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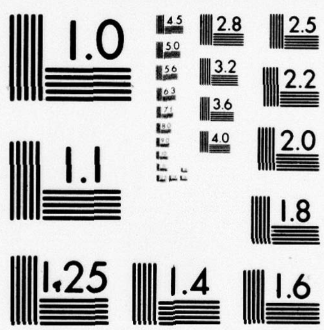

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SURVIVABILITY IN A NUCLEAR WEAPON ENVIRONMENT

DCPA Contract DCPA01-77-C-0229
Work Unit 1621H

FINAL REPORT

by

A. Longinow

for

Defense Civil Preparedness Agency
Washington, D.C. 20301

May 1979

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This report contains information on protective capabilities of a variety of different personnel shelters against prompt effects of nuclear weapons. This information was collected from previous studies performed for DCPA in this subject area. Protective capabilities are expressed in terms of "people survivability functions" which relate the probability of survival (or percent survivors) to the free field overpressure at the shelter site. Respective shelters are described in terms of their geometry and material properties. The following shelter categories are included. (see other side)

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1. Existing Engineered Buildings (Upper Stories and Basements),
2. Designed Basements,
3. Single-Purpose Shelters,
4. Dual-Purpose Shelters,
5. Expedient and Special Purpose Shelters and
6. Expediently Upgraded Shelters.

These results may be used as a guide for the evaluation of effectiveness of alternative shelter systems, development of shelter plans, damage assessment studies, i.e., provided that personnel shelters used in each are the same as those described in this report or are very similar to them. Deficiencies in the results as well as special considerations involved in the "people survivability" analyses of these shelters are noted.

PREFACE

This is the final report on IIT Research Institute (IITRI) project J6427 entitled "Survivability in a Nuclear Weapon Environment". The study was performed for the Defense Civil Preparedness Agency (DCPA) under Contract DCPA01-77-C-0229. Work was initiated September 30, 1977 and completed April 30, 1979.

The objective of the effort was to collate, consolidate and structure casualty estimates and estimating techniques and to prepare a reference text. The text prepared is suitable for use by agencies making casualty estimates, however specific emphasis is given to data suitable for DCPA use.

The work was performed in the Structural Analysis Section, Engineering Division of IITRI by A. Longinow. Mr. D. A. Bettge of the Hazards Evaluation Division, DCPA was the project monitor.

Respectfully submitted,
IIT RESEARCH INSTITUTE

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Project Engineer

APPROVED:

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Director of Research
Engineering Division

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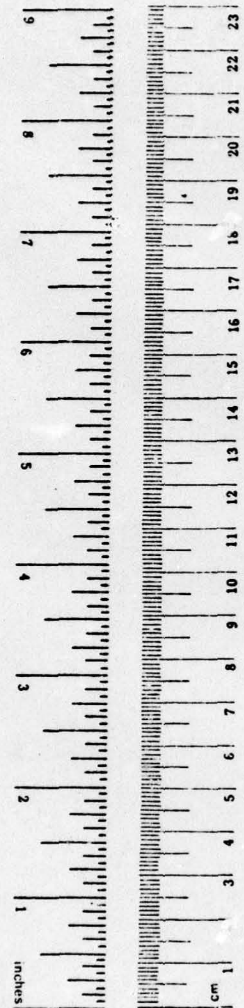
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

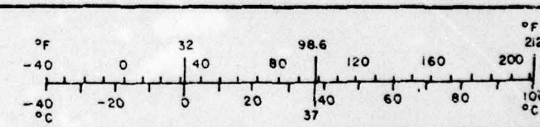
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

The objective of the effort reported was to collate, consolidate and structure casualty estimates and estimating techniques and to prepare a reference text. The text should be suitable for use by agencies making casualty estimates, however specific emphasis is to be given to data suitable for DCPA use.

To meet this objective pertinent unclassified study reports produced for DCPA over approximately the past ten years were assembled, reviewed and summarized. Subject areas included:

- Casualty estimating methodology
- Existing casualty estimates for people in shelters

In the process of reviewing existing results an attempt was made to determine if these are sufficiently current when measured relative to the capabilities and data of the current state of the art. Deficiencies were noted and are discussed in Chapter 4. Where possible, adjustments and corrections were made. This report contains the following information.

Chapter 2 is a state of the art review of the analysis of people survivability in a direct effects nuclear weapon environment. It is described in terms of a computer program developed for predicting the survivability of people located in buildings when subjected to the prompt effects of megaton range nuclear weapons. It was developed for civil defense purposes and specifically for the rating of existing buildings in terms of inherent protection afforded. This is a simplified, "table look-up type" of computational routine which was developed on the basis of results generated by the use of more general routines for the purpose of a speedy analysis of large numbers of buildings capable of sheltering people. It is specifically geared to the analysis of buildings when subjected to the effects of a single 1MT surface burst. The more general routines and data used in casualty estimation are also described in Chapter 2 and references on which they are based are provided.

Chapter 3 is a summary of selected existing estimates of people survivability in a direct effects environment. These results are introduced in the following paragraphs.

A typical people survivability function, P_s, is shown in Figure 1. This particular estimate is for people located in a five-story school building* with masonry walls and an interior steel frame. Superimposed on it is a casualty function, P_c, (shown by a dash line) which is its opposite, i.e.,

$$P_c = 1 - P_s \tag{1}$$

where P_c is the probability of casualty and P_s, the probability of survival.

A survivability (casualty) function relates the probability of survival (casualty) to a particular casualty producing environment. For convenience, the functions in Figure 1 are related to the free field overpressure at the site of the shelter.

Functions shown in Figure 1a are for combined effects. Individual effects on which they are based are shown in Figure 1b, and include the effects of thermal radiation, ionizing radiation, debris and impact due to tumbling of individuals by the blast winds. Combined effects probability of survival at a given overpressure level is obtained on the basis of individual effects probabilities as follows.

$$P_s = P_{ti} P_d P_{ir} P_{tr} \tag{2}$$

where P_{ti}, P_d, P_{ir} and P_{tr} are probabilities of survival against the effects of tumbling impact, debris, ionizing radiation and thermal radiation respectively. Procedures, on the basis of which these estimates are made are described in Chapter 2 of this report.

Over the past several years casualty functions were developed for a number of different types of personnel shelters which are grouped as follows.

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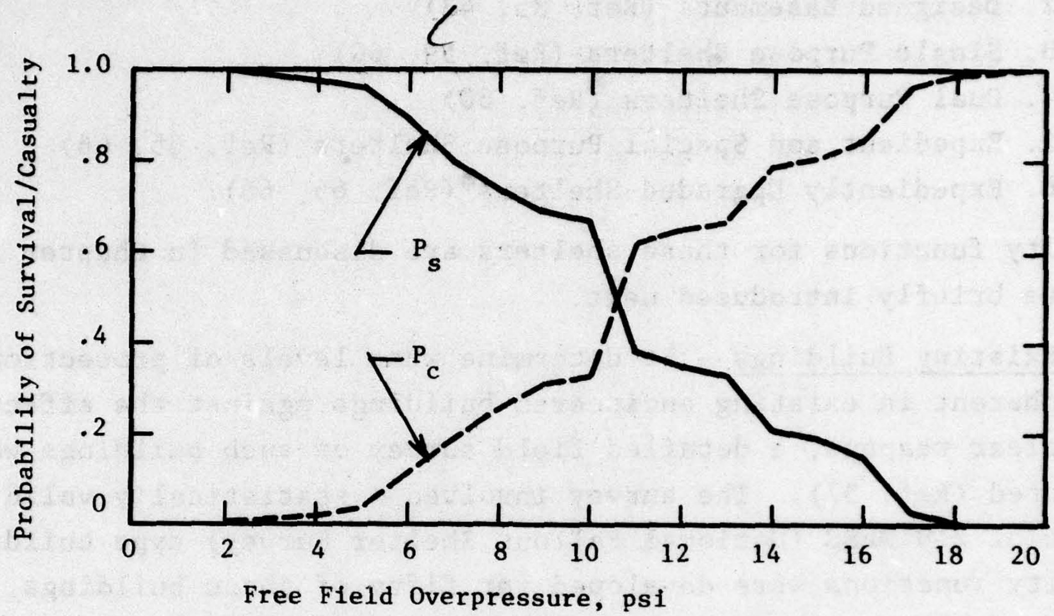
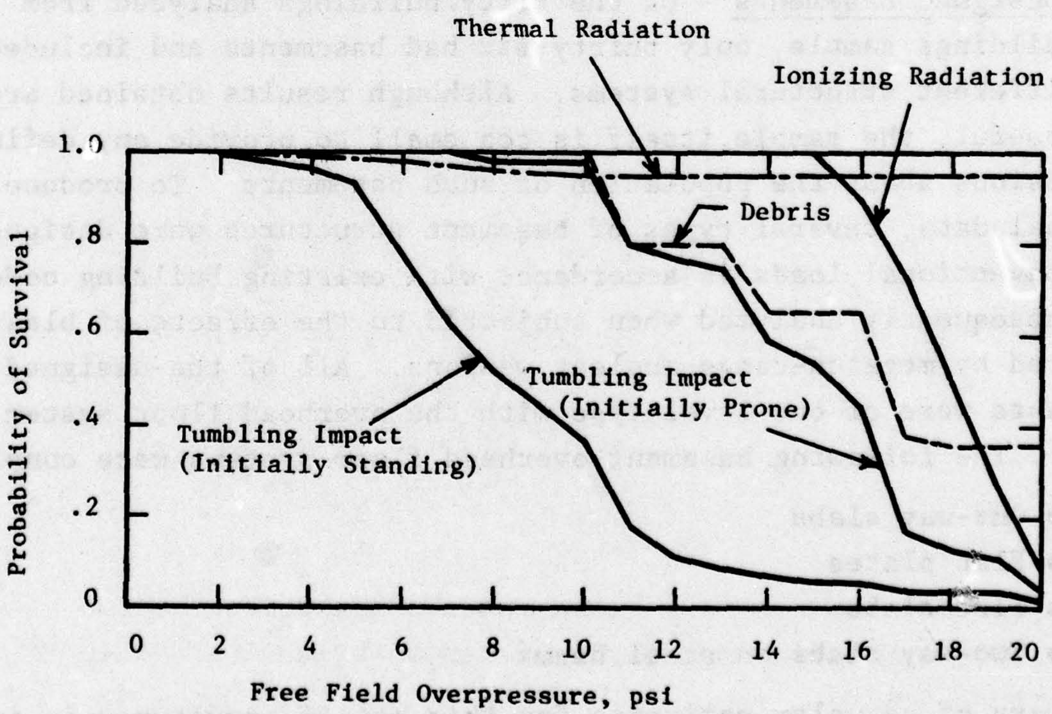
*Physical properties for this building (Rindge Technical School) are given on the first line of Table 5, page 39.



(a) Combined Effects Estimate



(b) Individual Effects Estimate

Figure 1. People Survivability Estimate

1. Existing Buildings (Upper Stories and Basements)(Ref. 38)
2. Designed Basements (Ref. 35, 43)
3. Single Purpose Shelters (Ref. 59, 60)
4. Dual Purpose Shelters (Ref. 60)
5. Expedient and Special Purpose Shelters (Ref. 65, 66)
6. Expediently Upgraded Shelters (Ref. 65, 66)

Casualty functions for these shelters are discussed in Chapter 3, and are briefly introduced next.

Existing Buildings - To determine what levels of protection are inherent in existing engineered buildings against the effects of nuclear weapons, a detailed field survey of such buildings was conducted (Ref. 37). The survey involved a statistically valid sample of 219 NFSS (National Fallout Shelter Survey) type buildings. Casualty functions were developed for fifty of these buildings, both when people are located in upper stories and in basements. Results are summarized in Sections 3.1 and 3.2.

Designed Basements - Of the fifty buildings analyzed from the 219 buildings sample, only thirty-six had basements and included six different structural systems. Although results obtained are very useful, the sample itself is too small to provide any definite conclusions about the population of such basements. To produce additional data, several types of basement structures were designed for conventional loads in accordance with existing building codes and subsequently analyzed when subjected to the effects of blast produced by megaton-range nuclear weapons. All of the designed basements were of one level type with the overhead floor system at grade. The following basement overhead floor systems were considered.

- One-way slabs
- Flat plates
- Flat slabs
- Two-way slabs on steel beams

A summary of casualty estimates for this set of structures is included in Section 3.2.3.

Single Purpose Shelters - Personnel shelters in this category are those whose single function would be to provide protection in the event of a nuclear weapon attack. In a study described in Reference 59 arch and rectangular shelters were designed to resist one of the following nuclear weapon effects environments

a. fallout radiation
b. 10 psi
c. 20 psi
d. 30 psi

(b.–d.) free field overpressure and associated effects of prompt nuclear, thermal and fallout radiation resulting from a single megaton weapon in its Mach region.

These shelters were designed to be located on the peripheries of large population centers to provide protection to an evacuated population. Casualty functions for these shelters against the blast effects of nuclear weapons are contained in Reference 60 and summarized in Section 3.3.

Dual Purpose Shelters - Shelters falling in this category are those which serve a primary function (a school basement for example) during normal operation and as a shelter during an emergency. Such structures are designed and built with both functions in mind. In previous studies conducted for DCPA a number of different dual-use (purpose) shelters were designed. These included school basements (Ref. 63), underground parking garages (Ref. 64), and an expressway grade separation (Ref. 60). Individual design weapon environments ranged from fallout radiation alone to 50 psi free field overpressure and associated effects resulting from a single nuclear weapon in its Mach region. They were subsequently analyzed against the effects of blast produced by nuclear weapons and casualty functions were developed for each. Casualty functions for school and parking garage shelters are summarized in Section 3.4.

Expedient Shelters - In the context of this narrative, expedient shelters are those that may be constructed in a relatively short period of time, several days, using available materials (lumber, logs, soils, etc); no or few specialized tools and mostly unskilled labor. In high risk areas located in geographic regions where basements are not constructed it will be necessary to construct blast shelters for key workers using such expedient materials and methods. Expedient blast shelters have been constructed on an experimental basis and tested in the field (Ref. 67). Casualty functions for this category of shelter have not been developed. However, estimates of their protective capabilities were made and are discussed in Section 3.5.

Special Purpose Shelters - In the context of this narrative special purpose shelters are those that may be constructed by individuals or communities to provide blast and/or radiation protection. When considered by individual families such shelters may be constructed in the basement of a residence or near the residence when a basement does not exist. Over the past two decades a number of different special purpose shelter concepts have appeared in the civil defense literature (Ref. 68, 73). Eight of these were evaluated in Reference 65 and include,

1. Basement concrete block shelter (Ref. 68)
2. Lean-to shelter (Ref. 69)
3. Rigid frame shelter (Ref. 69)
4. Reinforced concrete block shelter (Ref. 69)
5. Aboveground A-frame shelter (Ref. 70)
6. Plywood box shelter (Ref. 71)
7. Wood grate roof shelter (Ref. 72)
8. Gable roof shelter (Ref. 73)

Casualty estimates for this set of shelters are given in Section 3.6.

Expediently Upgraded Shelters - Basements and other areas of existing buildings which may be effectively upgraded during the crisis period to provide blast and radiation protection are referred to as expediently upgraded shelters. References 65 and 66 contain casualty functions for several categories of existing basements, both as built and as upgraded using expedient techniques. These casualty functions are discussed in Section 3.7.

Results included in this report may be used as a guide in the evaluation of alternative shelter systems, development of shelter plans, damage assessment, etc. However, in doing so the following special considerations and deficiencies should be noted.

The majority of results given here are for shelters subjected to the effects of a single, megaton range nuclear weapon detonated at the ground surface. Laws for scaling to other yields were not developed and are therefore not included. Also, it is not clear that such laws are capable of being developed.

Results are for individual shelters located in the open and away from buildings which can either provide some degree of shielding against the effects of blast and radiation or become additional sources of debris capable of producing damage and/or casualties.

Results, for the most part are based on deterministic models which did not take into account variabilities in weapon effects parameters, material and geometric properties of shelter structures or physical variations in the makeup of the population. Although physical variations in the population can be considered, available casualty criteria are crude and for the most part are not capable of accommodating such refinements.

In preparing survivability estimates for people in the upper stories of large engineered buildings, possible overturning (collapse) of the building frame was considered in a very approximate manner. The level of uncertainty associated with predicting casualties from this effect is greater than that associated with any of the other casualty mechanisms considered. This means that for high-rise buildings (approximately ten stories and higher), the number of people surviving in the upper stories may be somewhat less than indicated here.

The interaction of the superstructure with the basement and foundation when subjected to blast loading was not considered. Since such interaction can initiate damage in the basement overhead slab, foundation and peripheral basement walls, then for buildings approximately ten stories and higher the number of people surviving in basements may be up to ten percent less than that indicated by the estimates given here.

People survivability estimates for people in single- and dual-purpose shelters do not consider prompt nuclear radiation as a casualty mechanism. These results are therefore applicable to shelters for which this effect can be neglected.

This report does not contain procedures whereby casualty extimates for people in different shelters may be made. Casualty estimation is still mostly a research area and procedures which may be used on a routine basis by engineers and planners for the purpose of evaluating the effectiveness of shelter systems have not been developed. Evaluation of the effectiveness of alternative shelter systems is currently best accomplished by practitioners in this area.

2. ANALYSIS OF PEOPLE SURVIVABILITY

2.1 Introduction

This chapter describes a computer program developed for predicting the survivability of people located in buildings when subjected to the prompt effects of nuclear weapons. Prompt effects considered include thermal radiation, prompt nuclear radiation, primary and secondary blast. The formulation of the model, its physical basis and usage are discussed, and representative results are described by means of an example problem.

This computer model was developed for civil defense purposes and specifically for the rating of existing buildings in terms of inherent protection afforded. Therefore the usage of this model is discussed herein in civil defense terms. However, the overall methodology produced can also be used for the assessment of primary and collateral damage resulting from a nuclear weapon attack.

The emphasis is on casualty mechanisms produced by secondary blast effects, i.e., diffraction loadings, blast winds and debris. Only the models used in predicting and quantifying these casualty mechanisms are described in detail. Simulation models used for predicting casualties due to thermal radiation, prompt nuclear radiation and primary blast are described in general terms. For a more detailed description of these models, the reader is referred to References 1 and 2. The following paragraphs provide a brief discussion of the relationship of this work to previous studies in this area.

Casualty/survivability studies are performed for the purpose of damage assessment and for designing or evaluating alternative shelter systems. Initial efforts in this area relative to a nuclear weapon environment were performed following the detonation of the first nuclear device. Shortly after World War II, the U.S. Strategic Bombing Survey teams examined casualties and destruction at Hiroshima and Nagasaki with the object of determining the effects of nuclear weapons on these two cities. A large quantity of information was collected and included data on casualties and structural damage. These data were analyzed with the object of establishing damage-distance relationships. As a result a median lethal radius corresponding to an overpressure of 7.0 psi for the 13 KT airburst was established. Fatalities in general were taken to be the result of initial nuclear radiation, blast, thermal radiation, and fires. In subsequent time periods attempts to establish how these effects broke down were made by numerous individuals (e.g., Ref. 3). The results, however, were in general sketchy and not entirely conclusive. Further, relationships for extrapolating effects from low-yield airbursts to high-yield near-surface bursts are not as yet established nor necessarily capable of being established.

In the 1950's a series of nuclear weapon field tests were conducted (Ref. 4). Subjects of these tests were full-scale structures, scaled structures, structural components, and animals. This was followed by high explosive (HE) tests on similar subjects. Since then a great deal of effort was devoted to the simulation of weapon effects mostly in the laboratory. Concurrently with experimental studies, analysis methods aimed at predicting casualties based on weapon effects and associated casualty mechanisms were initiated. In the civil defense sector of this subject area, the work of Smith (Ref. 5), Childers (Ref. 6) and Heugel and Feinstein (Ref. 7) was included. The method described herein is a revision/update of that originally formulated in Reference 7.

2.2 Emphasis of this Simulation Model

The civil defense planner must have knowledge of the best available shelter space in his community. Conventional buildings constitute the only significant, current sheltering resource. Each building has some level of inherent ability to provide protection from the effects of nuclear weapons, and also natural disasters such as earthquakes, tornados and hurricanes. It is important to have reliable and readily usable knowledge on their protective capabilities and on the possible types of evasive action that can be taken by personnel to gain full advantage of these capabilities in any emergency situation.

Assuming that the attack situation is such that there is little warning time then buildings of primary interest to the civil defense planner are those which contain substantial numbers of people for significant portions of the day. Representative types include large, multistory, reinforced concrete or steel framed buildings, combination reinforced concrete shear wall and framed buildings, load-bearing buildings, and combination load-bearing and framed buildings.

Framed buildings with weak walls are for the most part diffraction sensitive, i.e., when interacting with the blast wave the walls are expected to fail and be removed early in the loading history with the frame remaining essentially intact. In the upper stories, hazards to occupants in a nuclear weapon blast environment are due to thermal radiation, prompt nuclear radiation, blast diffraction, high velocity winds and debris from the breakup of walls, partitions and furniture. People located in unprotected areas are expected to be translated by the blast winds and experience impacts with the floor, walls, debris and/or the ground surface. In deep basements the hazards are primarily due to nuclear radiation and debris from the breakup of the overhead slabs.

The simulation model described is capable of considering low- and high-rise framed and partially framed buildings and determining the extent of survivability afforded with a fairly high degree of confidence. It is not capable of treating load-bearing buildings with the same level of confidence. Load-bearing buildings are expected to collapse catastrophically once the structural (load-bearing) walls fail. Although in load-bearing buildings with large or moderate window sizes, blast translation of personnel will pose a serious hazard prior to the failure of walls, debris casualties produced by the breakup and collapse of the structure are expected to be at least as significant.

In evaluating the survivability potential in buildings, this simulation model considers only the prompt effects which occur in the Mach region of a nuclear weapon. These effects, corresponding casualty mechanisms, and types of casualties considered in this analysis process, are listed in Table 1 in the order of event.

