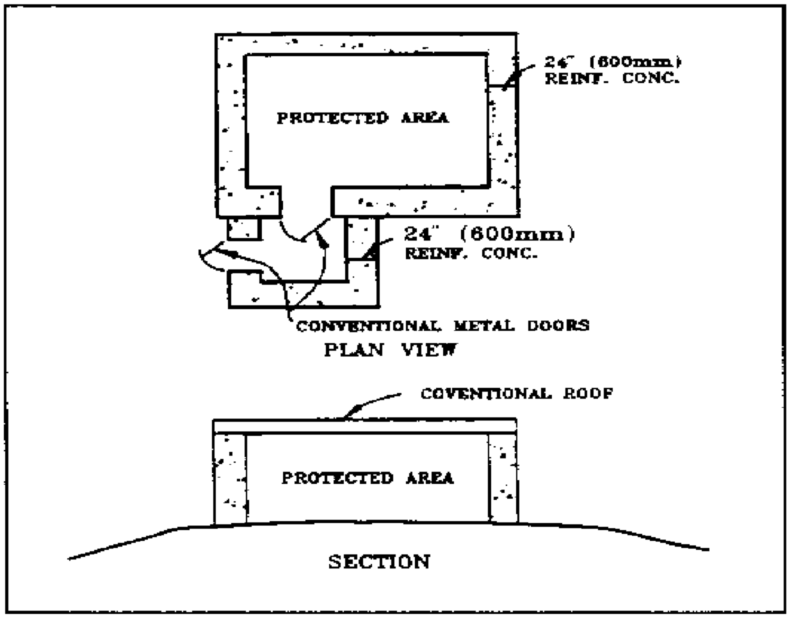


Figure 71
Building Layout Example

7.4.2.1 Retrofit of Walls

1) Concrete Wall Retrofit. Sand in combination with predetonation screens can be used in sandbags or in sand-grid revetments to retrofit concrete walls. Sand-grids (see Figure 74) are more easily transported and require less construction time than sandbags. The expanded configuration shown in Figure 74 is placed in a vertical configuration and filled with sand. The required thickness of sand for concrete and a predetonation screen at various standoffs is summarized in Figure 75. A spall plate consisting of 0.5 inch (12.5 mm) of polyethylene is also employed on the interior wall. This plate reduces the concrete thickness required to stop the RPG from penetrating. Choices of standoff distance, sand depth, and wall thickness will vary with user requirements. Figure 75 allows the user to determine the combinations that best fit his needs.

2) CMU Wall Retrofit. Sand can also be used with CMU to reduce the jet penetration of an RPG. For example, test results for 12-inch (300-mm)- thick CMU require 32 inches (812 mm) of sand on the exterior with 0.5 inch (12.5 mm) of polyethylene on the inside (as a spall plate) to successfully stop the jet. Presently, there is no test data for other CMU wall sizes.

3) Other Materials. Other materials such as wood cannot effectively be retrofit-hardened against an RPG attack.

7.4.2.2 Retrofit of Roof and Floors. Because of the large quantities of material required to stop an RPG jet, structural considerations preclude their application to roofs or floors open from above or below. Critical assets can only be protected from above and below using sacrificial areas as discussed in par. 7.4.1.2.

7.4.2.3 Windows. Areas to be protected against an RPG attack should be free of windows.

7.4.2.4 Retrofit of Doors. Foyers should be provided at protected entrances or openings should be offset such that each door is opposite a solid-wall construction associated with a sacrificial area. Examples are given in par. 7.4.1.3.

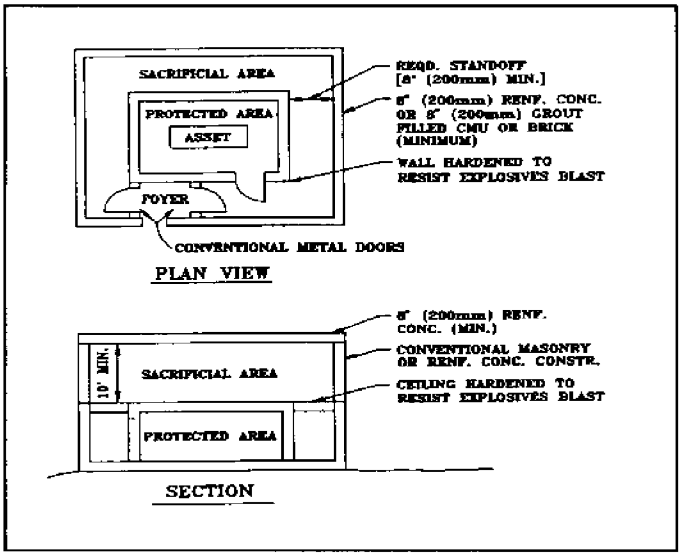


Figure 72
Building Layout Example

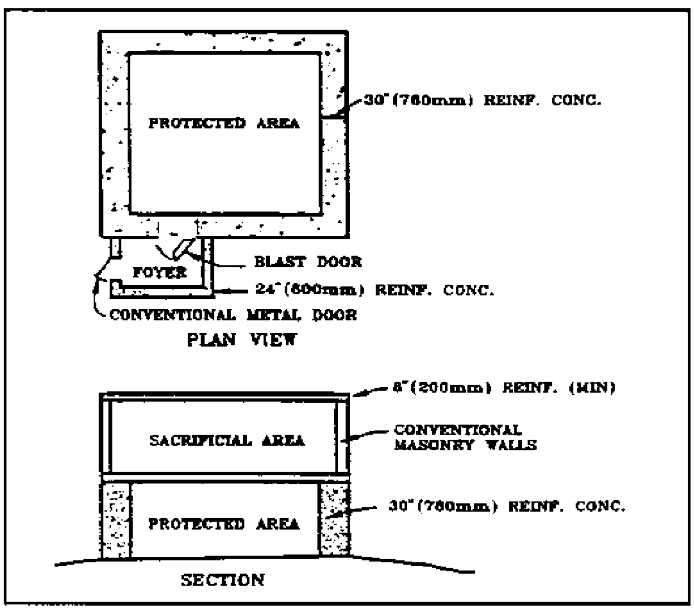


Figure 73
Building Layout Example

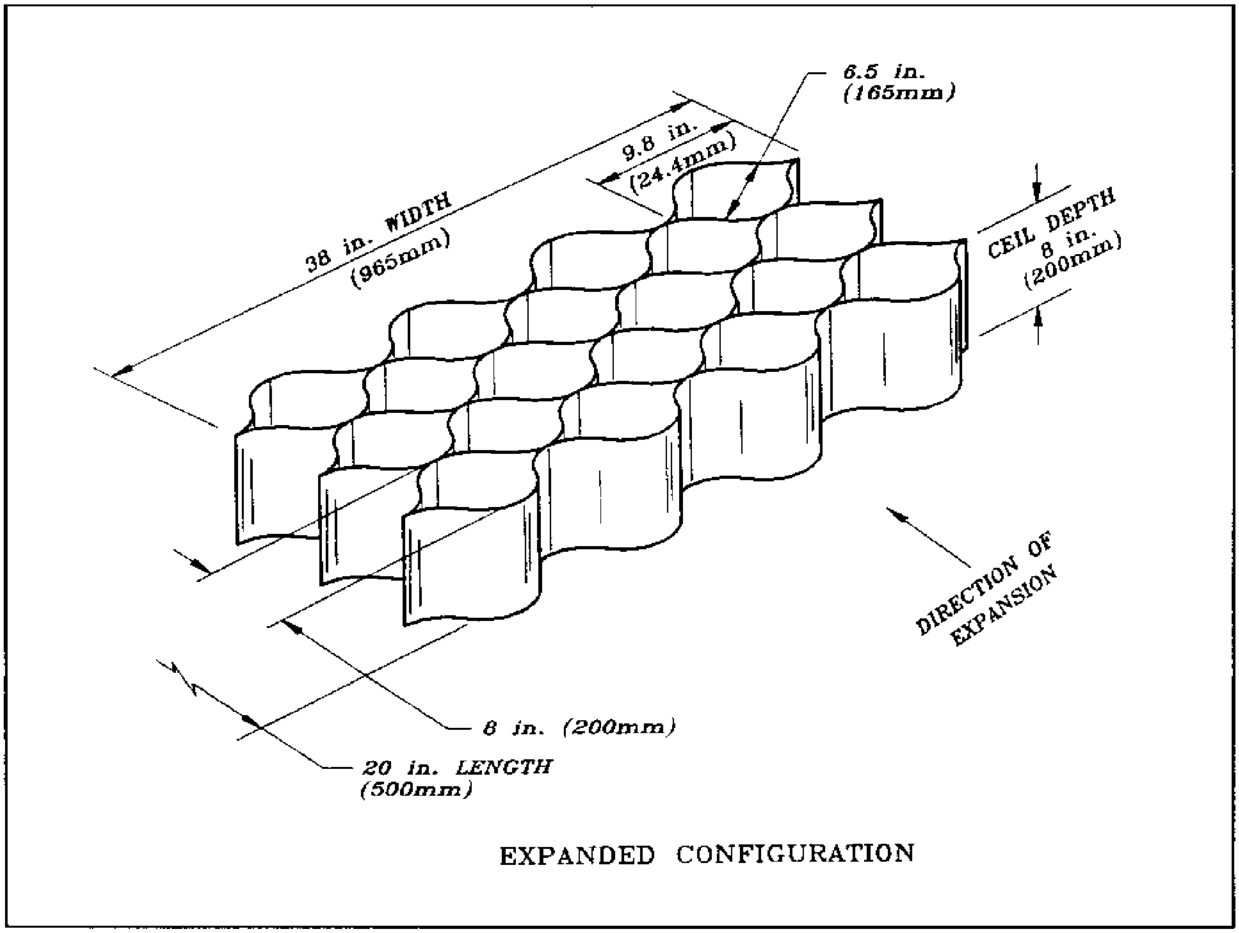


Figure 74
Standard Sand-Grid Materials (from Army Technical Report SL-88-39, Expedient Field Fortifications Using Sand-Grid Construction)