TABLE 1. EFFECTS AND ASSOCIATED TYPES OF CASUALTY

1. Thermal Radiation	⟶	Burn Casualty (Whole Body)
2. Prompt Nuclear Radiation	⟶	Radiation Casualty (Whole Body)
3. Primary Blast	⟶	Casualty Due to Fast Rising Overpressure
4. Secondary Blast (Diffraction and Dynamic Pressure)		
• Translation ⟶ Impact Casualty	⟶	Head, Whole Body
• Debris ⟶ Impact Casualty	⟶	Head, Thorax, Abdomen, Limbs
• Acceleration ⟶ Whole Body Acceleration Casualty		

This simulation model currently does not make a distinction between injured and uninjured personnel in its predictions. Numbers of survivors based on several general, major categories of trauma are predicted (see Table 1). *Survivors include those persons who are expected to live (survive) at least one week after the event provided that basic rescue operations are carried out and injured survivors are removed to areas conducive to recovery.* Influence of fires which may occur subsequent to the prompt effects is not considered.

The ultimate usage of results is to provide for reliable on-site assistance at the local civil defense level. The results would take the form of a concise building classification scheme which would be used for the rating of buildings in terms of their inherent protective capabilities and thus provide for the optimum distribution of the local population within them in the event of an emergency.

The simulation model is specifically oriented for predicting people survivability in a direct effects nuclear weapon environment. As such, in addition to being able to provide shelter information for the civil defense planner, this methodology can also be used by the damage assessor to assess primary and collateral damage resulting from a nuclear weapon attack.

2.3 People Survivability Simulation Model

The computational process used in this simulation model is described in Figure 2, and a typical application is illustrated in Figure 3. This is an elevation view of a ten-story, reinforced concrete framed building.

Problem Definition - The building to be analyzed is described in the terms of overall and room geometries, type of structural system, relevant nonstructural systems (exterior curtain walls, interior partitions) and the distribution of building mass. Data also include information on window sizes, sill heights and types of interior window covering.

Information on people located within the building is provided in terms of their distribution in various building areas and their initial body positions, i.e., standing or prone.

The hazard environment is specified in terms of a single weapon, its size, height of burst, and range to ground zero. This information is used to determine the time-dependent free field intensities of thermal radiation, prompt nuclear radiation, overpressure and dynamic pressure at the building location.

Structural, Blast-Load Analysis - The structural analysis portion of the process is a separate computation. Its purpose is to determine the onset of debris effects should this be important at the given overpressure level. Debris is defined as any structural or nonstructural component that separates from the building as a result of blast wave passage. For most framed buildings of interest, in the relevant range of overpressures, this includes exterior walls, interior walls and partitions, and slabs over basements. Glass fragments and furniture items are not considered in the present model.

The structural analysis uses procedures such as described in Reference 8. It determines incipient collapse overpressures, times to collapse and average velocities at collapse for exterior walls, interior walls and partitions, and slabs over basements. A check is made to see if the particular failure mode is the lowest for the particular structural system considered.

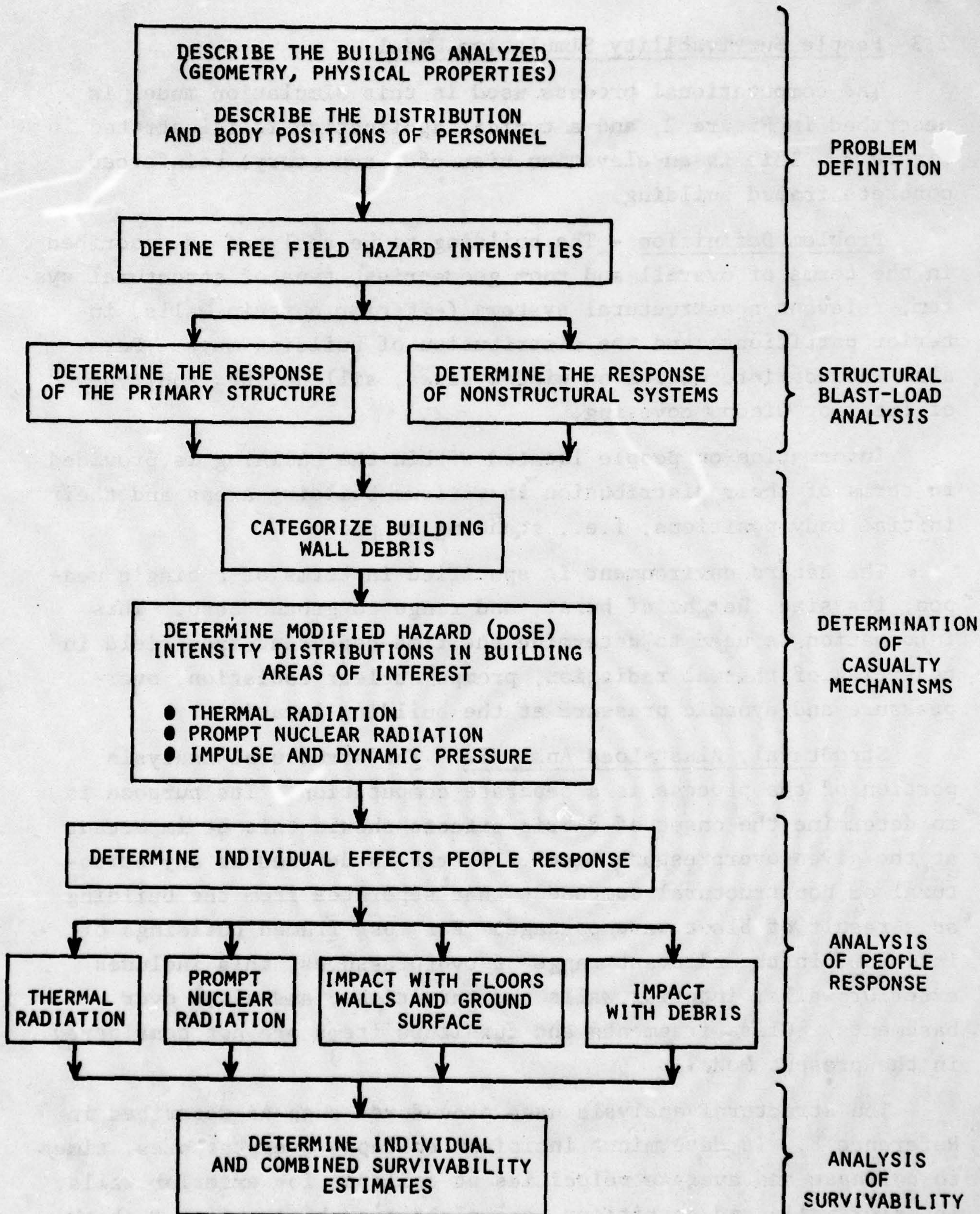


Figure 2. People Survivability Computation Process

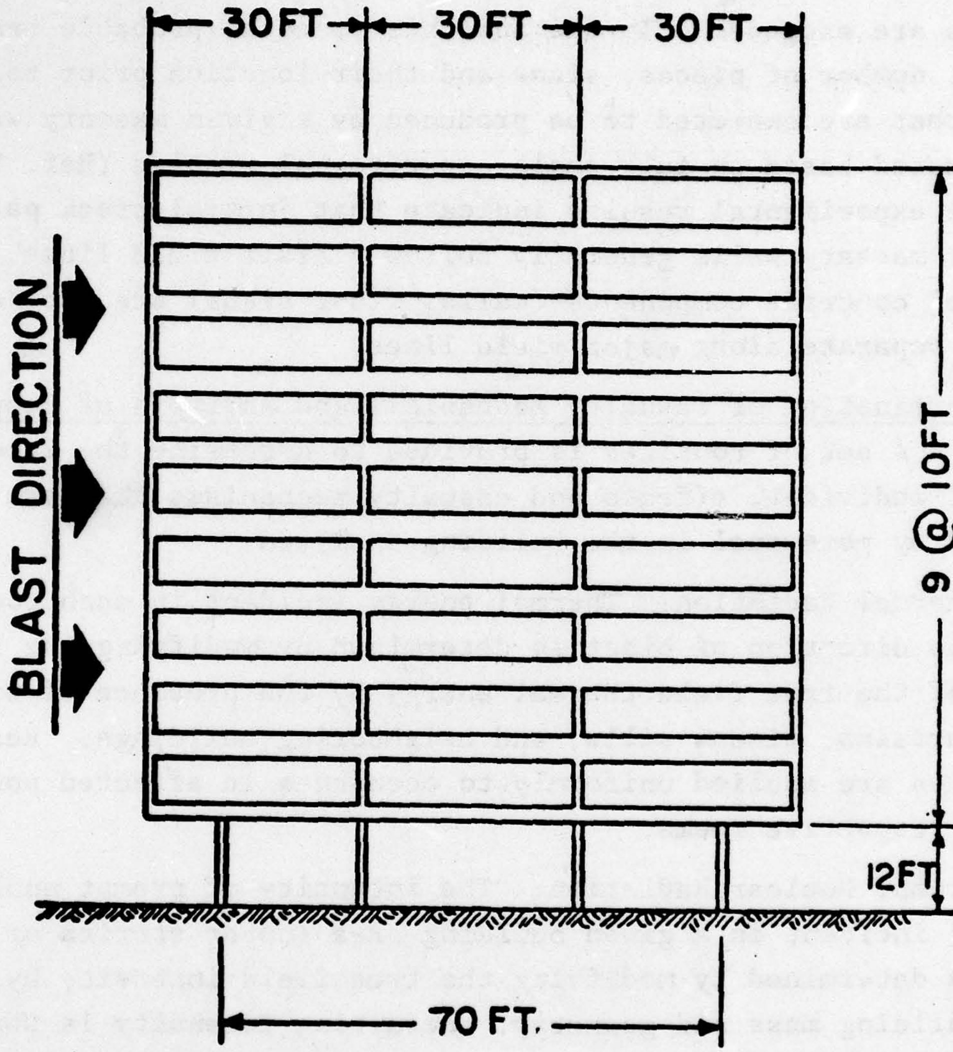


Figure 3. Sample Building

Masonry (brick, concrete block, clay tile) walls break up into a series of fragments when their incipient collapse overpressures are exceeded. In the analysis process, probable crack patterns, number of pieces, sizes and their location prior to separation that are expected to be produced by a given masonry wall are estimated based on full-scale experimental results (Ref. 9). Available experimental results indicate that initial crack patterns for masonry walls generally follow classic yield lines. Reinforced concrete components (walls, floor slabs) are also assumed to separate along major yield lines.

Determination of Casualty Mechanisms and Analysis of People Response - A set of routines is provided to determine the intensities of individual effects and casualty mechanisms that are experienced by personnel in the building analyzed.

- Thermal Radiation: Thermal energy incident in each room facing the direction of blast is determined by modifying the intensity of the free field thermal energy by the presence of window glass, curtains, window sills, and neighboring buildings. Resulting intensities are applied uniformly to occupants in affected portions of respective rooms.

- Prompt Nuclear Radiation: The intensity of prompt nuclear radiation incident in a given building area (upper stories or basements) is determined by modifying the free field intensity by the use of building mass and geometry. Resulting intensity is then applied uniformly to the occupants in the given building area.

- Interior Blast Winds: By making use of free field blast wave characteristics, building geometry, window sizes, sill heights, room geometries, incipient collapse overpressures for walls and interior partitions, diffraction impulses and dynamic pressure-time histories are computed at specified locations in the room(s) analyzed.

- Debris: Using previously determined wall fracture patterns, times to incipient collapse and average velocites at collapse, this routine determines trajectories for each debris piece comprising a given wall. Use is made of a two-dimensional (vertical plane) trajectory model which includes both the translational and rotational motions of a given piece of debris which are induced by the aerodynamic forces generated by the blast winds. Once separated from the wall, debris pieces are assumed not to break up while in flight. Also, possible interaction between debris pieces while in flight is ignored in the present procedure. Information computed includes displacements, velocities and accelerations of each debris piece.

• Blast Translation and Impact of Personnel: This routine determines the types and magnitudes of impact velocity experienced by personnel located within the building when subjected to blast winds and debris from the breakup of walls.

Blast loadings (diffraction impulses and dynamic pressure-time histories) determined previously are applied to individual persons. Individuals are simulated using a two-dimensional (vertical plane) free-flight model. Individual trajectories are computed and impact velocities (head and/or whole body) with walls and/or floor and/or ground surface are determined for comparison with casualty criteria.

Previously computed debris trajectories are compared with corresponding people trajectories for the same time intervals to see if interactions occur. If an interaction occurs, the relative velocity between the individual and debris at the point of contact is determined for comparison with casualty data. Types of interactions considered include contact with head, thorax, abdomen or limbs. Possible people with people interactions while in motion are not considered.

Analysis of People Survivability - A routine is provided to relate each of the computed hazard (dose) intensities to corresponding casualty criteria. These criteria are contained within the simulation model and are described:

• Thermal Radiation: The thermal pulse producing second and third degree burns resulting from direct exposure of the skin, reradiation and ignition of clothing and subsequent burning of the skin is considered. The probability of mortality is then related to percent of body area burned (Ref. 10 and 11).

• Prompt Nuclear Radiation: Radiation casualties from initial gamma and neutron radiation are determined in extrapolating animal data and Hiroshima and Nagasaki results. The mean lethal dose (50 percent probability of mortality) was estimated at 500 REM (Ref. 12, 13, 14 and 15).

• Primary Blast: Blast casualties due to fast rising overpressures are based on data collected from animal experiments and extrapolated by weight of species. This resulted in an estimated LD_{50} (mean lethal overpressure) of 75 psi for man (Ref. 16, 17, 18, 19 and 20).

• Blast Translation: Translation and tumbling of people by the blast winds can cause casualties with resulting impacts on hard surfaces. Impact data from animal experiments, related human free fall accident experience, and skull impact experiments resulted in mean lethal velocities for two types of impacts; head and whole body (Ref. 21, 22 and 19). The mean lethal velocities for man are estimated at 18 ft/sec for head impact and 54.4 ft/sec for whole body impact.

• Debris: Blast generated debris from building walls and contents accelerated by the blast winds may cause casualties. Three debris mechanisms were identified (Ref. 2): impulse loading related to debris momentum (MV); crushing or tearing related to debris energy (MV^2); and cutting or penetration related to energy times the square of the velocity (MV^4). Wound data for human cadavers and animals were reviewed (Ref. 23, 24, 25, 26 and 27) and casualty criteria developed as a function of mass and velocity of the debris particles.

• Acceleration: Persons in direct line of the blast jet as it enters a building are subject to possibly harmful accelerations without translation. The mean lethal dynamic pressure (q) as related to acceleration casualties is estimated at 8.7 psi (Ref. 6 and 28).

After considering these effects in context of given building parameters, the model arrives at probabilities of mortality for each effect for the building occupants. Combination of the separate effects results in a combined effects survivability estimate for the building as a whole or for various areas of interest.

2.4 Blast Wind Model

Brode's equations for the free field conditions in the Mach region of a nuclear blast (Ref. 29) may be used to estimate winds and pressures in and around an isolated building on which the blast impinges. The coupling between flowfield and failing building elements constitutes a novel feature of this analysis.

Since a point in the free field experiences a pressure-time history consisting of a shock wave which produces an overpressure Δp over ambient pressure p_i, followed by an exponential decay of p(t) over the "positive phase" duration t_p^+, it follows that the pressure-time history in a particular room exposed to this blast will consist of a shock wave increase in pressure due to shock penetration through window or door orifices followed by a short period of "filling" of the room by outside air until the room pressure equalizes with the exterior pressure. After all rooms in a particular story have reached nearly free field pressure, the flow through the story will be retarded only by the viscous dissipation of the subsonically (incompressibly) flowing air. This "flow through" phase will then persist throughout the positive phase t_p^+. Typically, 1 sec $\leq t_p^+ \leq$ 4 sec, and a single room with no outflow at the rear has a filling time $t_f \simeq V/kA$ where V = volume of room (ft^3), k = 2 ft/msec, and A = area of orifice (ft^2), giving a typical order of magnitude of 10 msec. Thus, the most significant wind-delivered impulses will be those occurring during the flow through phase.

With the flow through phase being dominant, the temptation arises to ignore the shock penetration and filling phases altogether, but this cannot be justified since the peak pressure differentials across walls occur during these phases. Wall failures are initiated by the early-time loading, and this analysis must be included to set the cracking time, t_c, of the walls. Once a wall is cracked, the model assigns as immediate loss of 15 percent of its area, and the remainder is removed by falling, so that the orifice area A(t) of a wall of height H and width W, which originally had an orifice (window or door) of area A_o, becomes

$$A(t) = A_o + [0.15 + g(t-t_c)^2/2H]\ HW\ 1(t-t_c) \tag{1}$$

where $g = 32.2\ ft/sec^2$ and $1(t-t_c)$ is the Heaviside unit step function. It should be noted that equation (1) represents a lower bound on the rate of removal of failed walls, since it ignores the streamwise separation of wall elements as they are moved downstream. Also, because A(t) has a time scale of $(H/g)^{1/2}$=0.5 sec, comparable to t_p^+, while the flow adjustment time is on the order of the room filling time, there is no need to track expansion waves produced at initial wall crackings, which provide only negligible perturbations on the quasi-steady flow impulse.

In addition to the flow through wind impulse, occupants of the room will experience shock-imparted impulses, once from the incoming shock wave, plus, depending on position in the room, possibly from the shock reflected off the rear wall. The many possible secondary diffracted shocks and impulses delivered by the high-speed but short duration jet flows of the filling phases are all crudely lumped with the shock penetration impulses by assigning

$$I = I_F + (x-x_F)\ I_R/L \tag{2}$$

as the total impulse I delivered to an object at distance x from the front of the building. Here x_F is the position of the front wall of the chamber, L is the chamber length, and I_F and I_R are the impulses imparted by the forward propagating and reflected shocks, respectively. Details of this computation are given in Reference 1.

The flow through phase winds are in the incompressible flow range for any problem in which the building has not been totally destroyed, so they are modeled using conventional orifice plate coefficients (Ref. 30). To determine the flow through a chain of orifices representing a story, one must know the driving pressure drop front-to-rear on the building. This is specified by assigning a wake pressure $p_w(t)$;

$$p_w(t) = p_{ff}(t) + C_d(q_{ff} - q_w) \tag{3}$$

where $C_d = -0.4$ is the "drag coefficient" for flow over a solid block (Ref. 14) and q_{ff} and q_w are the dynamic pressures of free field and wake, respectively. The form of equation (3) is chosen to obtain appropriate limits for flow through a story with walls gone (where $q_{ff}=q_w$, so that $p_w=p_{ff}$) and for a story with no flow through it due to solid walls (where $q_w=0$, so that $p_w=p_{ff}+C_d q_{ff}$). With these assumptions, a quadratic equation results for the volume flowrate Q(t) through the story:

$$\left\{\sum_{i=1}^{NB1}\left[r_1^2(-1+1/\alpha_i^2)/C_v^2+(2r_{i+1}^2-2r_i r_{i+1}/\alpha_i)\right] + 2 - C_d\right\}U^2-2u+C_d=0 \tag{4}$$

where i is the wall index = 1,2,...NB1 with NB1 = number of bays in story + 1; $r_i = A_{ext}/H_iW_i$; $\alpha_i = A_i(t)/H_iW_i$; and $U = Q(t)/V_{ff}A_{ext}$ with V_{ff} = free field velocity of flow and A_{ext} = area of upstream exterior face of story, including frame area. The coefficient of velocity for the orifices is C_v. Note that the flow is coupled to wall failures through the time dependence of $\alpha_i(t)$, computed from equation (1).

Once the flowrate at each station is determined from equation (4), a jet flow geometry can be specified (Ref. 1) and the interior dynamic pressure q(x,y,z,t) is known. Aerodynamic loading on objects and occupants can be computed, and the impulse from equation (2) gives initial velocities.

When the very open construction of the sample building in Figure 3 is considered, the interior winds can be obtained as a special case analytical solution. Specifically, the absence of the rear walls removes the reflected shock impulse, and there is no filling phase duration. The large constant area orifices imply a constant solution to equation (4), so that the interior wind is simply a constant factor times the free field wind.

Extensions of the interior wind analysis would be desirable in two directions: effects of nearby structures should be included if urban areas are to be realistically simulated; and the free field winds of natural origin should be considered.

The blast problem for groups of buildings contains several features for which wholly new models will have to be developed. Considering that separation distances will typically be less than building heights, it becomes clear that all shocks to which a building is exposed will be diffracted shocks. Thus, no simple free field exists below roof level. Secondly, a high density of windborne debris can be expected, producing intense, hard-to-analyze loads on upwind surfaces. In short, a statistical, highly-parameterized approach would be necessary, perhaps based on Monte Carlo runs of deterministic models of the type used here.