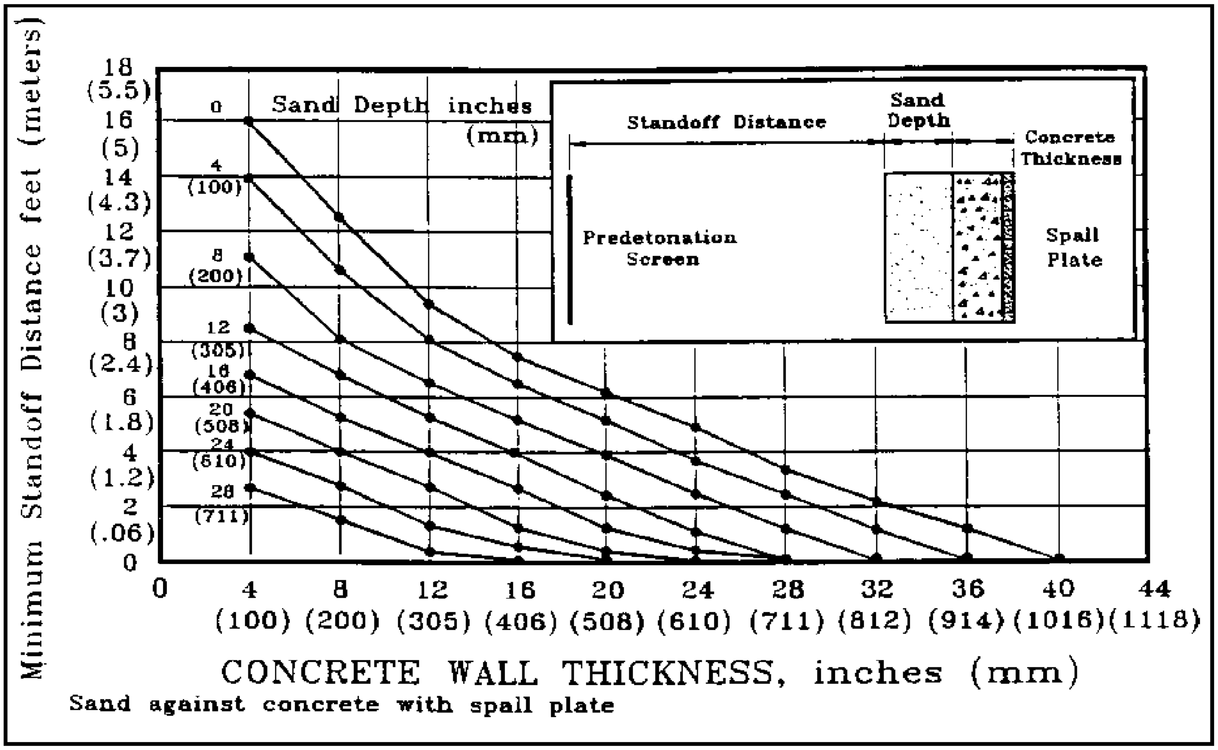


Figure 75
Retrofit Hardening—Concrete/Sand Thickness Versus Distance

Section 8: BOMB BLAST HARDENING

8.1 Introduction. This section summarizes the design approach for hardening against bomb blast effects. A brief summary of design approaches for both new and existing construction is provided. The intent is to illustrate the basic standoff distance versus blast hardening tradeoff for designing against such threats. See the Navy Terrorist Vehicle Bomb Survivability Manual and the Army Security Engineering Manual for details.

8.2 Design Threats

8.2.1 Stationary Bomb Threats. Stationary bomb threats may consist of either a bomb-ladened vehicle parked near perimeter fence lines or entry point areas or dropped-off, concealed packages. In these cases, the design threat explosive level can range from 50 pounds (22.5 kg) of trinitrotoluene (TNT) for the low-level threat up to 1,000 pounds (450 kg) for the high-level threat as shown in Table 53. In this regard, one operational requirement focuses on the higher order threat requiring protection against detonation of 1,000 pounds (450 kg) net explosive weight from at least 400 feet (122 m); however, it is also indicated that this is not absolute, but must be adapted to site conditions.

Table 53
Stationary Bomb Threats

Threat	Explosive Level, lb (kg) of TNT
Low	50 (22.5)
Medium	220 (100)
High	500 (225)
Very High	1000 (450)

8.2.2 Moving Vehicle Bomb Threat. There are also four levels of moving vehicle design threats ranging vehicle design threats ranging from low to very high, as shown in Table 54. Explosives range from 50 to 1,000 pounds (22.5 to 450 kg) of TNT. Vehicle weights are 50 (22.5) 4,000 pounds (1,800 kg) for automobiles and up to 10,000 pounds Medium 220 (100) (4,500 kg) for trucks, with speeds varying from 15 to 50 mph (24 to 80 km/h). In general, the basic tradeoff is to design vehicle barriers to stop such threats at a standoff distance that is consistent with the hardness of the building against blast effects. Kinetic energy (KE) equivalents for the vehicle can be computed using the expression:

EQUATION $$KE(ft\text{-}lb)=0.033\ W\ V^{2} \qquad (1)$$

where W = vehicle weight in pounds
V = the vehicle velocity in miles per hour

or

EQUATION KE(M-KG) = 0.0497 WV.2- (2)

where W = vehicle weight in kilograms
V = vehicle velocity in kilometers per hour

Again, one operational requirement requiring detonation of 1,000 pounds (450 kg) net explosive weight from at least 400 feet (122 m) should be considered; however, it is also indicated that this is not absolute, but must be adapted to site conditions.

Table 54
Moving Vehicle Transported Bomb Threats

Threat Severity	Explosive Level lb (kg) of TNT	Vehicle Transport GVW, lb (kg)	Vehicle Transport Speed, mph (km/h)	Vehicle Transport Kinetic Energy Equivalent, ft-lb (kg-m)
Low	50 (22.5)	4,000 (1,800)	15 (24)	30,000 (40,000)
Medium	220 (100)	10,000 (4,500)	15 (24)	75,000 (100,000)
High	500 (225)	4,000 (1,800)	50 (80)	334,000 (450,000)
Very High	1000 (450)	10,000 (4,500)	50 (80)	836,000 (1,140,000)

8.3 Standoff/Hardening and Protection Levels. Figure 76 shows the geometry of a bomb-blast wave. In general, the pressure levels of bomb blasts fall off approximately as the inverse square of the distance from the blast. Consequently, the larger the standoff distance, the lower the pressure delivered to the structure. To illustrate, Figure 77 shows the pressure from a blast wave versus standoff distance for several different charge weights. For example, the pressure from a 100-pound (45-kg) charge at a standoff distance of 10 feet (300 cm) is about 280 psi (1,900 kPa). If the standoff distance is increased to 100 feet, the pressure is reduced to about 2.8 psi (19 kPa).