2.5 Personnel Response Model

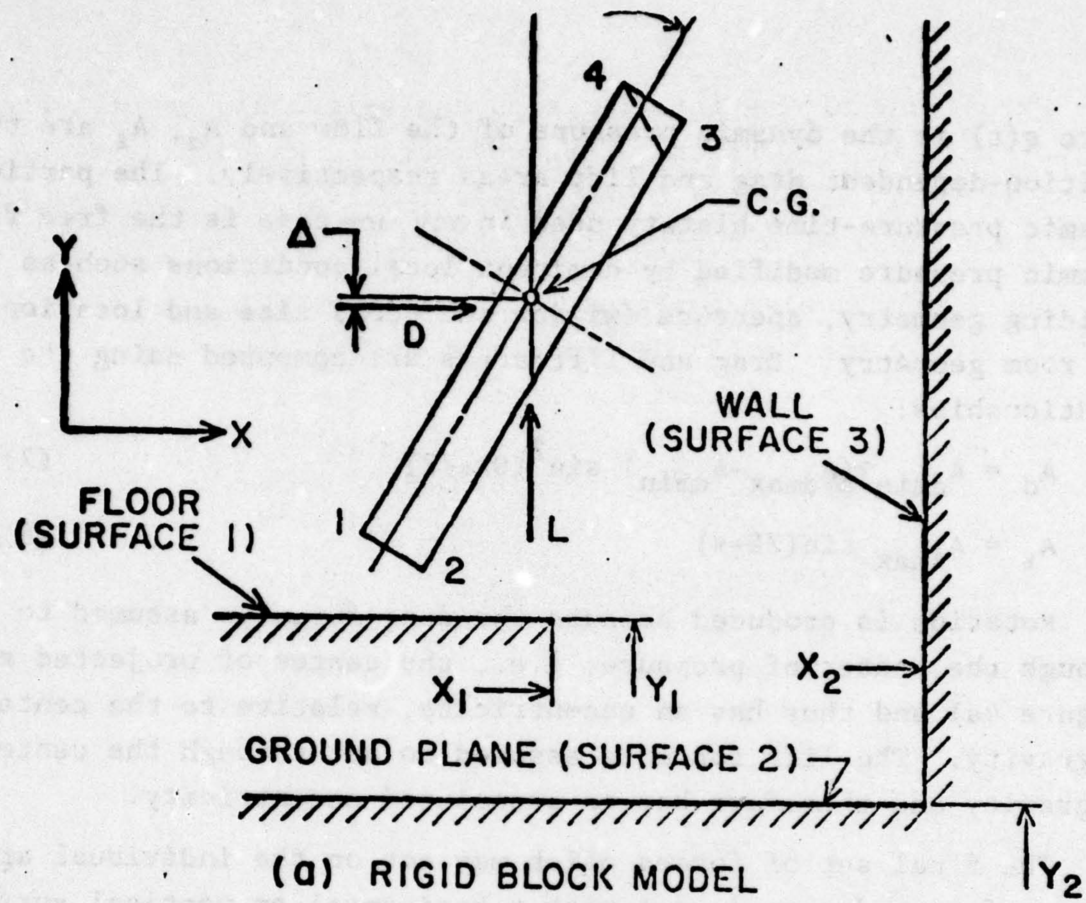
Several simulation models have been used to predict the response of building occupants in a blast wind environment. Two of these are illustrated in Figure 4.

Originally, a simple rigid block free to translate and rotate in two dimensions (vertical plane) was used to simulate the gross response of a person when subjected to blast loading. Its basic geometry is as indicated in Figure 4a. The simulated person is defined by four corner points such that points 3 and 4 define the head. The dashed line is used to identify the front and the back of the individual in the plotted output.

Under the action of blast loading a person would be subjected to diffraction, drag, lift and contact forces. Contact forces come into play when impact with the floor, wall or the ground plane occurs. Diffraction loading occurs when the shock front interacts with the individual and lasts approximately for the time required for the wave to clear around him. Drag (D) and lift (L) forces are assumed to be as indicated in Figure 4a.

$$D = q(t)\ A_d(\theta) \tag{5}$$

$$L = q(t)\ A_\ell(\theta) \tag{6}$$



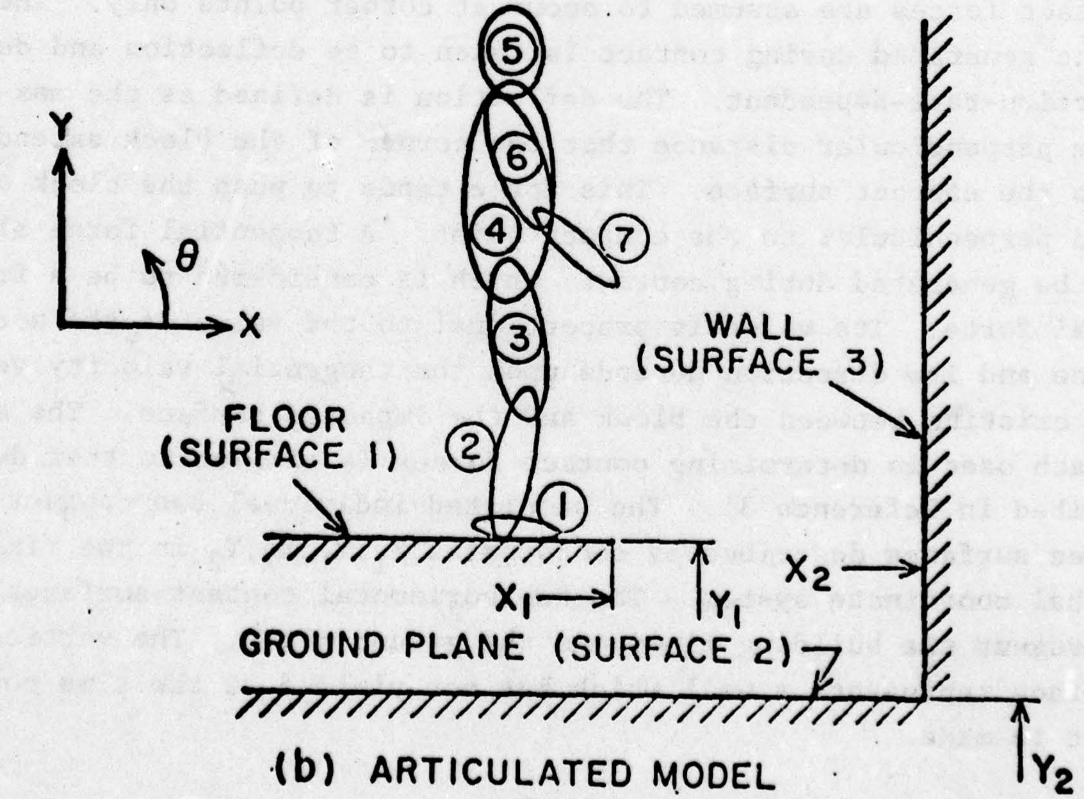


Figure 4. Mathematical Model of Man

Where q(t) is the dynamic pressure of the flow and A_d, A_ℓ are the position-dependent drag and lift areas respectively. The particular dynamic pressure-time history used in any one case is the free field dynamic pressure modified by dominant local conditions such as building geometry, aperture (window and door) size and location, and room geometry. Drag and lift areas are computed using the relationships:

$$A_d = A_{dmin} + (A_{dmax} - A_{dmin}) \sin^2(\theta - \pi/2) \tag{7}$$

$$A_\ell = A_{\ell max} \sin(2\theta - \pi) \tag{8}$$

Rotation is produced because the drag force is assumed to act through the center of pressure, i.e., the center of projected area (Figure 4a) and thus has an eccentricity, relative to the center of gravity. The lift force is assumed to act through the center of gravity and therefore has no associated eccentricity.

The final set of forces which may act on the individual are contact forces due to impact with a horizontal or vertical surface. Contact forces are assumed to occur at corner points only. The force generated during contact is taken to be deflection and deflection-rate-dependent. The deflection is defined as the maximum perpendicular distance that the corner of the block extends into the contact surface. This force tends to push the block outward perpendicular to the contact point. A tangential force also may be generated during contact, which is considered to be a frictonal force. Its value is proportional to the value of the normal force and its direction depends upon the tangential velocity vector existing between the block and the impacted surface. The approach used in determining contact forces is similar to that described in Reference 31. The simulated individual can contact three surfaces described by coordinates X_1, Y_1, X_2, Y_2 in the fixed global coordinate system. The two horizontal contact surfaces represent the building floor and the ground plane. The vertical surface represents a wall which has not yielded at the time contact is made.

In the more recent simulation model (Ref. 32) the individual is represented by means of seven elliptical cylinders interconnected at six flexible joints as shown in Figure 4b. Since only planar motions are allowed, this results in 21 degrees of freedom. As in the case of the rigid block model, forces acting on any element of the simulated man include gravity, joint, contact, aerodynamic and pressure forces. The gravity force is merely the weight of the element directed in the global negative Y direction. Each element has springs resisting motion in the local X(I) and Y(I) directions as well as torsional springs resisting rotation at each joint associated with the element. The total stiffness at a joint consists of a combination of the stiffnesses associated with the two elements joined. Force-deflection characteristics of the springs are general piecewise linear functions.

Normal and frictional contact forces acting between an element and the three possible contact surfaces are modeled as piecewise linear functions of the contact interference volume. They are assumed to act through the centroid of this volume. The contact interference volume is defined as the volume of an element that would extend beyond a contact surface if there were no deformation. Different functions are used for deformation and restoration.

Initial velocities can be applied to all or several components of the model. Aerodynamic forces are determined for each element using equations (5) and (6). The dynamic pressure is obtained for each element using its own velocity and wind parameters. Effective drag and lift areas are computed using equations (7) and (8).

Physical data describing the size, weight and joint positions of the elliptical elements were obtained from References 31, 33 and 34. These data correspond closely with the fiftieth percentile American male. Surface contact force and joint torsional spring data are approximately the same as those used in Reference 31. Since a "hard stop" was used at the ends of the range of normal motions of the joints in this reference, these torsional spring data were altered to approximate the large increase in the stiffness at these positions. Deflections in this range would ordinarily indicate injury, probably fatal in the case of the neck joint.

Figure 5 illustrates typical results using the two models. In this example a standing individual at a large window (not shown), with his back to the direction of blast is subjected to an overpressure at the range of 10 psi. Partial trajectories are given at increments of 0.1 sec. For the particular problem and physical data used, the gross response of the individual is essentially the same for both models. The articulated model provides more information on the probable casualty state of the individual.

Parametric studies utilizing the rigid block model have been conducted to examine the sensitivity of the first impact conditions on the statistical variation of parameters such as weight, height, width, moment of inertia, areas, and location of center of gravity. Generally impact conditions are not very sensitive to expected parameter variations. The validity of multiple impact conditions is indefinite due to the uncertainty of the response detail during the initial contact, and the somewhat unrealistic assumption of a rigid body. This aspect is discussed in Reference 35.

Development of the articulated man model represents an attempt to overcome such limitations and uncertainties. However, it is not clear that any real gain in the quality of the transport information or the details of the impact conditions is obtained. A more realistic motion appears to exist and a better geometric appearance is evident. Nonetheless the substantial increase in the number of degrees of freedom used to describe the motion requires the introduction of a rather large number of connection parameters, the character and values of which are not well defined. The magnitudes of the aerodynamic forces acting on each element of the model are complex functions of the collective orientation of all the elements. These shielding and interaction effects have not yet been adequately described. Under some conditions, voluntary internal forces may exist and thus influence certain aspects of the motion. For example, instead of the man falling over he may literally run with the wind or just squat down on the floor.

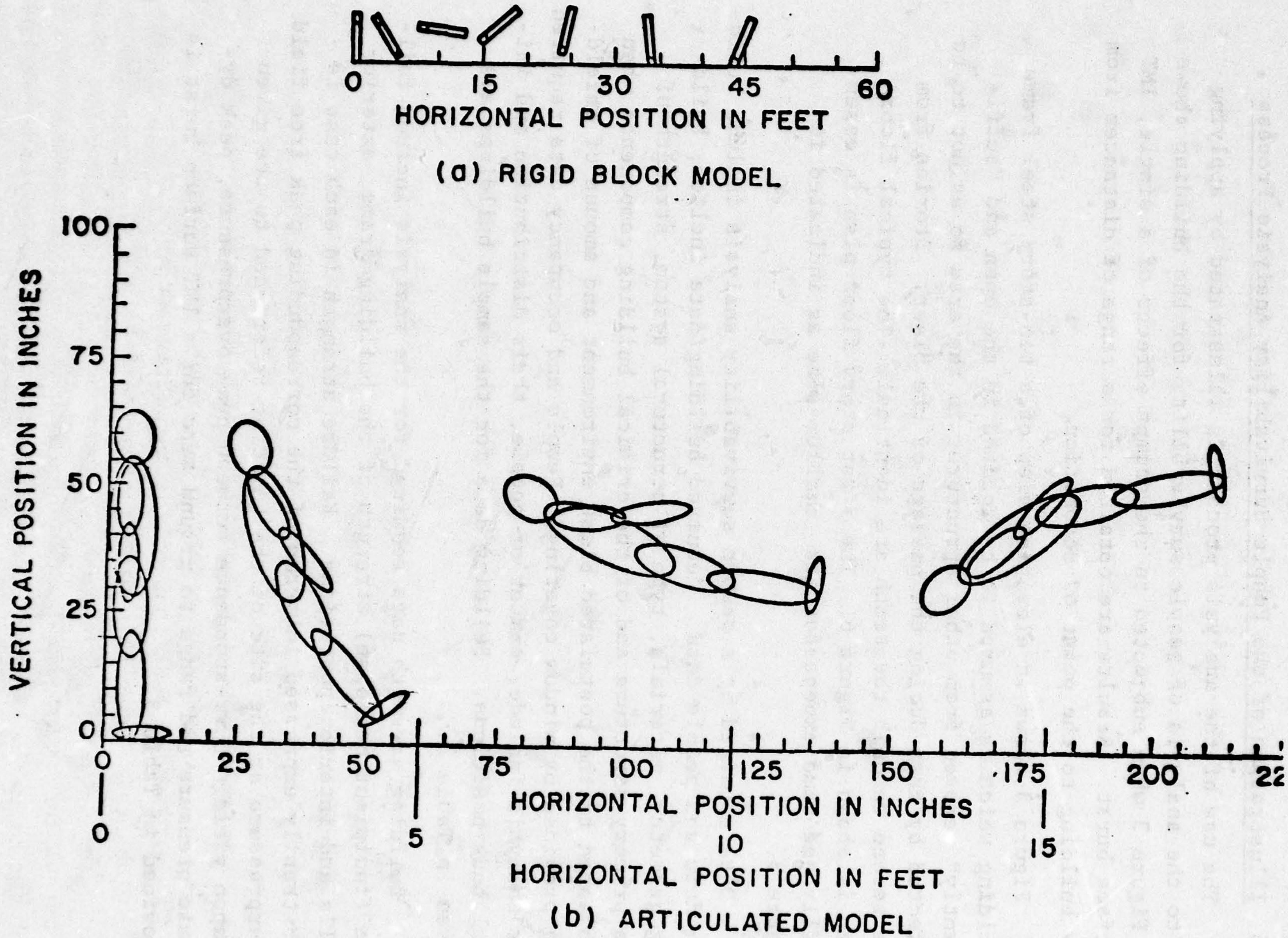


Figure 5. 10 psi Blast Trajectory

2.6 Illustration of the People Survivability Analysis Process

The use of the analysis process is illustrated by applying it to the analysis of people survivability for the building shown in Figure 3 when subjected to the prompt effects of a single, 1MT surface burst. Results are obtained for a range of distances from the building to the point of detonation.

Figure 3 shows an elevation view of a ten-story steel frame building which is assumed to be located in the open and "sufficiently" removed from other structures in the area so as not to be affected by them during the passage of the blast. Stories from the second through the tenth are identical. The typical floor plan is shown in Figure 6. The first story floor plan is essentially the same except for its smaller size as indicated in Figure 3.

Data required by a people survivability analysis include building data and people data. Required building data include; building geometry, materials, type of structural system, strength of the primary structure and of the critical building components when subjected to the postulated blast environment and amount of shielding provided by window covering. People and occupancy data required for analysis include; number of people, their distribution and initial body positions. Building data for the sample buildings are given in Table 2.

Building strength data required for the analysis include failure (incipient collapse) strength of the building frame, exterior walls and interior partitions. Failure strength in each case is arbitrarily expressed in terms of the corresponding peak free field overpressure at the site of the building referenced to the given weapon yield. Correspondence between peak overpressure, peak dynamic pressure and range to ground zero for a 1MT surface burst is provided in Table 3.

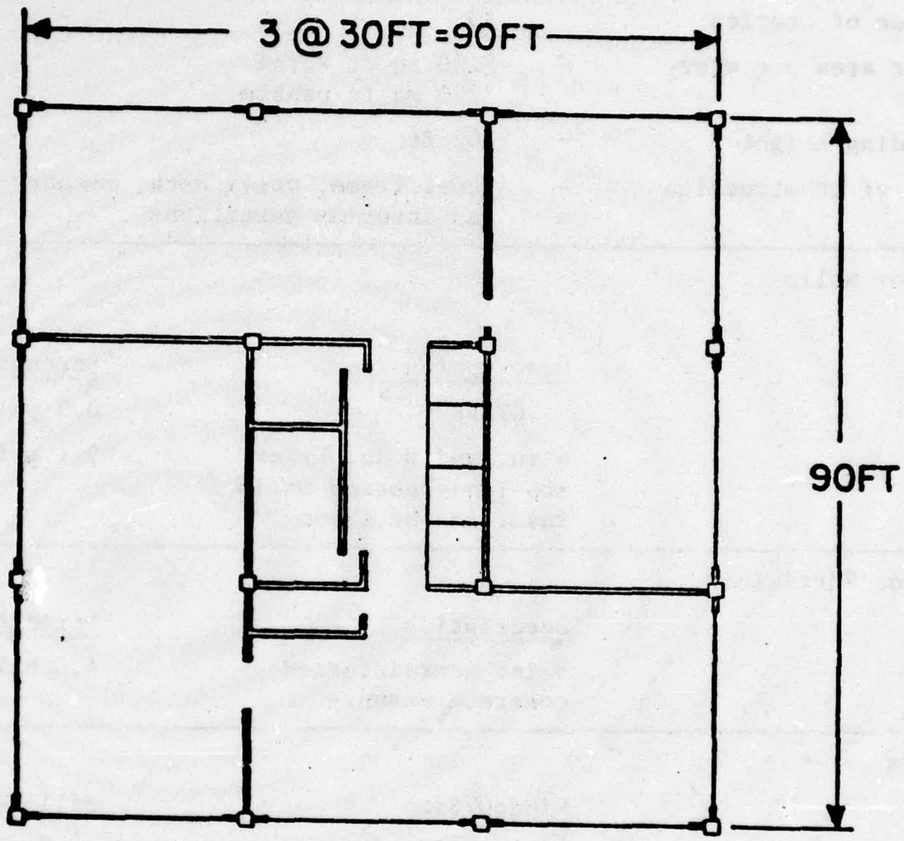


Figure 6. Typical Upper Story Floor Plan

TABLE 2. BUILDING DATA

1. Building Description

• Number of stories		10
• Floor area per story	-	8100 sq ft total 7200 sq ft usable
• Building height	-	102 ft
• Type of construction	-	Steel frame, steel deck, masonry walls and interior partitions

2. Exterior Walls

Story	Description	Strength*
1	Glass	0.5 psi
2 to 10	4 in. and 8 in. brick non-load-bearing walls inset in the frame	9.1 psi

3. Interior Partitions

Story	Description	Strength*
1 to 10	8 in. nonreinforced concrete masonry	4.0 psi

4. Windows

Story	Window Size	Sill Height
1	12 ft by 30 ft	0 ft
2 to 10	7 ft by 30 ft	3 ft

* Incipient collapse overpressure based on normal to the plane of the wall blast loading.

TABLE 3. 1MT SURFACE BURST BLAST CHARACTERISTICS

Peak Free Field Overpressure, psi	Peak Free Field Dynamic Pressure, psi	Range to Ground Zero, Miles
4	0.37	3.14
8	1.44	2.08
12	3.13	1.67
16	5.38	1.44
20	8.14	1.29

As indicated in Table 2, upper story building walls facing the direction of blast (Figure 3) are estimated to be at the point of incipient collapse at 9.1 psi. Corresponding overpressure for the interior partitions is 4 psi. This is a framed building with moderately strong walls, though large window areas and is therefore considered to be primarily diffraction sensitive. For the range of overpressures relevant to this problem (up to about 16 psi) the building will lose its windows, exterior walls and interior partitions. However, the building frame is not expected to collapse.

People are assumed to be uniformly distributed in all building areas at approximately 10 sq ft per person and both the "initially prone" and the "initially standing" cases are examined. In the context of this analysis the initially standing case is considered to represent the condition when no warning is given. The initially prone case represents limited evasive action corresponding to limited warning time. In this example problem people are simulated using the "rigid block" model shown in Figure 4a.

Results are given in Figure 7. They represent total (combined) survivors taking into account all relevant prompt effects. They were obtained by selecting discrete overpressure levels, computing percent survivors for the individual effects, combining individual results and connecting the points with straight lines. Conceivably smoother curves would be produced with a larger number of discrete points. The individual effects results on which the results of Figure 7 are based are given in Figure 8. These results are briefly discussed.