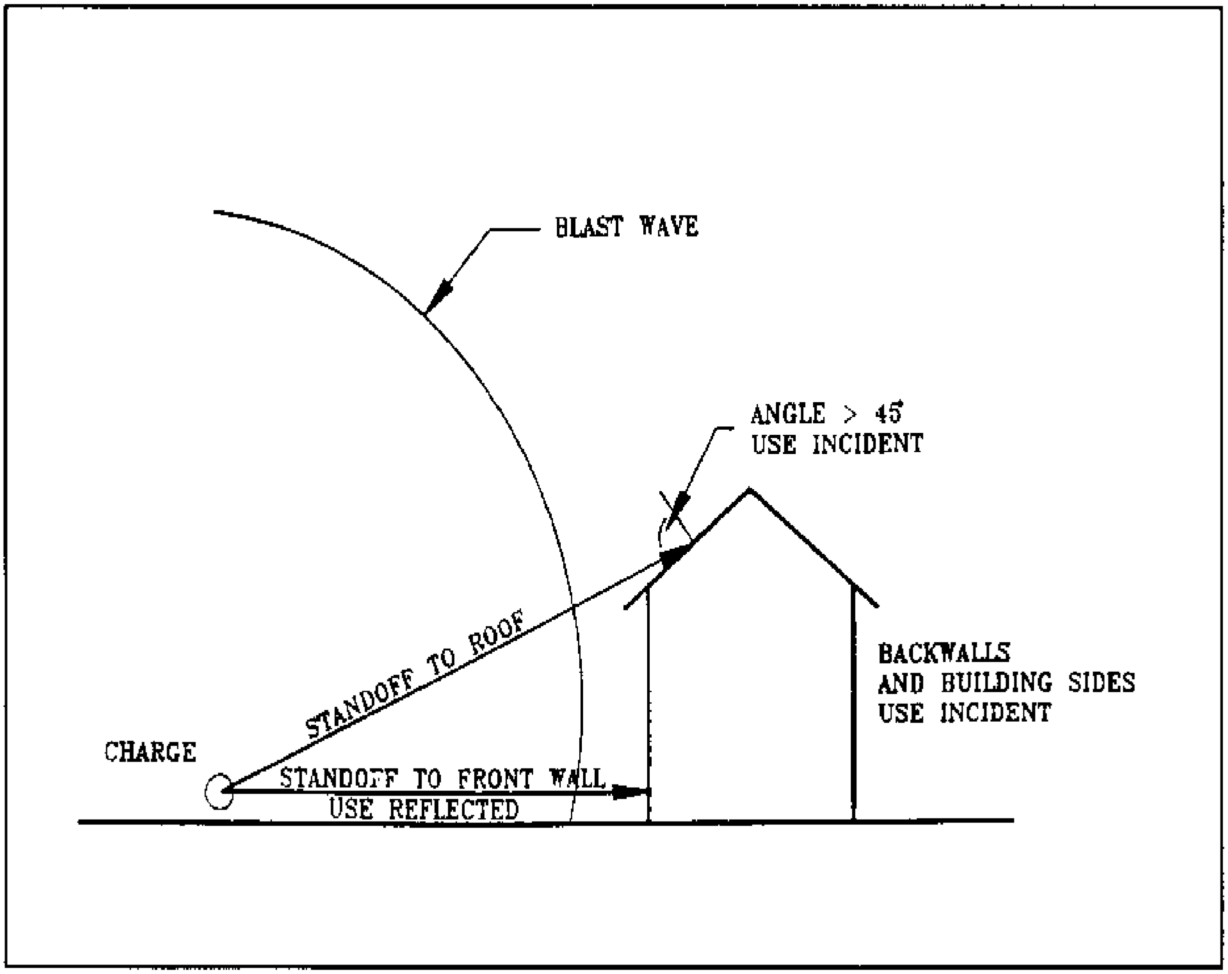


Figure 76
Blast Wave Geometry

8.3.1 Protection Levels for New Construction. In the Army Security Engineering Manual there are three levels of protection to which facilities can be hardened: a low level in which damage is unreparable; a medium level in which the damage can be repaired; and a high level in which the facility suffers only superficial damage.

8.3.2 Protection Levels Existing Structures. The Navy Terrorist Vehicle Bomb Survivability Manual describes two levels of protection for existing structures: Rebuild or Repair. These are provided for charge weights from 1 to 4,000 pounds (0.45 to 1,800 kg) and standoff distances from 1 to 1,000 feet (0.3 to 300 m) for 12 different building types intended to be representative of facilities used by the Armed Services worldwide. Examples are provided in par. 8.4.3.1.