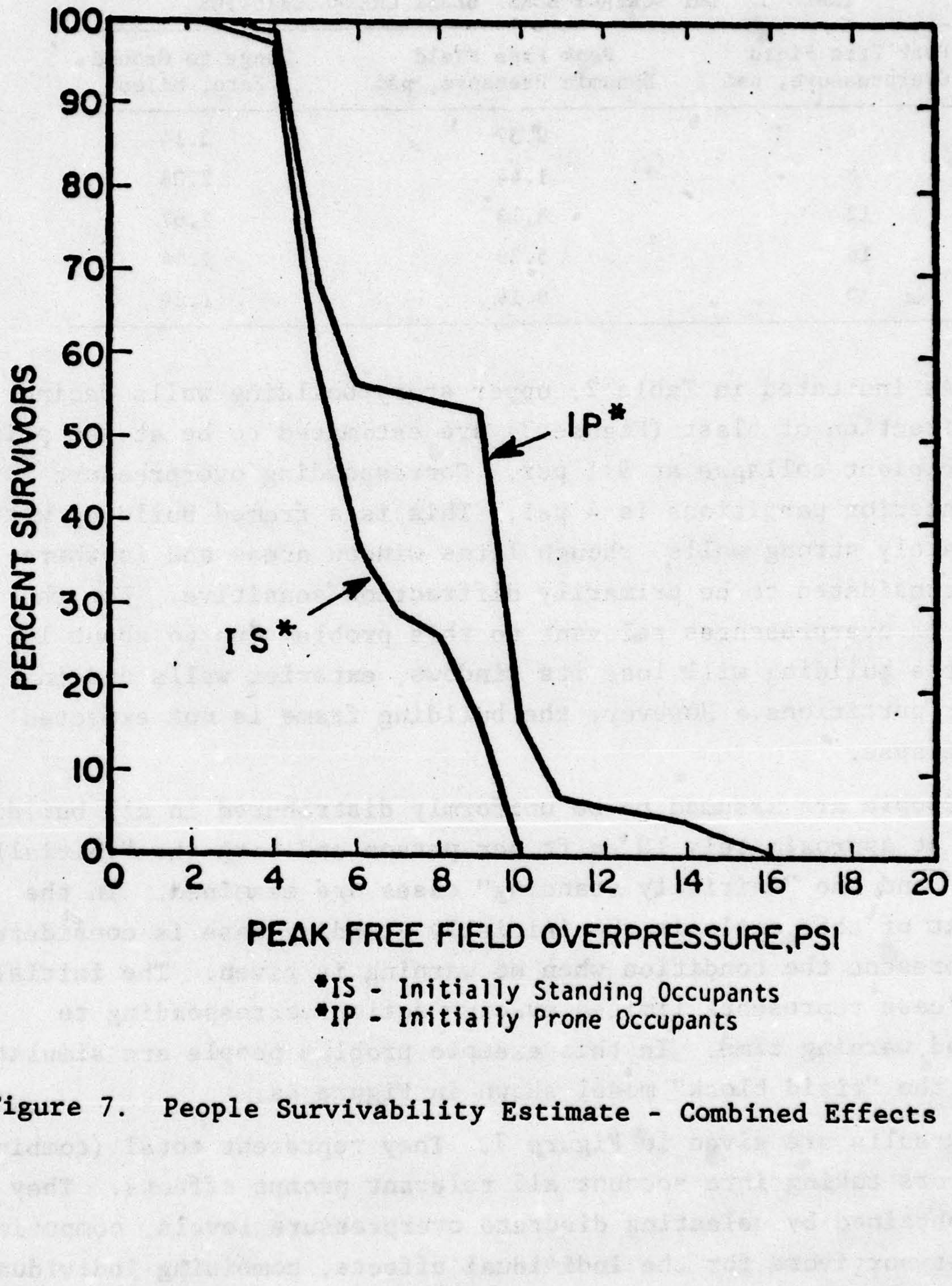


Figure 7. People Survivability Estimate - Combined Effects

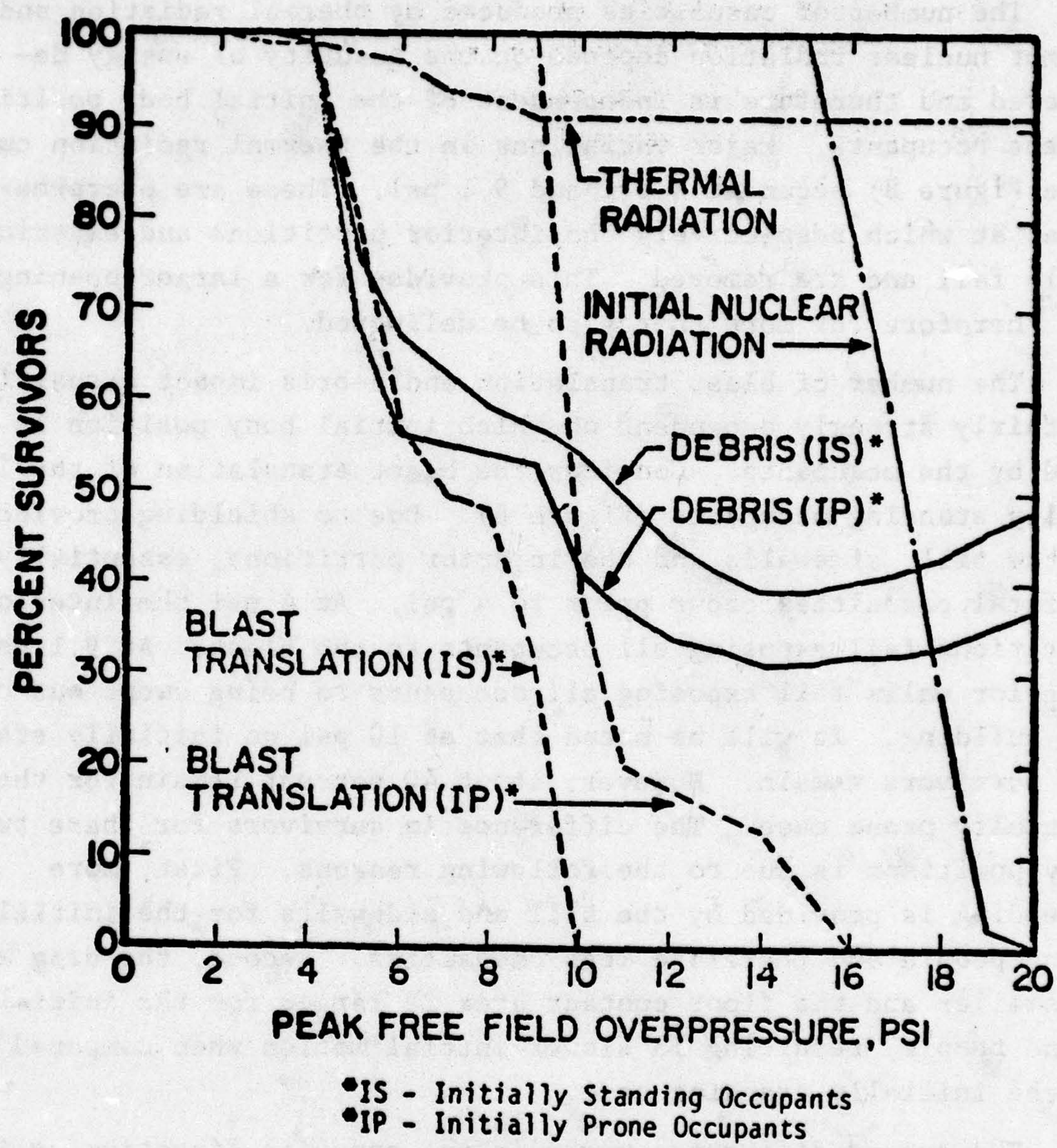


Figure 8. People Survivability Estimate - Individual Effects

The number of casualties produced by thermal radiation and prompt nuclear radiation depends on the quantity of energy delivered and therefore is independent of the initial body positions of the occupants. Major variations in the thermal radiation curve (see Figure 8) occur at 4 psi and 9.1 psi. These are overpressures at which respectively the interior partitions and exterior walls fail and are removed. This provides for a larger opening and therefore for more energy to be delivered.

The number of blast translation and debris impact casualties is fairly strongly dependent on which initial body position is used by the occupants. Consider the blast translation of the initially standing occupants (Figure 8). Due to shielding provided by the sill, sidewalls and the interior partitions, essentially no fatal casualties occur prior to 4 psi. At 4 psi the interior partitions fail exposing all occupants to the blast. At 9.1 psi exterior walls fail exposing all occupants to being swept out of the building. It will be noted that at 10 psi no initially standing survivors remain. However, about 40 percent remain for the initially prone case. The difference in survivors for these two body positions is due to the following reasons. First, more shielding is provided by the sill and sidewalls for the initially prone people and therefore less casualties. Second, the drag area is smaller and the floor contact area is larger for the initially prone people, resulting in slower initial motion when compared to the initially standing case.

The second difference works in the opposite direction as far as debris impact is concerned. Initially standing people are translated by the blast faster than the initially prone people, resulting in less interaction with debris. One reason for the upswing in the debris curves (see Figure 8) at higher overpressures is that debris tend to be translated further before impacting the floor. This reduces interaction with building occupants.

Results produced allow for the rating of individual building areas and the relative effectiveness of evasive action. Such results can also be used for rating individual buildings relative to protection afforded.

2.7 Summary and Conclusions

Conventional buildings constitute the only viable, current sheltering resource. In providing for population safety in the event of an emergency, the civil defense planner is faced with several difficult problems. One is to identify the best available shelter space in various buildings in his particular locality. Another is to identify modes of evasive action that can effectively be used by building occupants so as to enhance the inherent protective capabilities of these buildings. A third is decide which buildings warrant being upgraded and in what manner so as to provide the required protection. The goal is to save lives and provide for continuity of the community in complex, multieffect situations, i.e., prompt and indirect effects of nuclear weapons, and natural disasters such as earthquakes, hurricanes and tornados.

A reliable building classification and rating system is needed, that can be quickly and effectively used at the local level by nonengineers for the purpose of classifying individual buildings in accordance with their overall protective capabilities and for the rating of the various spaces within them using an easy to apply ranking procedure. The task of developing effective, easy to apply tools is a difficult one. Numerous building types vary according to the socioeconomic function, geographic location, local building codes, year of construction, whim of the architect, etc. On the commercial or the professional plane a building classification system that identifies and categorizes the salient features of buildings in desirable detail, and one that can be used as a starting point for developing the classification and rating system described does not exist at this time.

Some believe that integrity of the building primary structural system is a good indicator of its inherent protective capabilities. This is not generally true. This is amply demonstrated in several recent natural disasters (Ref. 36) where the primary structure survived and numerous persons were killed or injured by so-called nonstructural items such as failed masonry partitions and ceilings. A classification system which uses the strength of the primary structure as a rating base can lead to serious errors.

The simulation model bypasses many of these difficulties. Assuming that representative buildings can be surveyed as described in Reference 37, this simulation model can be used to develop a reliable classification system after analyzing a sufficiently large and representative sample. It can be used for the judging of the relative merits of various modes of evasive action and the adequacy of various shelter upgrading concepts.

The problem is one of establishing relative safety in a complex, multihazard environment. For stated purposes the model is considered to be sufficiently valid and adequate.

3. SUMMARY OF PEOPLE SURVIVABILITY ESTIMATES

3.1 People Survivability in the Upper Stories of Large Buildings

3.1.1 Introduction

In 1972 DCPA supported a survey which produced (Ref. 37) detailed data on the physical makeup of 219 buildings of the type surveyed in the NFSS. This sample contained mostly large engineered buildings which in terms of use-classes included office buildings, hotels, schools, apartment buildings, etc. Fifty buildings were subsequently selected from this sample and analyzed to determine the extent of protection provided when the hazard environment consists of direct effects produced by the detonation of a megaton range nuclear weapon exploded at the ground surface. The analysis was performed using the BUILDINGS computer program previously described in Chapter 2 of this report. Results are presented in Reference 38 and are summarized and discussed here in updated form. The building sample considered is described in Table 4.

TABLE 4. CATEGORIZATION OF BUILDINGS IN THE SAMPLE

Building Type	Exterior Wall Type	Frame Type	Number in Sample
1 Framed	NLBW-A*	Steel	11
		R/C	12
		Steel-R/C	4
	NLBW-NA	Steel	6
		R/C	2
	R/C	R/C	1
			36
2 Combination	LBW	Steel	5
		R/C	6
			11
3 Load-bearing	LBW	-	3
TOTAL			50

*NLBW-A - nonload-bearing with arching support conditions
NLBW-NA - nonload-bearing and nonarching (i.e., a curtain wall)
R/C - reinforced concrete
LBW - load bearing

3.1.2 Summary of Results

Results are summarized in Table 5. In this table the buildings are arranged in the order of their "survey identification numbers". Percent survivors (50, 10 and 90) in each building are related to corresponding hazard environments in terms of the free field overpressure at the building site. The three percentages of survivors were chosen to facilitate an initial comparison of people survivability for this set of buildings. Complete curves from which these values were taken are included in Reference 37. Additional information describing these buildings in Table 5 includes the following:

- Number of stories
- Type of building frame
- Types of exterior walls
- Average wall strength (in terms of incident free field overpressure)
- Average window (aperture) percentage
- Type of floor over the basement (where basements exist)
- Average strength of the floor system over the basement (in terms of incident free field overpressure)

Average values referred to are weighted averages for up to the first four stories of each building. Floors higher than the fourth were not considered viable shelter areas against the effects of blast. Types of exterior walls were classified in four general categories, i.e., nonload-bearing with arching support conditions (NLBW-A), nonload-bearing and nonarching (NLBW-NA) (i.e., a curtain wall), load-bearing (LBW), and reinforced concrete (R/C).

BUILDINGS computer program does not have the capability of considering overall building failure (overturning, instability) as a casualty mechanism and therefore in the original people survivability evaluation (Ref. 37) this aspect was not considered. In a subsequent study (Ref. 35) a simplified building failure analysis was formulated and applied to this set of buildings. Results given in Table 5 therefore include the influence of overall building failure as a casualty mechanism. It is emphasized however that

TABLE 5. PEOPLE SURVIVABILITY SUMMARY

Building Number and Name	Upper Floor Survivability						Basement Survivability			Building Characteristics						
	50%		10%		90%											
	Initially Standing	Initially Prone	Initially Standing	Initially Prone	Initially Standing	Initially Prone	50%	10%	90%	Number of Stories	Building Frame Type	Exterior Wall Type	Wall Strength, psi	Percent Apertures	First Floor Type	First Floor Strength, psi
6 Rindge Technical School	8.0	13.5	11.7	16.7	5.1	10.2	3.8	4.3	3.0	5	Steel	LBW	15.4	39.0	Concrete flat slab	3.8
7 St. Francis School	8.8	13.7	11.9	18.2	5.0	13.1	-	-	-	2	RC	NLBW-A	15.2	41.0	-*	-
13 Leavitt's Department Store	6.0	12.8	10.6	12.8	4.3	4.6	8.7	14.6	6.6	5	Steel	NLBW-A	27.9	75.0	Concrete joist/ Steel beams	12.4
20 Fort Dix Barracks	4.4	6.1	8.6	12.4	3.2	4.3	12.2	15.1	9.6	3	RC	NLBW-A	4.0	34.4	Concrete slab/ concrete beam	12.2
29 Co-op City Building 23	4.6	5.0	8.0	9.6	3.4	3.2	5.3	6.3	3.6	33	RC	NLBW-A	3.2	29.9	Concrete flat plate	3.6
33 P.S. 116	7.2	11.6	11.0	15.4	5.0	8.5	-	-	-	4	-	LBW	13.5	20.0	-	-
35 Nassau County Executive Bldg.	7.5	7.5	7.5	7.5	5.5	7.5	9.7	11.0	8.9	5	RC/Steel	NLBW-A	9.5	25.0	Concrete slab/ steel beams	10.4
36 Office Building	4.3	8.5	6.9	13.5	2.5	5.0	8.8	12.6	4.0	41	Steel	NLBW-NA	1.0	100.0	Concrete slab/ steel beam	10.8
37 Chase Manhattan Bank	3.7	9.3	5.7	11.6	2.4	5.9	30.5	38.8	20.8	61	Steel	NLBW-NA	1.0	100.0	Concrete slab/ steel beam	32.9
44 School for the Deaf	6.7	9.6	9.5	12.0	4.8	9.0	4.7	5.7	3.8	6	Steel	NLBW-A	9.1	40.3	Concrete slab/ steel beam	4.7
51 RCA Building	2.0	2.0	2.0	2.0	2.0	2.0	18.0	20.0	7.0	69	Steel	NLBW-A	9.4	45.0	Concrete slab/ steel beam	18.3
55 J. C. Penney Building	3.8	8.8	6.7	10.8	2.5	5.8	13.0	17.5	10.4	46	Steel	NLBW-NA	1.0	50.0	Concrete slab/ steel beam	10.7
56 Gracie Green Apartment Bldg.	3.6	6.3	6.1	10.5	2.4	3.7	7.1	9.0	5.8	21	RC	NLBW-A	3.0	40.2	Concrete slab/ concrete beams	7.1
62 Atlantis Building	6.4	9.4	9.5	14.1	4.3	7.1	-	-	-	13	RC	NLBW-A	1.5	25.0	-	-

* Indicates that the building has no basement.

TABLE 5. PEOPLE SURVIVABILITY SUMMARY (continued)

Building Number and Name	Upper Floor Survivability 50% Initially Standing	Upper Floor Survivability 50% Initially Prone	Upper Floor Survivability 10% Initially Standing	Upper Floor Survivability 10% Initially Prone	Upper Floor Survivability 90% Initially Standing	Upper Floor Survivability 90% Initially Prone	Basement Survivability 50%	Basement Survivability 10%	Basement Survivability 90%	Building Characteristics: Number of Stories	Building Frame Type	Exterior Wall Type	Wall Strength, psi	Percent Apertures	First Floor Type	First Floor Strength, psi
63 Amityville Jr. High	5.8	9.2	8.3	15.0	4.2	7.6	6.3	11.0	5.0	3	Steel	NLBW-NA	1.0	50.0	Concrete slab/ steel joist	5.9
66 West Dormitory Building	5.9	6.3	8.0	8.5	5.1	5.2	8.1	27.8	7.0	3	-	LBW	6.2	26.0	Concrete flat slab	8.1
76 Garfinkel's Department Store	4.8	4.8	4.8	4.8	4.8	4.8	8.0	10.0	5.5	9	Steel	NLBW-A	32.6	35.0	Concrete slab/ concrete joist	8.0
81 Federal Office Building	7.0	14.0	11.2	15.6	5.1	10.6	5.5	5.9	4.0	10	RC	NLBW-NA	12.4	60.0	Concrete slab/ concrete joist	4.5
84 Saratoga Municipal Building	5.9	9.0	8.6	12.4	4.5	6.6	9.0	10.5	7.5	8	RC	NLBW-A	1.0	60.0	Concrete flat slab	7.5
89 Water Department Building	9.1	10.5	9.8	12.0	6.2	10.0	-	-	-	2	RC/Steel	NLBW-A	10.0	22.0	-	-
93 Sears Roebuck Store	5.8	13.4	9.4	15.5	4.5	5.6	8.4	9.3	6.5	3	RC/Steel	NLBW-A	5.5	15.0	Concrete flat slab	6.8
114 Blue Mountain Academy	5.6	7.6	9.2	14.1	4.0	3.5	5.7	6.8	4.6	1	Steel	NLBW-NA	1.0	48.0	Concrete joist/ concrete beams	5.7
119 Royal Globe Insurance Bldg.	1.6	1.6	3.9	4.3	1.1	1.1	-	-	-	2	Steel	LBW	2.0	13.6	-	-
129 Harbour House South Bldg.	3.9	7.1	8.7	12.6	2.2	4.1	2.7	4.2	2.0	14	RC	NLBW-NA	1.0	60.0	Concrete flat plate	2.5
130 Physics-Astronomy Building	6.2	9.8	9.4	16.6	5.2	6.4	4.7	5.5	3.8	3	RC	NLBW-A	5.5	20.0	Concrete slab/ concrete joist	3.5
132 Jackson Hill Church	5.3	6.2	7.3	9.9	4.2	4.4	-	-	-	4	Steel	LBW	6.5	25.0	-	-
136 First Federal Savings & Loan	6.9	9.5	9.5	15.0	5.2	7.2	3.4	3.8	2.6	4	RC	NLBW-A	6.4	25.0	Concrete slab/ concrete joist	2.5
138 U.S. Post Office Building	2.5	2.5	2.9	2.9	2.1	2.1	8.0	12.0	5.0	1	-	LBW	2.8	25.0	Concrete joist/ concrete slab	8.9
139 Davidson College Church	8.6	16.7	16.4	19.5	4.7	5.1	-	-	-	2	Steel	NLBW-A	22.5	19.3	-	-

TABLE 5. PEOPLE SURVIVABILITY SUMMARY (continued)

Building Number and Name	Upper Floor Survivability						Basement Survivability			Building Characteristics						
	50%		10%		90%											
	Initially Standing	Initially Prone	Initially Standing	Initially Prone	Initially Standing	Initially Prone	50%	10%	90%	Number of Stories	Building Frame Type	Exterior Wall Type	Wall Strength, psi	Percent Apertures	First Floor Type	First Floor Strength, psi
140 Sunrise Towers	6.9	11.0	9.9	16.6	4.5	7.5	-	-	-	11	RC/Steel	NLBW-A	3.6	20.0	-	-
143 Extendicare Knoxville	6.0	9.0	9.0	14.5	4.4	6.9	-	-	-	1	RC	LBW	2.9	20.0	-	-
146 Marine Drive Apartments	6.1	7.8	7.6	10.0	4.2	6.6	9.7	14.7	5.5	20	RC	NLBW-A	4.4	85.0	Concrete slab/ concrete beam	9.0
147 Racquet Club Building	7.7	15.1	20.0	20.0	0.5	0.5	5.0	6.0	4.0	6	Steel	LBW	24.9	19.2	Concrete slab/ steel beam	5.0
152 Standard Club Building	3.0	3.0	3.0	3.0	3.0	3.0	4.9	19.2	3.2	11	Steel	NLBW-A	15.7	45.4	Concrete joist/ steel beam	5.1
160 Commonwealth Edison Building	8.3	8.3	8.3	8.3	6.3	8.3	17.8	20.8	12.5	3	Steel	NLBW-A	38.0	23.0	Concrete slab/ steel beam	16.3
161 American Red Cross Building	6.0	8.9	8.6	11.5	5.2	6.7	16.5	18.2	9.5	1	Steel	NLBW-A	5.7	10.0	Concrete slab/ steel beam	17.0
168 National Brewing Co. Bldg.	4.9	5.9	8.7	12.6	4.2	4.3	10.6	12.7	7.8	3	Steel	NLBW-A	4.6	21.7	Steel joist/ concrete slab	9.8
171 Maple Manor Building	7.2	8.8	9.0	11.5	4.5	7.0	-	-	-	1	RC	LBW	2.4	20.0	-	-
177 Willmar High School	1.6	1.6	5.5	8.1	1.1	1.1	8.5	12.3	6.2	3	RC	LBW	1.2	53.3	Concrete joist/ concrete slab	7.4
179 City-County Building	4.8	6.6	8.4	13.2	4.2	4.3	10.6	12.6	8.8	8	Steel	NLBW-A	4.2	51.5	Concrete joist/ steel beam	10.6
195 May Advertising Building	5.7	8.6	8.7	11.9	4.3	4.9	-	-	-	1	RC	LBW	1.9	20.0	-	-
198 Kallison Towers Building	7.2	15.0	10.2	16.7	4.4	7.1	5.8	7.1	4.4	10	RC	RC	8.0	68.5	Concrete joist/ concrete slab	5.8

TABLE 5. PEOPLE SURVIVABILITY SUMMARY (concluded)

Building Number and Name	Upper Floor Survivability						Basement Survivability			Building Characteristics						
	50%		10%		90%											
	Initially Standing	Initially Prone	Initially Standing	Initially Prone	Initially Standing	Initially Prone	50%	10%	90%	Number of Stories	Building Frame Type	Exterior Wall Type	Wall Strength, psi	Percent Apertures	First Floor Type	First Floor Strength, psi
202 Instrumentation Office Bldg.	6.8	7.0	20.0	20.0	6.2	6.2	-	-	-	1	Steel	LBW	18.8	0	-	-
204 Brady Moving and Storage	11.5	12.4	15.7	15.9	7.7	11.2	19.5	21.6	11.0	6	RC	NLBW-A	11.6	10.0	Concrete flat slab	54.1
207 Hanover Public School	7.6	11.3	9.7	14.7	5.0	8.3	-	-	-	2	RC	LBW	8.6	20.0	-	-
212 Edison Brothers Stores Bldg.	5.8	7.6	8.7	12.6	4.4	5.4	4.2	5.1	3.2	13	RC	NLBW-A	5.9	62.0	Concrete flat slab	4.2
223 Biltmore Hotel	10.0	12.4	12.4	12.4	5.7	12.4	5.2	6.3	3.6	14	Steel	NLBW-A	34.4	25.0	Concrete slab/ concrete beam	4.0
228 Starkman Building	4.3	10.2	8.9	15.4	2.6	6.4	6.3	7.4	5.0	5	Steel	NLBW-NA	1.0	50.0	Concrete slab/ steel joist	4.5
239 Stanford Hospital-West	8.4	8.6	8.9	9.0	7.3	8.1	10.7	12.9	8.5	3	RC	NLBW-A	8.3	16.7	Concrete hollow slab	10.7
250N Arthur Hall Dormitory	4.4	7.9	8.8	15.2	2.5	4.6	-	-	-	4	RC	LBW	2.7	15.0	-	-

NOTE: NLBW-A - Nonload-bearing Wall-Arching; NLBW-NA - Nonload-bearing Wall-Nonarching; LBW - Load-bearing Wall the method used was very approximate. These results should therefore be verified using a more detailed analysis method.

3.1.3 Discussions of Results

Results given here are average values for up to four stories of each building considered. They were obtained using the BUILDINGS computer program on the basis of proportionally averaged data. For each story the data included the following parameters.

Type of exterior walls
Length and width of the building
Percent windows, i.e., (window area/gross wall area)x 100
Window sill height
Room height
Distance to first interior wall
Failure overpressure for exterior and interior walls

People were assumed to be uniformly distributed in all normally usable building areas. Therefore they did not preferentially occupy the better shelter space. In this sense the results are conservative. Assuming uniform distributions of people in each case allows for a consistent comparison of protective capabilities between individual buildings.

Only one mode of evasive action was examined, i.e., the advantage of taking a prone position relative to remaining standing.

For these reasons the results should be treated as being average, conservative and not fully representative of the sheltering potential of these buildings. Clearly, a given building does not provide uniform protection in all of its areas; the first story is likely to afford more protection than the fourth simply by virtue of elevation; unexposed building core areas are likely to provide more protection than exposed peripheral areas. People are not expected to be located in all building areas and possible modes of evasive action are not limited to lying down.

An attempt was made to gauge the significance of the various building parameters on people survivability. This was done by means of a regression analysis. Due to limitations imposed by the small size of the building sample, it was possible to consider only the following relationships, i.e.,

- mean survivability versus exterior wall strength,
- mean survivability versus percent windows

for each of the following building categories. i.e.,

Steel framed buildings
R/C framed buildings
Framed buildings with arching walls
Framed buildings with nonarching walls
All framed buildings
All combination buildings (framed and load-bearing)
Load-bearing buildings
All buildings

Wall strength was found to be the most significant parameter. The distinction between the above building categories relative to survivability was found to be weak. Whether a distinction exists or not could not be determined on the basis of this sample.

Average values of free field overpressure corresponding to 10, 50 and 90 percent survivors for four building categories characterized by the type of exterior wall are summarized in Table 6 and plotted in Figure 9. R/C wall category is not plotted since the sample contains only one building.

TABLE 6. PEOPLE SURVIVABILITY AVERAGES (UPPER FLOORS)
(Overpressure Levels at Indicated Percent Survivors)

Exterior Wall Type	Number in Sample	50%		10%		90%	
		Standing	Prone	Standing	Prone	Standing	Prone
1 NLBW-A	27	6.4	8.8	9.0	11.9	4.7	6.5
2 NLBW-NA	8	4.8	9.3	8.2	13.6	3.2	6.1
3 LBW	14	5.5	7.9	9.7	12.4	3.7	5.1
4 R/C	1	7.2	15.0	10.2	16.7	4.4	7.1
Average Upper Floors	50	5.9	8.8	9.1	12.4	4.2	6.1

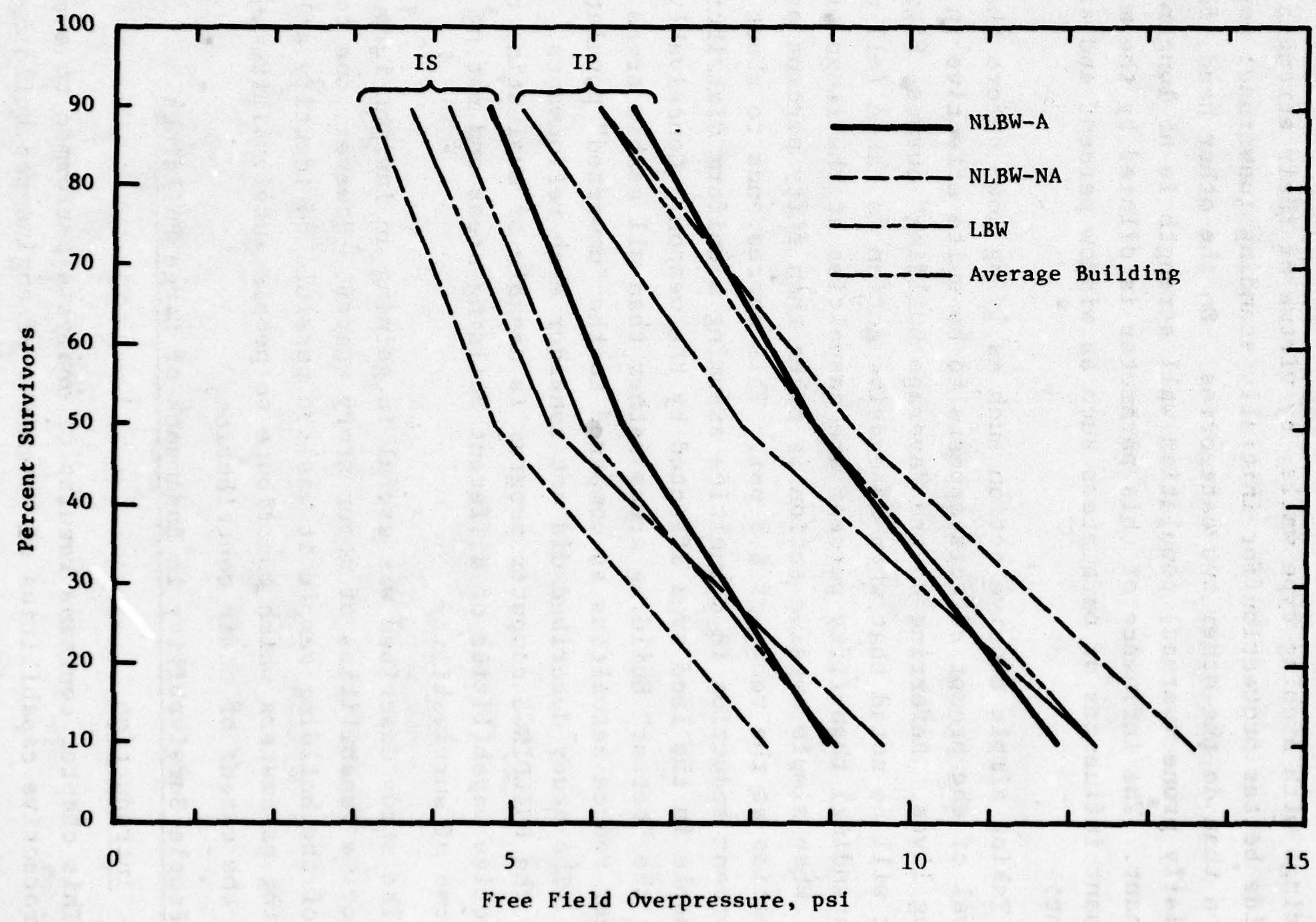


Figure 9. Average People Survival Estimates for Three Categories of Buildings

Referring to Figure 9 it will be noted that for the most part, buildings with arching type walls, by virtue of their strength, provide better protection for initially standing (unwarned) population than do the other two categories. On the other hand, for initially prone (warned) population wall strength is no longer dominant. The influence of this parameter is diluted by the more dominant influences of parameters such as window percent and sill height.

Taking simple evasive action such as lying down before the arrival of the prompt effects appears to be quite effective in saving lives. Referring to the "average building" curves, Figure 9, it will be noted that when no evasive action is taken (all people are standing) then fifty percent are casualties at the range of 5.9 psi. When simple evasive action is taken then fifty percent are casualties at the range of 8.8 psi. This corresponds to about a 36 percent reduction in casualties assuming a uniform distribution of people in the land area affected by the weapon. Conceivably, using the "better" building areas rather than all usable areas would further reduce casualties as compared to the "unwarned" population case. The study described did not consider such refinements. However, the BUILDINGS computer program is capable of evaluating the protective capabilities of different building areas and rating them in terms of survivability.

The study described was useful in gaining an insight into the protective capabilities of upper story spaces. However, due to the size of the building sample it was not possible to identify all building parameters which contribute to people survivability and to gauge the extent of their contribution.

3.2 People Survivability in Basements of Large Buildings

3.2.1 Introduction

This chapter contains results of analysis performed to evaluate the protective capabilities of basements of engineered buildings against the prompt effects produced by the detonation of megaton-range nuclear weapons. Two sets of results are presented. The first set is based on data collected in the field. These basements belong to the buildings discussed in the previous chapter. The second set of results is based on basements designed (Ref. 35) with the object of evaluating their protective capabilities. These are therefore not actual, existing basements, but basement designs. They were designed by practitioners in the field in accordance with the ACI and Chicago building codes. Results of the 50 building sample are presented first.

3.2.2 Results of the 50-Building Sample

Of the 50 buildings analyzed in Reference 38, 36 had basements. They are categorized by the type of overhead (first) floor slab (system) in Table 7. This table also includes estimated percentages of total U.S. NFSS spaces in each of these categories based on the 219 buildings sample (Ref. 37). The seven categories used are those previously identified in Reference 37. Collapse overpressures ranged from about 2 psi to 55 psi with 50 percent of the floors predicted to collapse at 7 psi or less, and 90 percent predicted to collapse at 18 psi or less. Collapse overpressures are given in Table 5. The values are weighted averages for normally usable portions of basements. Collapse overpressure predictions used here were obtained from Reference 39.

People survivability estimates are summarized in Table 5. As was done with the upper story people survivability estimates, percent survivors in each basement are related to corresponding hazard environments in terms of free field overpressure at the building site. Casualty mechanisms considered included debris from the breakup and collapse of the overhead slab and prompt nuclear radiation. Dynamic pressures (blast winds), which would affect basement areas when closures are not provided for are exceeded by blast loading, were not considered.

The reason why this potentially important casualty mechanism was not considered is that at the time this study (Ref. 38) was conducted, a readily usable and economic method for predicting the transient velocity fields within a basement did not exist.

TABLE 7. BASEMENT OVERHEAD (FIRST) FLOOR SYSTEM CATEGORIES

Type of Floor System		Number in Sample	Percent of Total U.S. Spaces*
1. Concrete slab-steel beam		9	22.1
2. Flat slab		6	4.9
3. Flat plate		2	5.7
4. Concrete slab-concrete beam		3	16.9
5. Concrete joist-concrete beam		1	0.8
6. Concrete joist-steel beam		3	2.1
7. Other:			
Concrete slab-concrete joist	-7	12	20.3
Concrete slab-steel joist	-3		
Concrete slab-steel/concrete beam	-1		
Hollow concrete slab	-1		
TOTAL SAMPLE		36	72.8

* Estimate based on the 219 buildings sample (Ref. 37)

Also, the development of such a tool was beyond the scope of the study (Ref. 38) reported. Hydro-codes of the type used in References 40, 41 and 42 are not considered here to be readily usable methods due to long and costly computer running times. However, they can be used to generate data on the basis of which simplified methods may be developed.

Since the influence of transient velocity fields on people survivability in basements was not considered, then results reported here represent fairly specific sheltering options, i.e., one in which the basement closures are stronger than its walls and overhead slab, or one in which the shelterees occupy the best (safest) places in each basement. In general, this would include all shielded areas and areas away from any openings.

Average percent survivors for each of the seven categories of basements are given in Table 8 and plotted in Figure 10. Based on these results the following conclusions are made.

TABLE 8. AVERAGE PERCENT SURVIVORS AT INDICATED OVERPRESSURE LEVELS (Basement Spaces)

Floor System	Free Field Overpressure (psi)							
	5	10	15	20	25	30	35	40
1. Concrete slab-steel beam	85.6	60.1	36.0	13.7	8.1	5.8	3.2	0.4
2. Flat slab	85.5	27.3	17.8	11.0	2.5	0.8	0.0	0.0
3. Flat plate	28.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4. Concrete slab-concrete beam	83.3	43.7	6.3	0.0	0.0	0.0	0.0	0.0
5. Concrete joist-concrete beam	77.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6. Concrete joist-steel beam	83.3	46.7	9.7	2.7	0.0	0.0	0.0	0.0
7. Other	78.4	17.8	0.0	0.0	0.0	0.0	0.0	0.0
Weighted average	78.4	36.5	13.9	5.0	2.6	1.8	1.0	0.1

1. Figure 11 is a relationship between free field overpressures at 50 percent survivors and the corresponding incipient collapse overpressures for the 36 basements analyzed. It is seen that except for a single data point, there is mostly a one to one relationship between the overpressure producing 50 percent survivors and the incipient collapse overpressure of the corresponding basement overhead floor system. This is approximately as expected. At lower overpressures structural strength governs survivability. At higher overpressures prompt nuclear radiation enters the picture and casualties can be produced prior to collapse of the slab.

2. For the sample of basements considered, basements with concrete slab-steel beam overhead floor systems provide the best shelter space. This is followed fairly closely by basements having flat slab overhead floor systems. The flat plate takes the last place in this ranking. (See Figure 10).

3. The only explicit structural parameter considered in the statistical analysis of these basements was the strength of the overhead floor system. Contributory parameters such as span length, floor to ceiling distance, size of exposed wall, aperture percentage, and interior basement partition were considered in the analysis of percent survivors. However owing to the small sample of basements, it was not possible to include these parameters in a regression analysis for the purpose of gauging their significance on survivability.

4. In comparing people survivability results for basements and upper stories it is important to note that final results are in terms of survivors as such, and a distinction between injured and uninjured survivors is not made. Since debris is the primary casualty producer in basements, while debris, thermal radiation, prompt nuclear radiation and dynamic pressure dominate in upper stories, then it is reasonable to assume that survivors in basements will have fewer injured than survivors in upper stories.

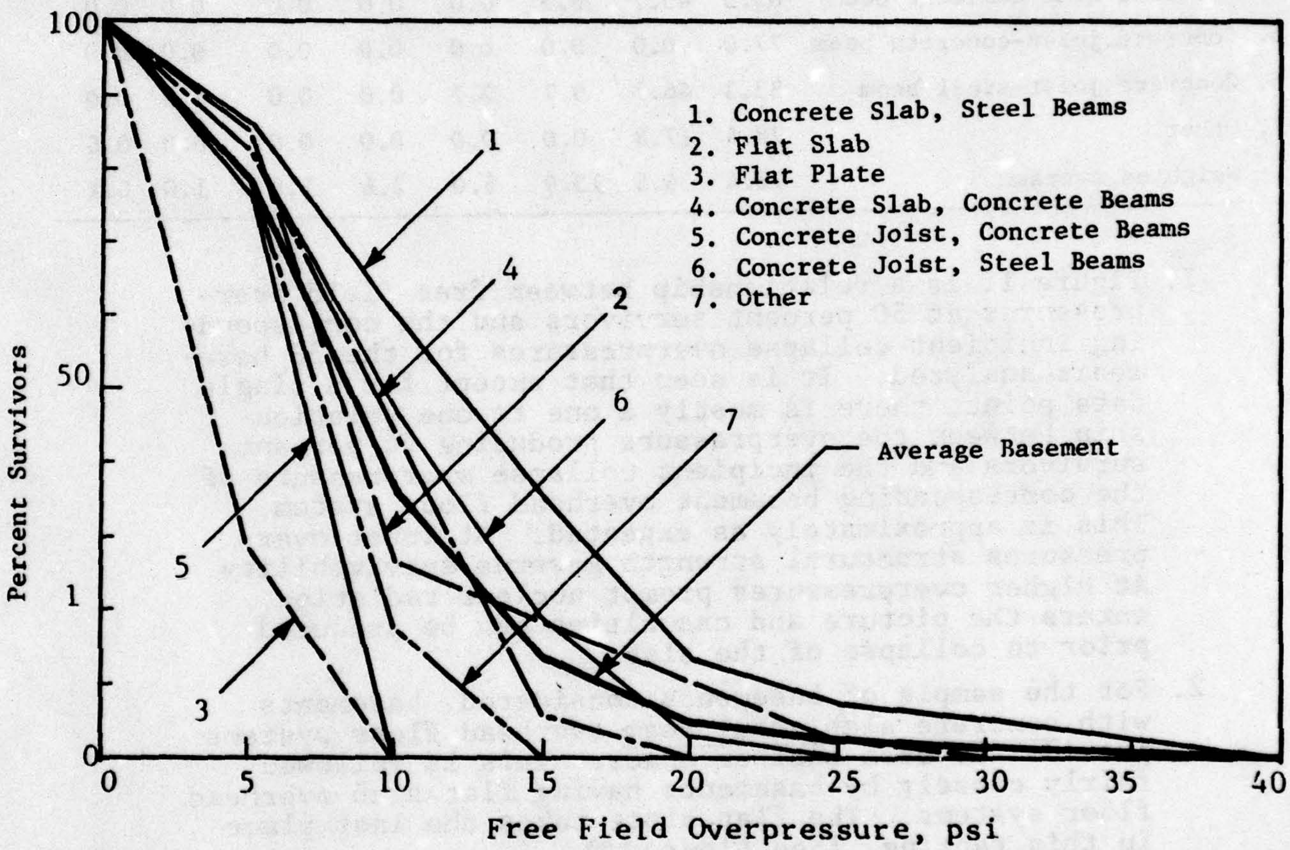


Figure 10. People Survivability in Basements (Average Values by Category)

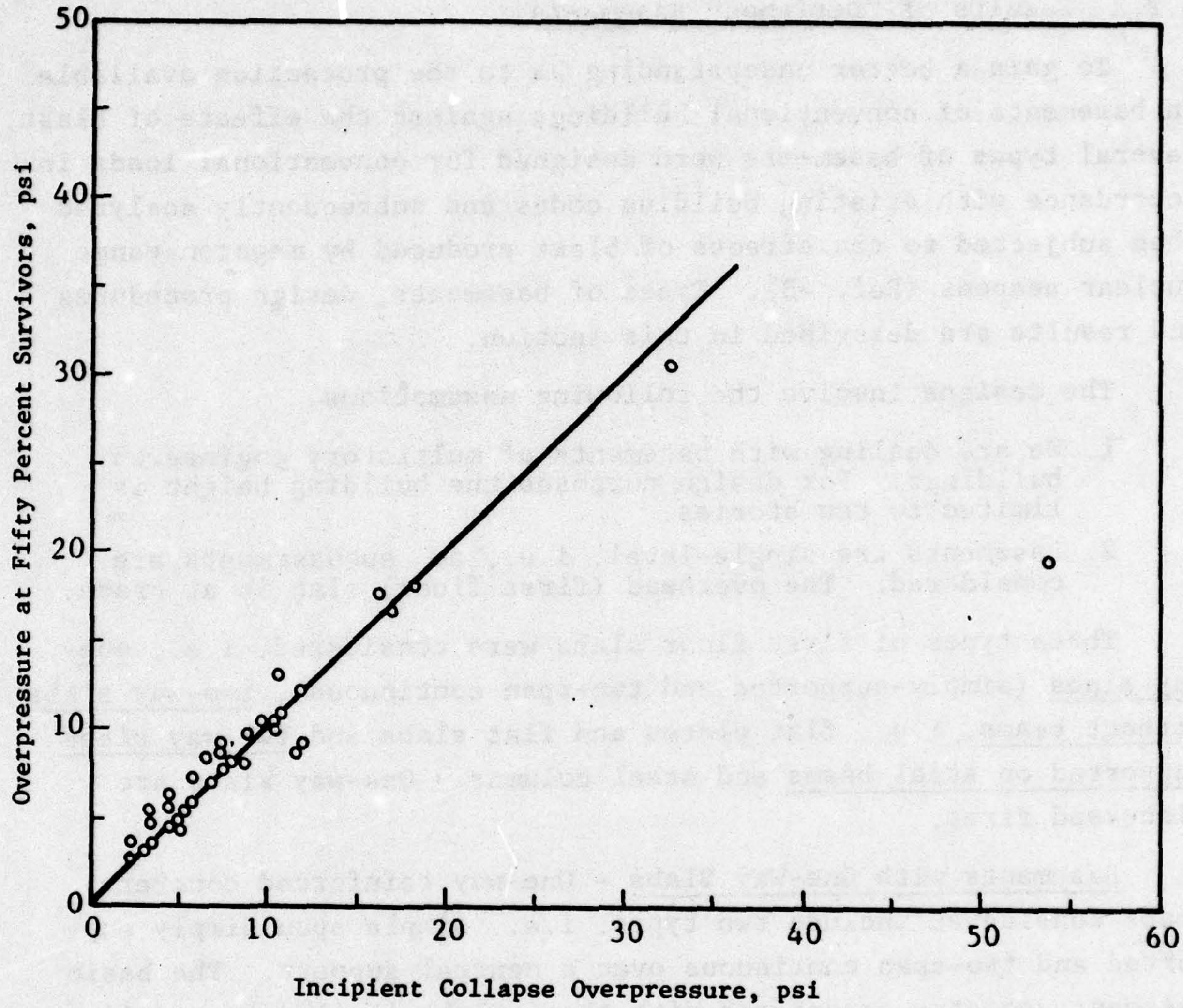


Figure 11. Comparison of Free Field Overpressure at Fifty Percent Survivors with Basement Overhead (First) Floor Strength

3.2.3 Results of "Designed" Basements

To gain a better understanding as to the protection available in basements of conventional buildings against the effects of blast, several types of basements were designed for conventional loads in accordance with existing building codes and subsequently analyzed when subjected to the effects of blast produced by megaton-range nuclear weapons (Ref. 43). Types of basements, design procedures and results are described in this section.