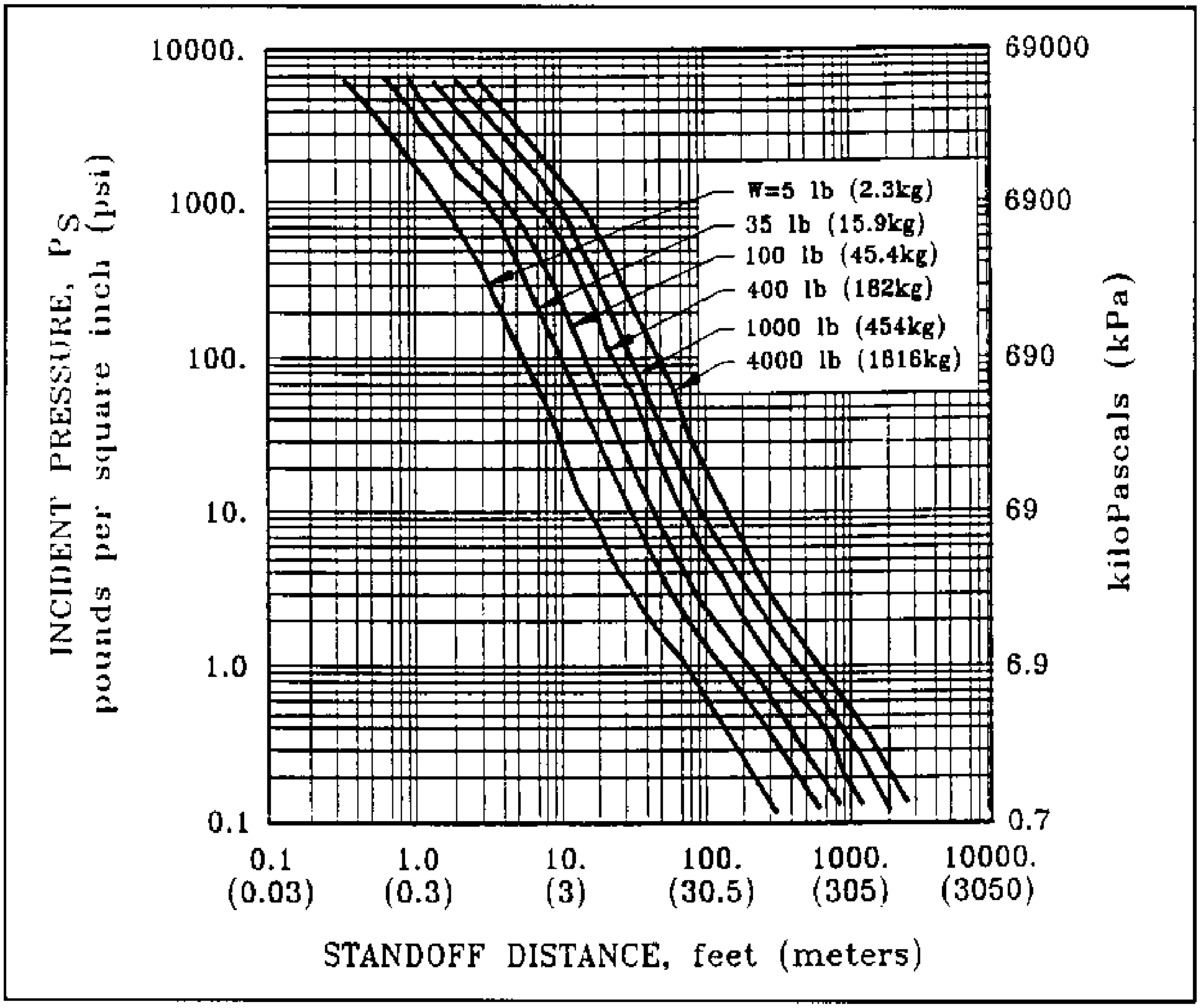


Figure 77
Pressure Levels Versus Standoff Distance

8.4 Design Approach

8.4.1 Introduction. This section summarizes the design approach contained in the Navy Terrorist Vehicle Bomb Survivability Manual and the Army Security Engineering Manual whereby one can establish the level of protection provided by various combinations of standoff distances and structural hardening. Vehicle barriers required to maintain standoff distances are also summarized.