The designs involve the following assumptions.

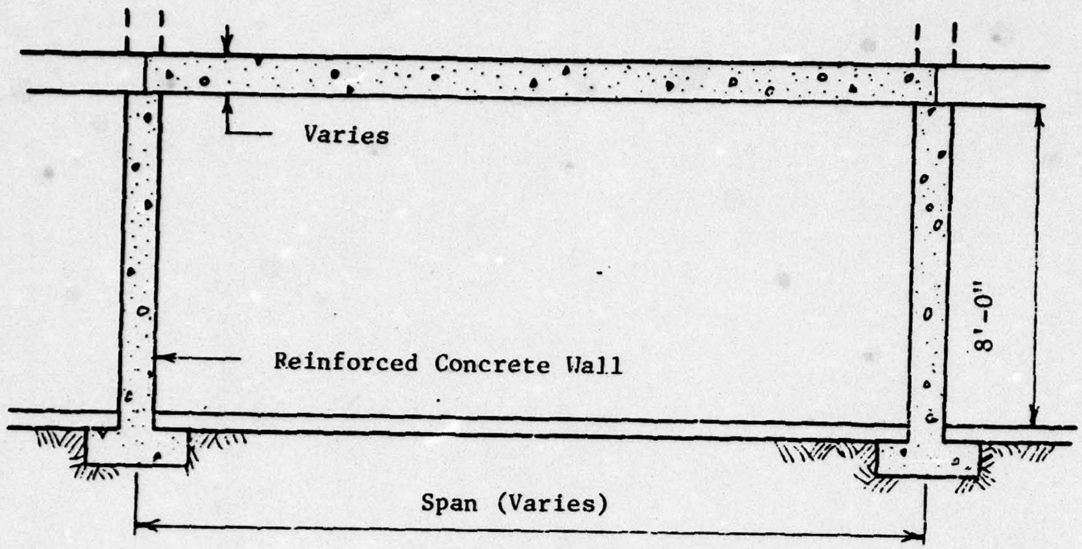
1. We are dealing with basements of multistory engineered buildings. For design purposes the building height is limited to ten stories.
2. Basements are single-level, i.e., no subbasements are considered. The overhead (first floor) slab is at grade.

Three types of first floor slabs were considered, i.e., one-way slabs (simply-supported and two-span continuous), two-way slabs without beams, i.e., flat plates and flat slabs and two-way slabs supported on steel beams and steel columns. One-way slabs are discussed first.

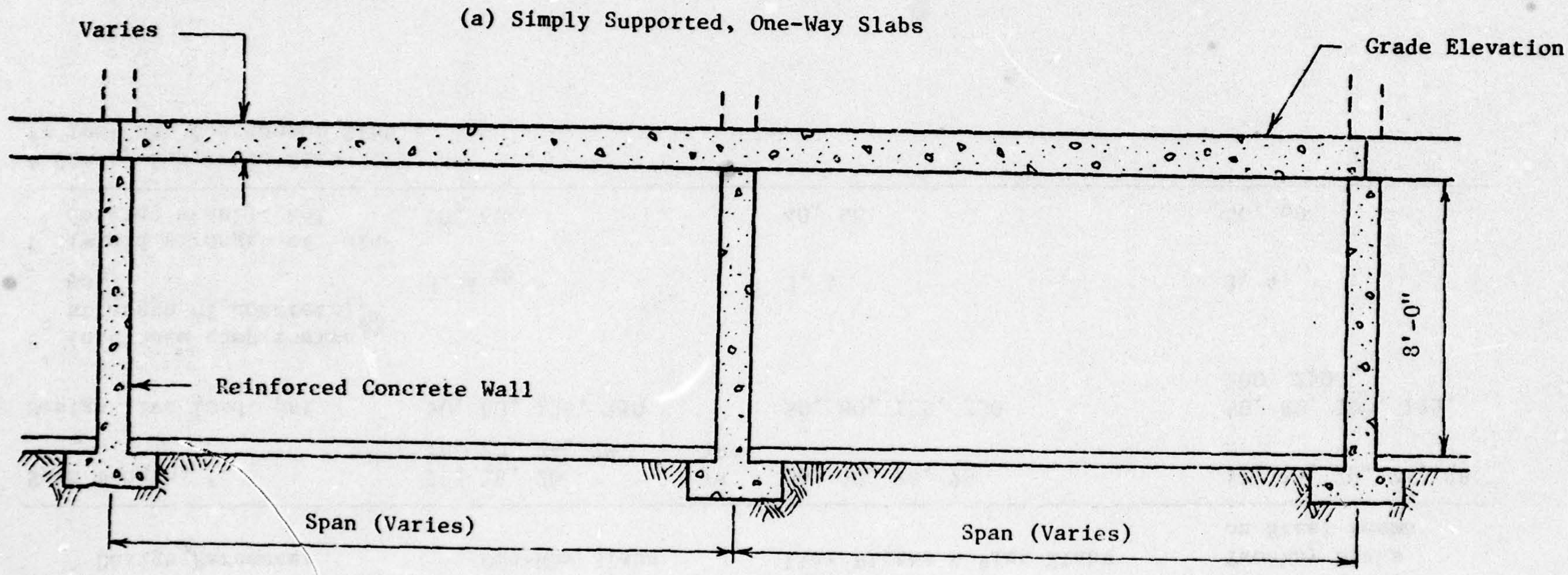
Basements with One-Way Slabs - One-way reinforced concrete slabs considered include two types, i.e., simple span simply supported and two-span continuous over a central support. The basic basement geometry associated with these slabs is illustrated in Figure 12. Design parameters considered were varied over the ranges given in Table 9. As indicated in Figure 12, a clear ceiling height of 8 ft was kept constant.

Slabs were designed using a procedure which utilizes the "Ultimate Strength Design" approach and satisfies the requirements of both the ACI 318-63 and ACI 318-71 "Building Code Requirements for Reinforced Concrete".

These slabs were subsequently analyzed with the object of identifying reasonable collapse mechanisms and determining corresponding collapse overpressures when subjected to the blast effects of a single, megaton-range nuclear weapon in its Mach region.



(a) Simply Supported, One-Way Slabs



(b) Two-Span Continuous, One-Way Slabs

Figure 12. Basic Basement Geometry for One-Way Slabs

TABLE 9. DESIGN PARAMETER RANGES FOR REINFORCED CONCRETE SLABS

Design Parameter	One-Way Slabs	Flat Plates & Flat Slabs	Two-Way Slabs on Steel Beams
Span length, ft	12, 16, 20)* 16, 20, 24, 28)**	16, 20, 24, 28	12, 16, 20, 24, 28
Design live load, psf	50, 80, 125, 250	50, 80, 125, 250	50, 80, 100, 125, 200, 250
f'_c (ultimate compressive strength of concrete), ksi	3, 4	3, 4	3, 4
f_y (yield strength of reinforcing steel), ksi	40, 60	40, 60	40, 60

* Simply Supported Slab
** Two-Span Continuous Slab

Collapse mechanisms were identified based on yield-line theory (Ref. 44), available experimental data (Ref. 45, 46, 47 and 48) and engineering judgment. Based on this, it was assumed that the only reasonably admissible collapse mechanisms to consider are those shown in Figure 13a and 13b.

Experience and theory indicate that a uniform, simply-supported one-way slab subjected to a uniformly applied load of sufficiently high magnitude will develop a plastic hinge at midspan (the position of maximum moment). This produces an unstable condition resulting in collapse. A symmetric collapse mode (Figure 13a) is expected under conditions of a symmetric structure and uniform load. However, since conditions are not expected to be ideal in every case, an unsymmetric mode (Figure 13b) is also considered. It is included as a reasonable alternate to account for the possibly significant movement of individual supports (basement walls) during the blast loading process and other variations producing unsymmetric response.

Since the likelihood of these collapse modes is not known, it is reasonable to assume that each is equally likely. This assumption has some experimental basis. For example, in Reference 46 approximately one-half of the symmetrically designed, symmetrically supported and symmetrically loaded slabs experienced unsymmetric collapse.

The minimum overpressure magnitude required to produce a plastic hinge at midspan is designated as P1. After the slab has experienced overpressure P1 or higher (see position 1 in Figure 13(a) and (b)), the subsequent symmetric and unsymmetric modes of collapse are described as follows.

The symmetric collapse (Figure 13a) is assumed to be followed by a stable postfailure position 2. At sufficiently high overpressures this is assumed to be followed by failure and collapse of the half-spans resulting in postfailure position 3. The minimum overpressure magnitude required to produce a plastic hinge at the midpoint of each half-span is designated as P2.

The unsymmetric collapse (Figure 13b) is assumed to include three events.

a. Rotation of span about support point A or B resulting in unstable position 2.

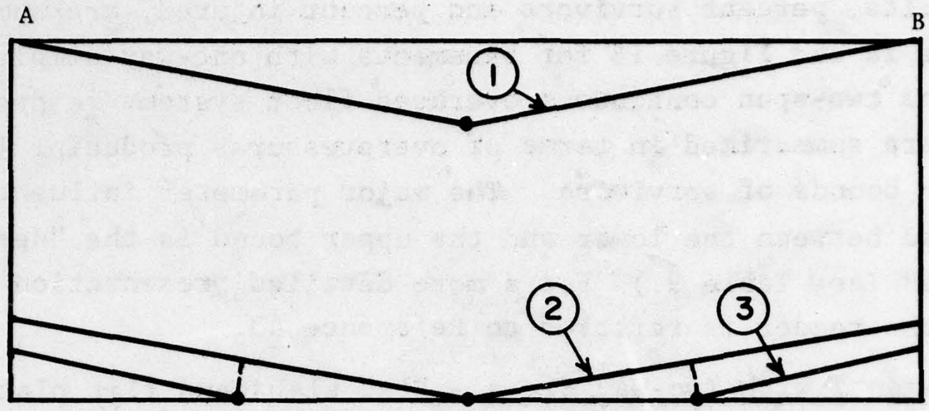
b. Further rotation and sliding resulting in stable position 3.

c. Failure and collapse of half-span due to overpressure P2 or higher, resulting in postfailure position 4.

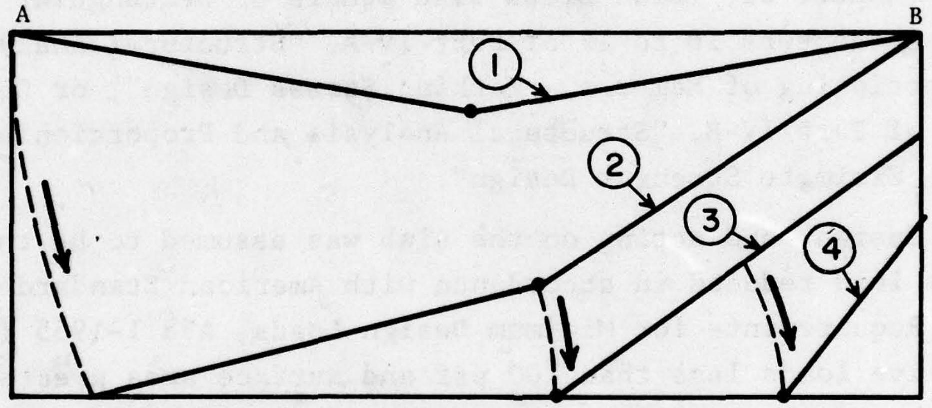
Only one collapse mode is assumed for the two-span continuous slab and is illustrated in Figure 13c). After the slab has experienced overpressures in the range between P1 and P2, it becomes a mechanism, i.e., plastic hinges have been formed at points C and B and the slab collapses. It is assumed to pull off support A, rotate about support B into unstable position 2 and further into stable position 3. If exposed to overpressures of P2 or higher, the propped part of the slab is assumed to form a plastic hinge at midspan, break loose at support B and then rotate and slide into postfailure position 4.

The structural analysis of the slabs was performed using blast-load design-analysis procedures of the type described in Chapters 7 and 8 of Reference 48.

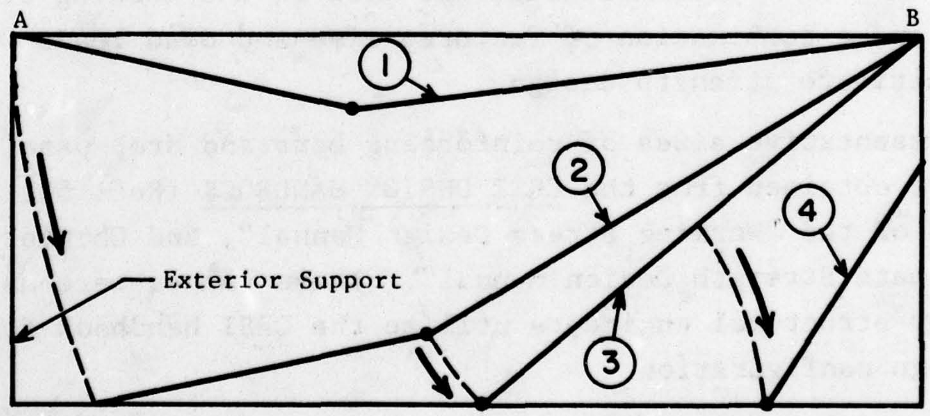
In estimating the numbers of survivors, the primary casualty mechanism considered was debris from the breakup of the overhead basement slab. The process used in estimating debris casualties is one in which basement areas occupied by people (in the various body positions, i.e., prone, sitting, standing) are superimposed on basement areas affected by the collapsed slabs. The interaction of collapse modes with body positions provides a rough (though realistic) estimate of corresponding casualties. Impacts to the head or the thorax were assumed to produce fatality. Impact to or pinning of the legs was assumed to produce injury or fatality depending on the particular area or length affected. Small amounts of debris breaking from the slab during the yielding of the slab were considered and were assumed to produce injuries. The possibility of injured people being rescued in the postattack period was <u>not considered</u> in making the final estimates.



(a) Symmetric Collapse Mode for Simply-Supported Slab



(b) Unsymmetric Collapse Mode for Simply-Supported Slab



(c) Collapse Mode for Two-Span Continuous Slab

NOTE: Numbers indicate successive positions of the failed slab

Figure 13. Assumed Collapse Modes for One-Way Slabs

Results, percent survivors and percent injured, are summarized in Figure 14 and Figure 15 for basements with one-way simply supported and two-span continuous overhead floor systems respectively. Results are summarized in terms of overpressures producing lower and upper bounds of survivors. The major parameter influencing the spread between the lower and the upper bound is the "design live load" (see Table 9.) For a more detailed presentation of results the reader is referred to Reference 43.

Basements with Two-Way Slabs - Flat slabs and flat plates (see Figure 16 and Table 9) were designed as square interior panels in accordance with ACI 318-63 (Ref. 50). The designs meet the requirements of Chapter 21, "Flat Slabs with Square or Rectangular Panels" and either Chapters 10 to 12 of Part IV-A, "Structural Analysis and Proportioning of Members - Working Stress Design", or Chapters 15 to 17 of Part IV-B, "Structural Analysis and Proportioning of Members - Ultimate Strength Design".

The design load acting on the slab was assumed to be the nominal live load reduced in accordance with American Standard Building Code Requirements for Minimum Design Loads, A58.1-1955 (Ref. 51) for live loads less than 100 psf and surface area greater than 150 sq ft, and the dead load consisting of the slab weight based on a unit weight of 150 pcf and an additional dead load of 10 psf. This combination of service loads was used in the working stress designs, and a combination of factored live and dead loads was used for the ultimate strength design.

Representative sizes of reinforcing bars and drop panel dimensions were obtained from the CRSI DESIGN HANDBOOK (Ref. 52, 53), Chapter 8 of the "Working Stress Design Manual", and Chapter 12 of the "Ultimate Strength Design Manual". These values were used since many structural engineers utilize the CRSI handbook for initial design configuration.

Two-way slabs on steel beams (see Table 9) were designed as square, interior panels in accordance to ACI 318-63 using ACI Method 2, (see Appendix A of Ref. 50). The design live load acting

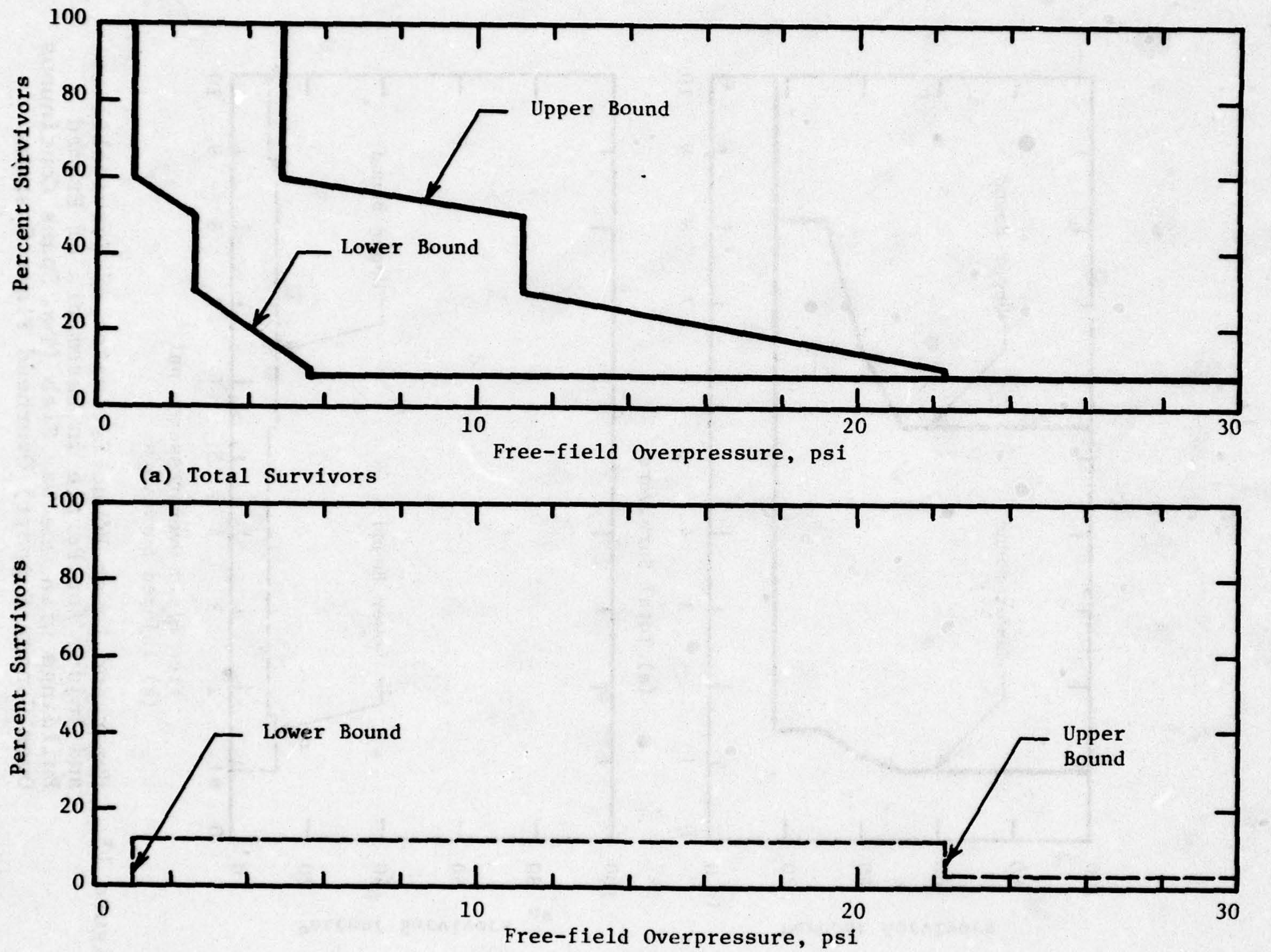


Figure 14. Upper and Lower Bound Estimates of Survivability and Injury for People in Basements of Framed Buildings with One-Way Slab (Simply Supported) Overhead Floor Systems

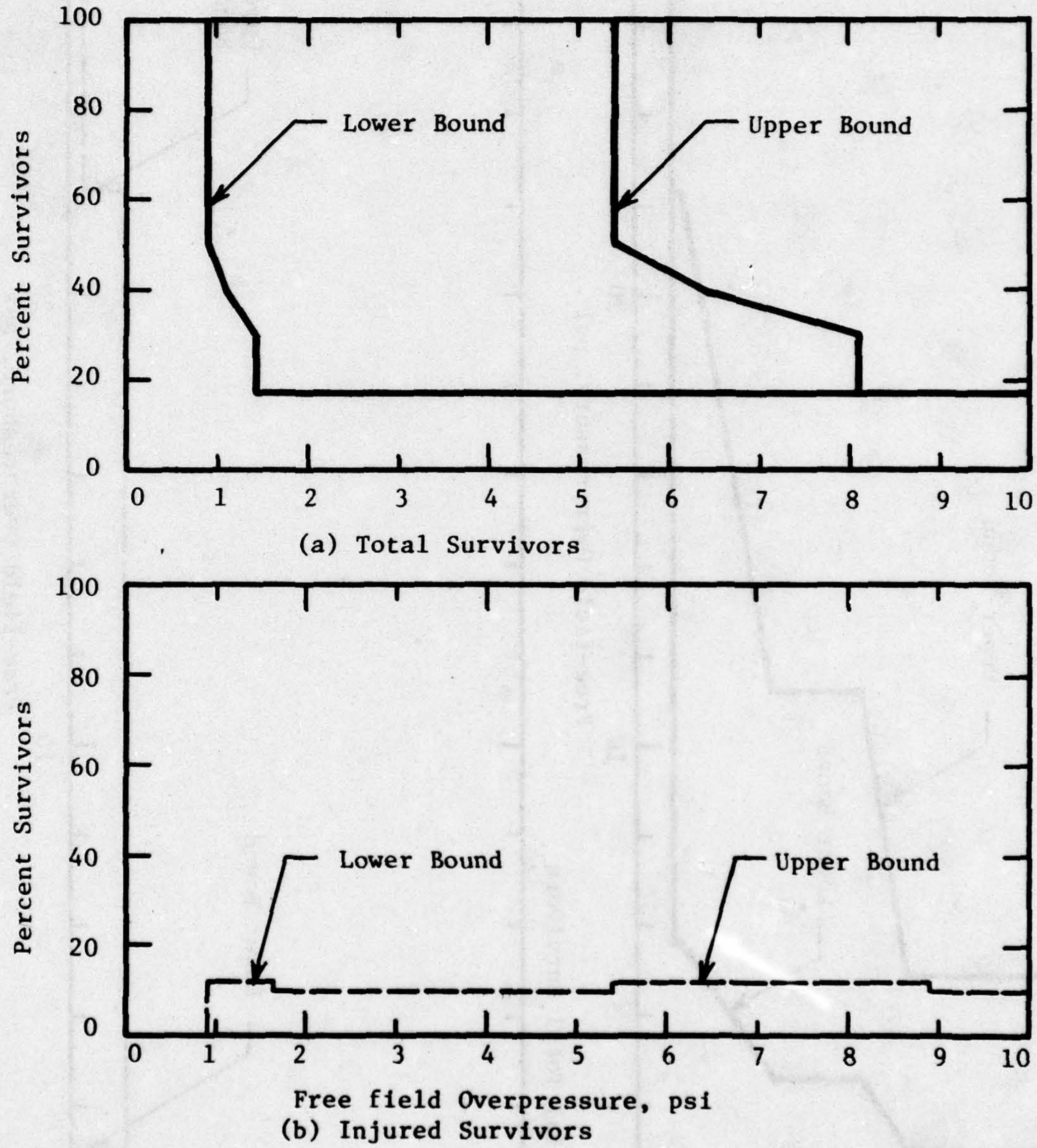


Figure 15. Upper and Lower Bound Estimates of Survivability and Injury for People in Basements of Framed Buildings with One-Way Slab (Two Spans Continuous Over Center Support) Overhead Floor Systems

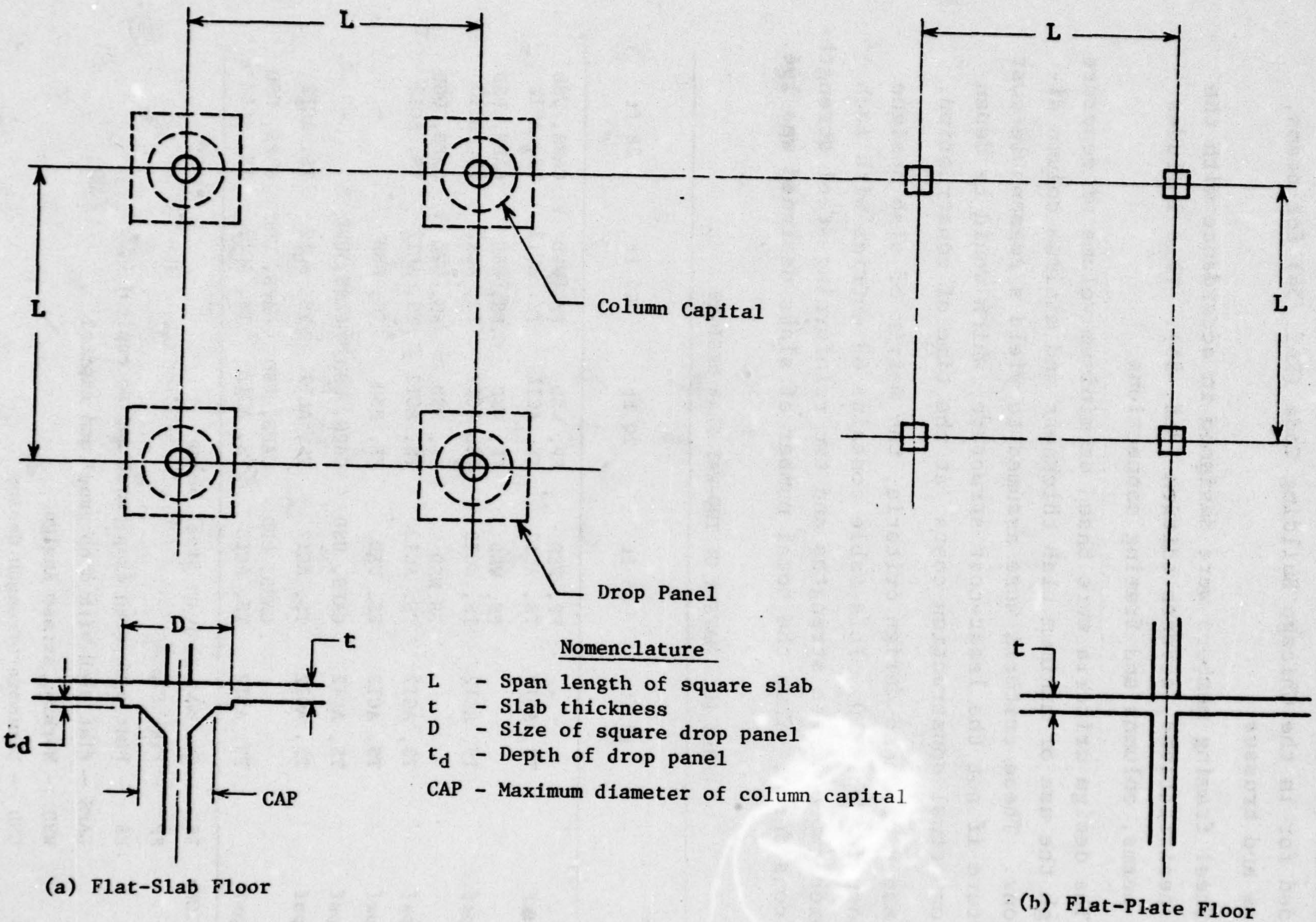


Figure 16. Flat-Slab, Flat-Plate Construction and Nomenclature

on the slab was assumed to be the nominal live load reduced as provided for in the Chicago Building Code (Ref. 54) for beams, girders and trusses.

Steel framing members were designed in accordance with the AISC specifications, seventh edition (Ref. 55). This includes steel beams, columns and framing connections.

The design criteria were based on minimum volume of concrete through the use of minimum slab thickness and minimum column dimensions. These criteria were assumed to yield a reasonable-cost structure if not the least-cost structure, which would be dependent on actual construction costs at the time of construction.

Based on these design criteria, the matrix of slab designs is shown in Table 10. This table contains 49 entries with each of which two concrete strengths and two reinforcing steel strengths were considered. Thus the total number of slabs designed was 196.

TABLE 10. MATRIX OF TWO-WAY SLAB DESIGNS

Span / Live Load	12 ft	16 ft	20 ft	24 ft	28 ft
50 psf	TS, ACI2	FP, WSD TS, ACI2	FP, WSD TS, ACI2	FP, WSD TS, ACI2	CAPS, USD TS, ACI2
80 psf	TS, ACI2	FS, WSD TS, ACI2	FS, WSD TS, ACI2	FS, WSD TS, ACI2	CAPS, USD TS, ACI2
125 psf	TS, ACI2	FS,WSD TS, ACI2	FS, WSD TS, ACI2	FS, WSD TS, ACI2	CAPS, USD TS, ACI2
125 psf	TS, ACI2	FS, USD	FS, USD	FS, USD	-
125 psf	TS, ACI2	CAPS, USD	CAPS, USD	CAPS, USD	-
200 psf	TS, ACI2	TS, ACI2	TS, ACI2	TS, ACI2	TS, ACI2
250 psf	TS, ACI2	CAPS, USD TS, ACI3	CAPS, USD TS, ACI2	CAPS, USD TS, ACI2	CAPS, USD TS, ACI2

NOTATION:
TS - Two-way slab on Steel beams
FP - Flat Plate
FS - Flat slab with drop panel and no capital
CAPS - Flat slab with drop panel and capital
WSD - Working stress design
USD - Ultimate strength design
ACI2 - ACI Method 2

A few words about Table 10. It will be noted that the entries are not uniformly distributed, i.e., some of the boxes contain two entries (two designs), some one and others none. For the 125 psf live load for example, there are four slab designs for the 24 ft span which include flat slab (FS) and two-way slab on steel beams (TS) concepts but no flat plate (FP) concepts. The reason is that for this combination of span and load it is practical to have a flat slab with a capital or one without. Also, the working stress design (WSD) or the ultimate stress design (USD) may be used without the penalty of excessive use of concrete. However, a flat plate (FP) is not a practical concept for this span and load combination. The results of the designs are included in References 35 and 43.

Each of these slabs and supporting structural components (columns, connections, etc.) were analyzed to determine collapse overpressures when subjected to the blast effects of a single, megaton-range nuclear weapon. Theory and experiments (Ref. 44, 45, 46, 47 and 56) indicate that two-way slabs of the type considered here will fail either in flexure, with yield lines forming along the lines of maximum bending moment, or in shear due to punching at the columns. Flexural failure is the likely mechanism for flat slabs on steel beams while shear failure is the likely mechanism for flat plates. Sequences of collapse and corresponding collapse overpressures were determined using standard procedures (Ref. 49, 57, 58).

The level of uncertainty associated with failure overpressures for two-way slabs is greater than for one-way slabs. Two-way slabs are more redundant. The response of redundant structures is generally more difficult to predict than that of simple structures especially in the postyield range. Also, there exists less experimental data on the response of two-way slabs than on one-way slabs.

Due to this, analyses to determine relative effectiveness of different body positions and distributions of people on survivability was not performed. Instead it was assumed that people are uniformly distributed in all basement areas and are either prone, sitting or standing at the time of attack. Survivability is measured as indicated in Figure 17.

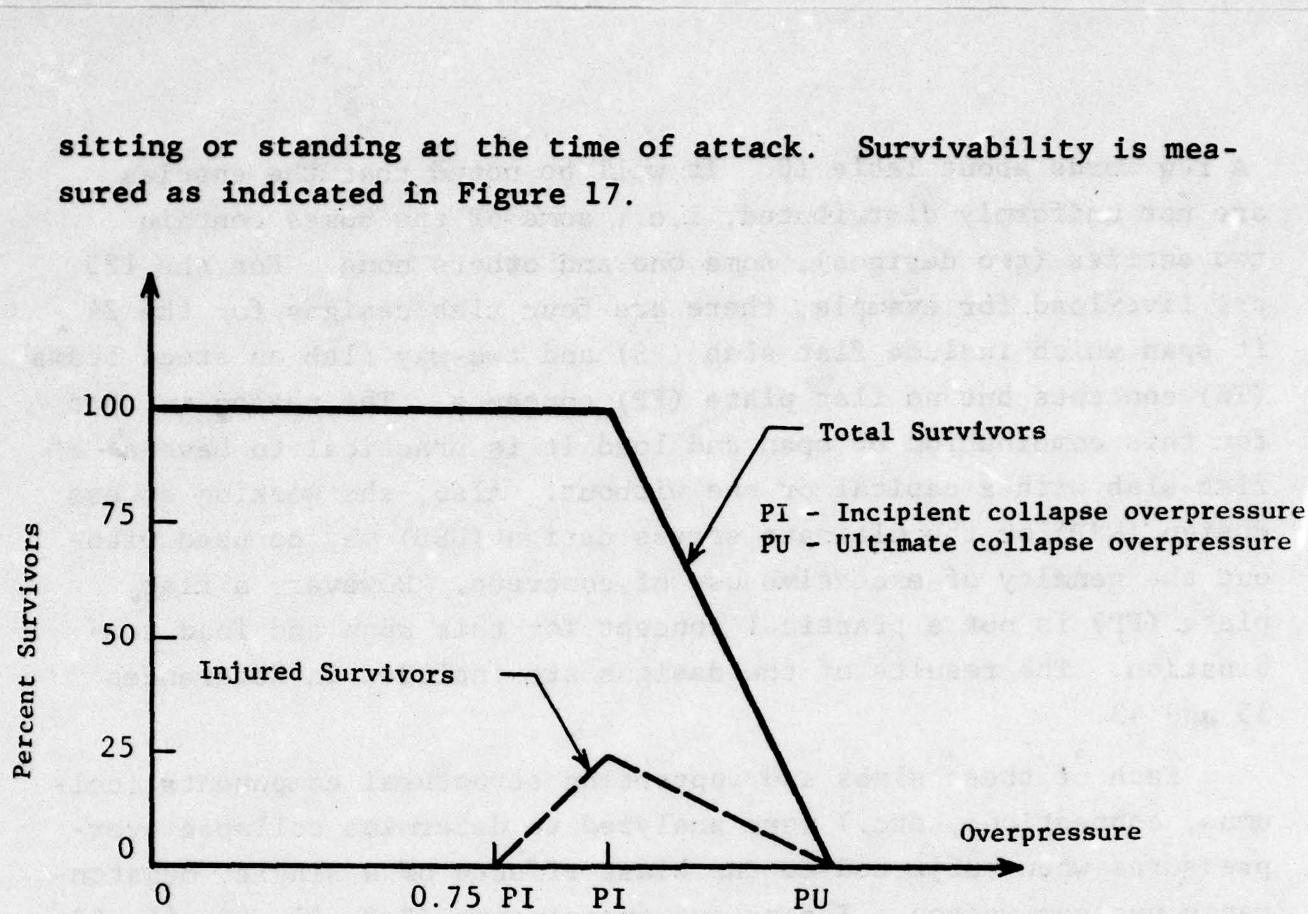


Figure 17. Definition of People Survivability Estimate for Basements with Two-way Slabs

For overpressure levels up to and including incipient collapse (PI) no fatality level casualties are assumed to be produced. For overpressure levels between PI and PU, fatality level casualties are assumed to be produced at the rate indicated by the straight line between PI and PU. Nonfatal injuries are assumed to begin at 3/4 PI, reach a maximum at 25 percent at PI and to decrease at a linear rate to PU. Nonfatal injuries are assumed to be produced by spalled chunks of concrete from the overhead slab.

For the set of basements considered in this section, the upper and lower bounds on PI and PU are summarized in Table 11.

TABLE 11. BOUNDS ON PI* AND PU*

PI		PU		Structural Member**
Lower Bound	Upper Bound	Lower Bound	Upper Bound	
0.57	0.81	1.80	2.40	FP
0.70	2.74	1.10	4.20	FS
0.56	3.38	0.60	13.50	CAPS
0.87	3.40	2.07	7.50	C/S
0.60	1.60	1.13	2.81	SB
-	-	1.30	6.40	Conn

* PI - Incipient Collapse Overpressure
PU - Ultimate Collapse Overpressure

**FP - Flat plate
FS - Flat slab with drop panel and no capital
CAPS - Flat slab with drop panel and capital
C/S - Two-way R/C slab on steel beams
SB - Steel beam
Conn - Bolted connections

Incipient collapse overpressure (PI) was computed on the basis of the structural member experiencing a ductility ratio (μ) of one. The ultimate collapse overpressure (PU) for concrete slabs responding in flexure was computed on the basis of a ductility ratio in accordance to the following equation:

$$\mu_m = \frac{0.10}{\rho - \rho'} \leq 30 \qquad (9)$$

in which

μ_m = the maximum ductility ratio,
ρ = ratio of tensile steel A_s/bd,
ρ' = ratio of compressive steel A_s'/bd,
A_s = area of tensile steel,
A_s' = area of compressive steel,
b = unit width of section of slab
d = effective depth of slab, distance from extreme fiber in compression to centroid of tensile steel

Corresponding criteria for reinforced concrete members responding in shear and steel members are included in Reference 35 and 43.

Corresponding people survivability estimates are given in Figures 18 and 19. For a more detailed presentation of results the reader is referred to Reference 35 and 43.

The flat slab structural system for basements has the widest bounds (see Figure 18). Depending on the magnitude of the design load it can be the weakest or the strongest basement available. The flat plate system has the narrowest bounds and is generally the weakest structural system of those examined here.

3.2.4 The Use of Results

The ultimate use of results (Figure 10, 14, 15, 18 and 19) contained here would be one or all of the following.

1. Allow for the ranking of shelter space in a given community that is developing a shelter system.
2. Selection of basements to be upgraded from a set of surveyed basements.
3. Evaluation of the effectiveness of alternative shelter systems, etc.

Obviously in the form they are given here, these results are not fully capable of being put to such use. The reasons are the following.

1. The data set is incomplete, i.e., not all of the major structural systems have been considered. According to Reference 37, the breakdown of basement spaces by type of overhead floor system in the NFS structures is as indicated in Table 12.

TABLE 12. BREAKDOWN OF BASEMENT SPACES

Type of Overhead Floor System	Percent of Total U.S. Spaces	Normalized Percentages
1. Concrete slab-steel beam	22.1	30.4
2. Flat Slab	4.9	6.7
3. Flat Plate	5.7	7.8
4. Concrete slab-concrete beam	16.9	23.2
5. Concrete joist-concrete beam	0.8	1.1
6. Concrete joist-steel beam	2.1	2.8
7. Other	20.3	28.0
Total with basements	72.8	100.0

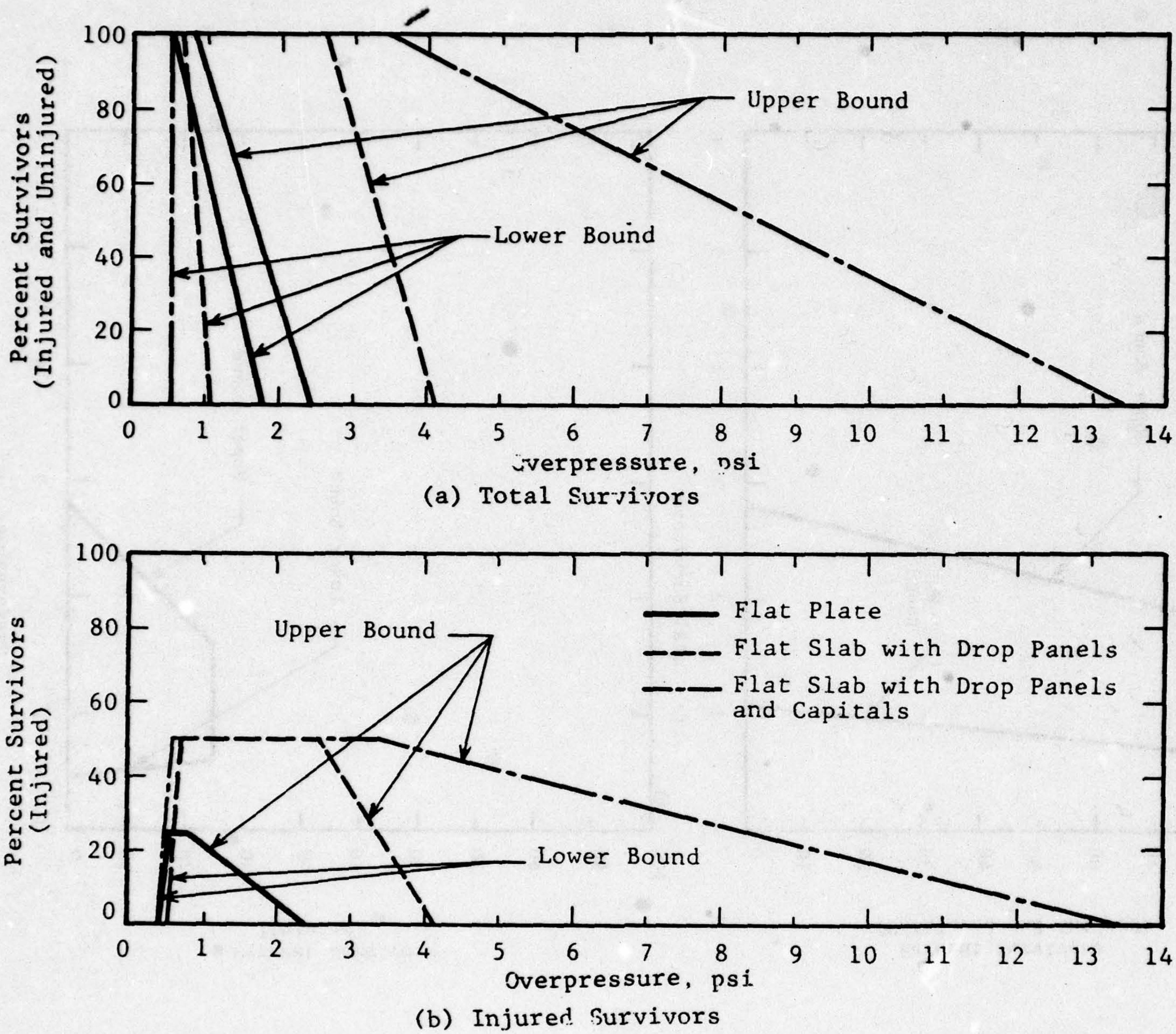


Figure 18. Upper and Lower Bound Estimates of Survivability and Injury for People in Basements of R/C Buildings with Flat Plate and Flat Slab Framing Systems

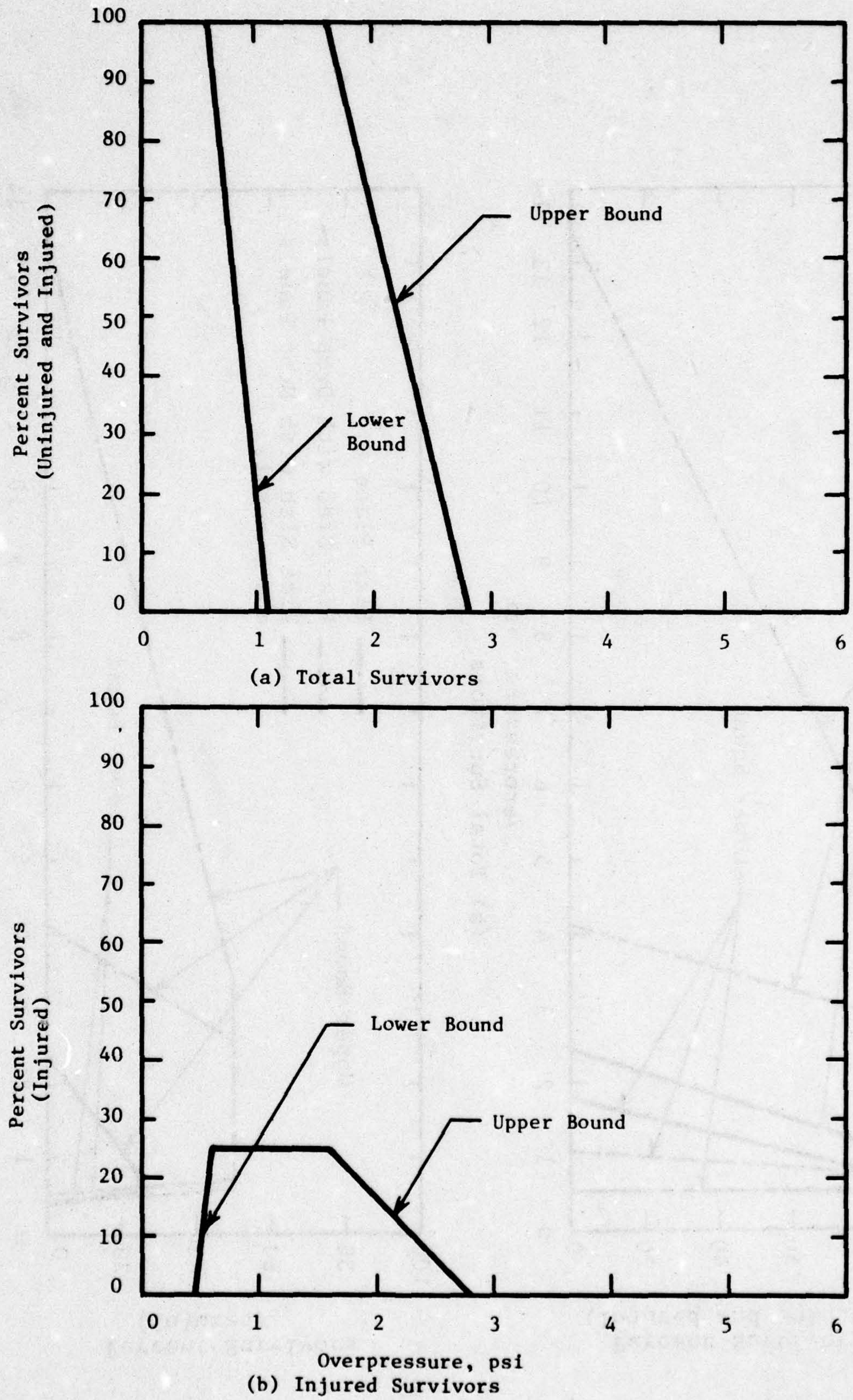


Figure 19. Upper and Lower Bound Estimates of Survivability and Injury for People in Basements of Steel Framed Buildings (Two-Way R/C Slab on Steel Beams)

Results given in this section provide information on the first three categories.* Similar information on the remaining categories is needed.

2. The influence of dynamic pressures on survivability when blast closures are not provided or are exceeded was not specifically considered. Therefore these results apply mostly to the following sheltering options.

   - When basement closures are provided and are stronger than the overhead basement slab.
   - When basement closures are not provided and the shelterees occupy the "safer" shelter areas, i.e., shielded areas and areas not in direct communication with any of the openings.

3.3 People Survivability in Single Purpose Personnel Shelters

Shelters considered in this section are categorized in Table 13. They include two basic structural types, i.e., arches and rectangular (box) structures. Arch shelters are described first.

TABLE 13. SINGLE PURPOSE SHELTERS

Shelter Description	Shelter Capacity No. of Persons	Design Weapon Environment	Principal Materials of Construction	Location Relative to Ground Surface	Number of Shelters Considered
RC Arch	500	Fallout, 10, 20 & 30 psi	RC and soil	Semiburied	4
RC Arch	500	100 & 150 psi	RC and soil	Semiburied	2
Steel Arch	500	Fallout, 10, 20 & 30 psi	RC, steel and soil	Semiburied	4
Rectangular Shelter	500	Fallout, 10, 20 & 30 psi	RC and soil	Semiburied	4

3.3.1 Arch Shelters

Arch structures are subdivided with respect to materials of construction into two types, i.e., (1) reinforced concrete, and

*There is a fairly distinct difference in the ultimate resistence of slabs which were designed for analysis as compared to those whose data were obtained in the field survey. The reason for the difference is not clear. An effort to determine the reason was beyond the scope of this study. This should be investigated in a future study.

(2) corrugated and plate steel. With respect to "design weapon environment", they may be further divided into six categories to resist one of the following weapon environments:

(a) fallout radiation alone

(b) 10 psi (c) 20 psi (d) 30 psi (e) 100 psi (f) 150 psi	free field overpressure and associated effects of prompt nuclear thermal and fallout radiation resulting from a single megaton weapon

These shelters were designed (Ref. 59) to be located at specific sites (shelter complexes) on the peripheries of large population centers. The basic shelter, a single arch module, is capable of housing 500 persons at approximately 10 sq ft per person. Basic modules are combined to form larger complexes as the need dictates. Due to imposed siting conditions fires should not pose a serious hazard and for this reason were not specifically considered in their design. Consult Reference 59 for a more detailed description of peripheral shelter systems and their estimated costs for midyear 1967.

Shelters (a) through (d) are referred to as "low level weapon effects designs". For purposes of comparison they were designed using reinforced concrete in one case and corrugated and plate steel in the other. Shelters (e) and (f) are referred to as "high level weapon effects designs". One material-reinforced concrete was used in their design.

The general configuration of an arch shelter (500-man size) is shown in Figure 20. It has two levels with the second floor resting on two rows of reinforced concrete columns with footings separate from the rest of the structure. The second floor slab was designed to resist its own weight plus a live load of 150 psf. Location of this shelter relative to the ground surface (burial condition) is shown in Figure 21. Basic dimensions of the structure are given in Figure 22 and Table 14.

Reinforcement steel considered in their design includes intermediate grade A15, A16, A408, with f_y=40,000 psi for footings, foundation walls and floor slabs, and hard grade reinforcement A15, A16, A408 with f_y=50,000 psi for arch shells and end walls.

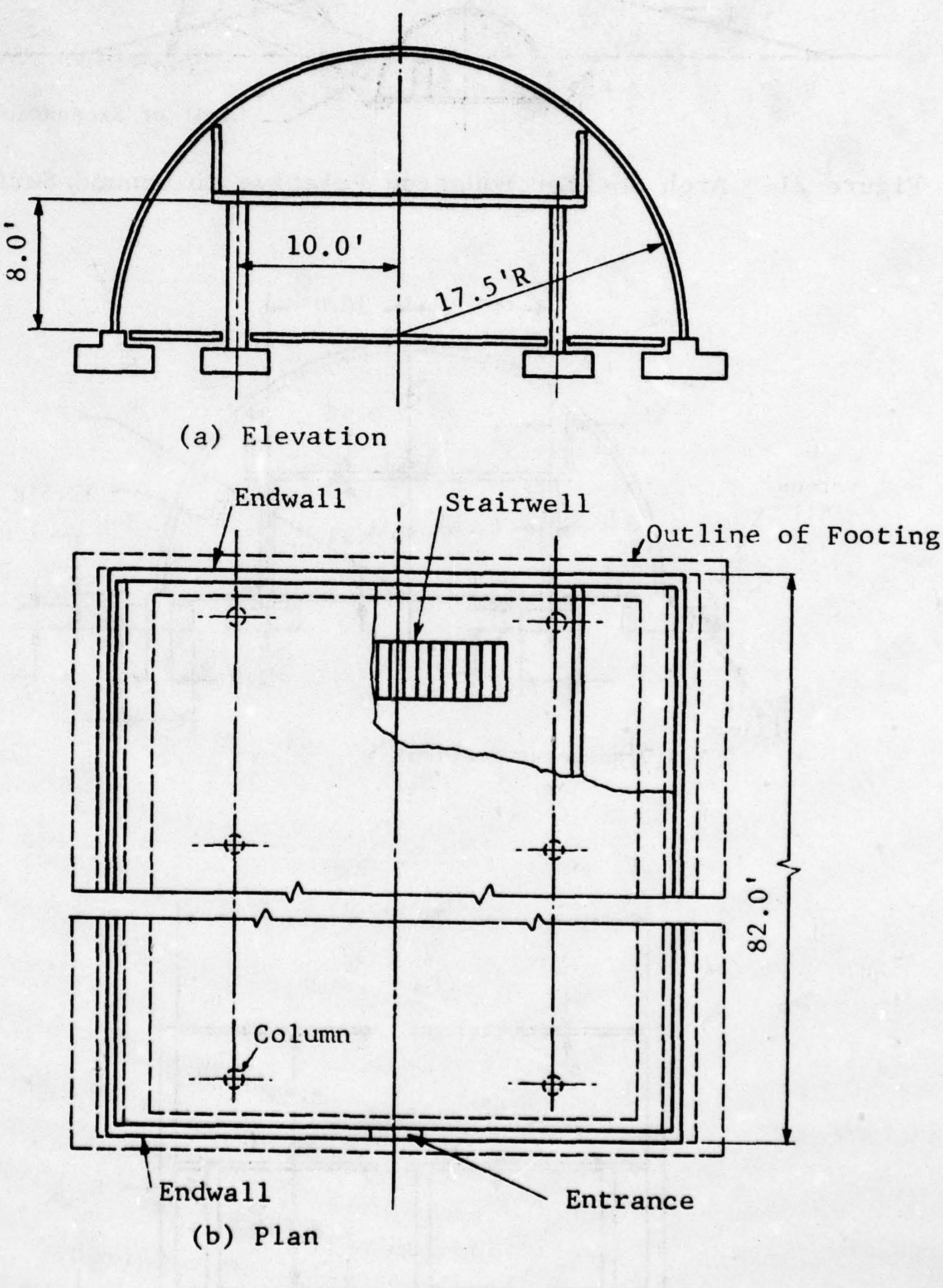


Figure 20. General Configuration of Basic 500-Man Arch Shelter

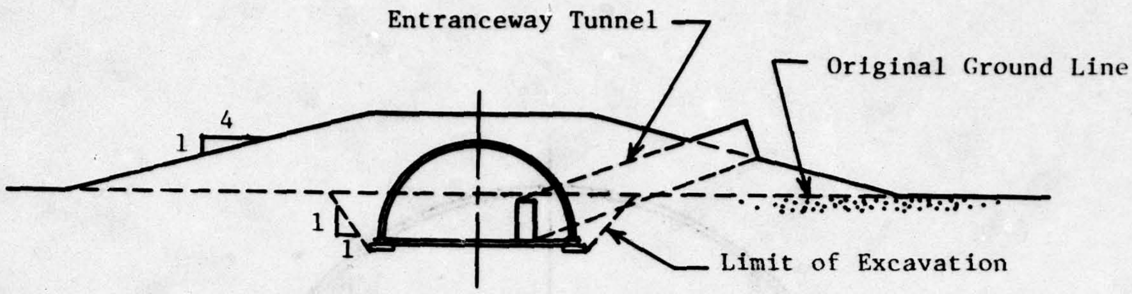


Figure 21. Arch Shelter Location Relative to Ground Surface

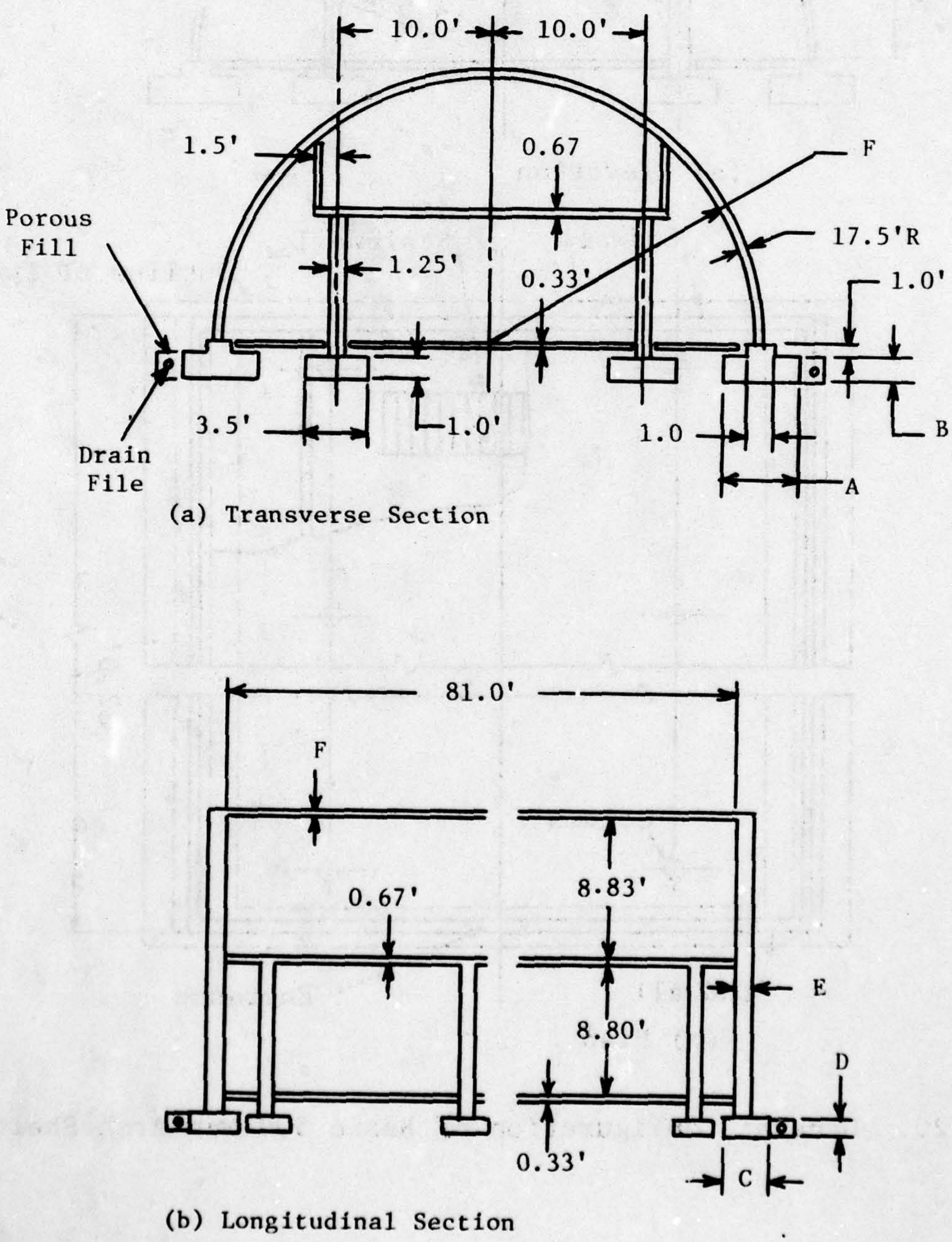


Figure 22. Basic Dimensions of Arch Shelter

TABLE 14. BASIC DIMENSIONS OF ARCH SHELTERS

Member	Dimensions for Indicated Design Weapon Environments, in.					
	FRE	10 psi	20 psi	30 psi	100 psi	150 psi
Arch Footing Width (A)	33	52	66	81	89	94
Arch Footing Depth (B)	8	10	14	17	22	30
End Wall Footing Width (C)	24	24	26	30	48	54
End Wall Footing Depth (D)	12	12	14	18	28	38
End Wall Thickness (E)	8	8	9	10	35	41
R/C Arch Shell Thickness (F)	4	4	4	4	8	13.5
Steel Arch Shelter Shell Thickness (gage)	12*	12*	12*	0.5**	--	--

FRE - fallout radiation environment (PF = 1000)

*corrugated steel plate
**formed flat plate
See text for description of arch shells.

Welded wire fabric with a yield strength of 65,000 psi is used for slabs on ground.

Steel arch shelters for fallout, 10 and 20 psi weapon environments were designed for the use of corrugated 12 gage steel plate with corrugations 2 in. deep and a pitch 6 in. wide. The shell of the 30 psi shelter was designed for the use of 0.5-in. flat steel plate formed into a circular arch and supported at intermediate positions by means of wide flange beam arch ribs. The basic dimensions of the steel arch shelter are the same as those of the reinforced concrete arch and are given in Figures 20, 22 and Table 14.

3.3.2 Rectangular Shelters

As in the case of arch shelters, reinforced concrete rectangular shelters are also subdivided into four design weapon environment categories, i.e.,

- fallout radiation alone,
- 10 psi, free field overpressure and associated effects of prompt nuclear, thermal and fallout radiation resulting from a single megaton weapon,
- 20 psi, as above, and
- 30 psi.

These are also "peripheral type" shelters. They may be located within population centers, however, siting in such a case must correspond to peripheral shelter design criteria (Ref. 59).

The general configuration of this shelter is shown in Figure 23. It is a basic 500-man module, exterior and interior walls forming a rectangular grid. Both exterior and interior walls are one-way slabs. The roof member is a two-way slab. Basic dimensions are given in Figure 24a and Table 15. Reinforcement grades are the same as in the case of arch shelters: intermediate grade for footings and hard grade for walls and roof slabs. The depth of protective soil cover can be taken as 12 in. Figure 24 also shows how two basic 500-man modules are combined to form a single 1000-man shelter. Location relative to the ground surface is shown in Figure 25.

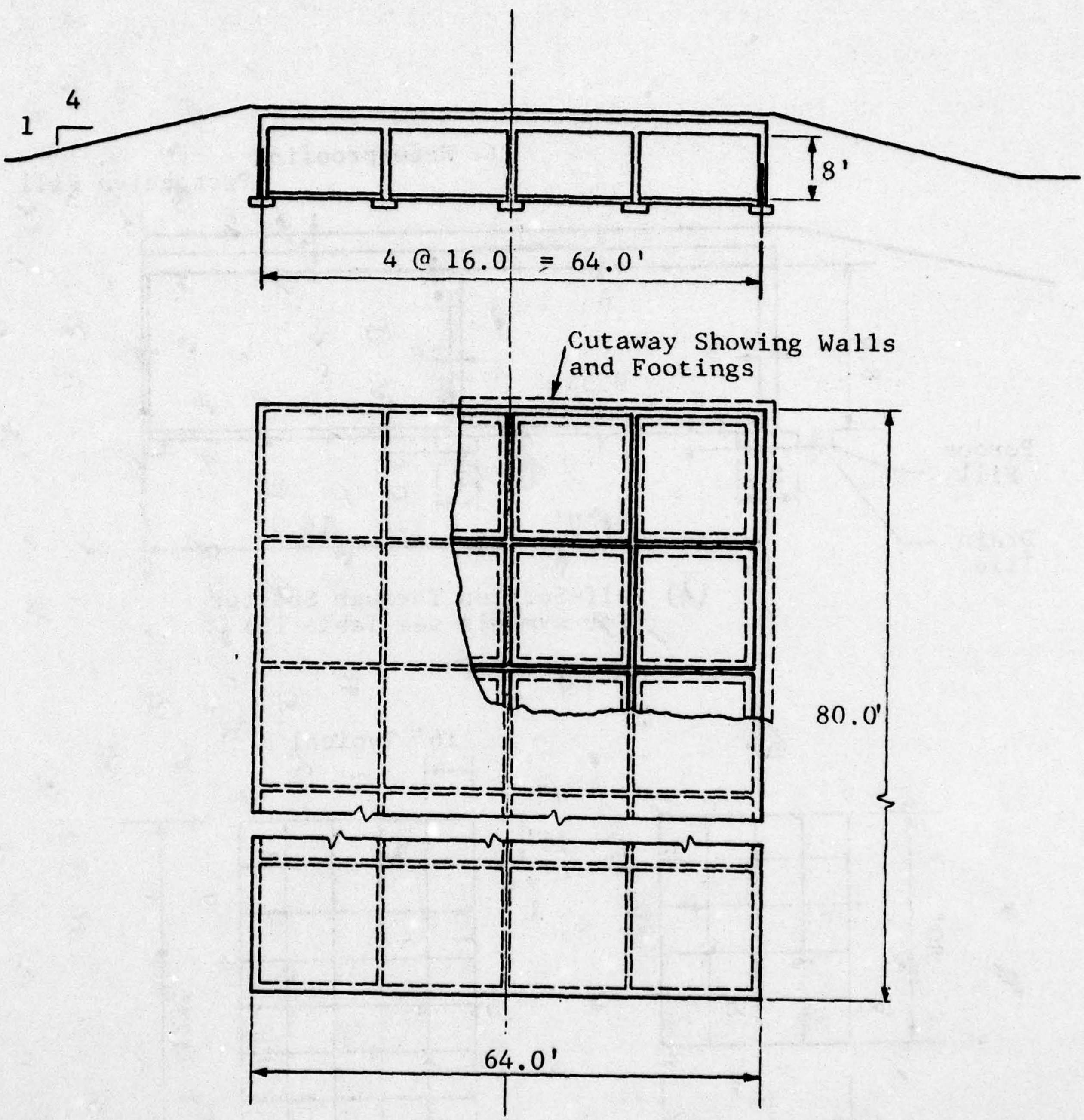


Figure 23. General Configuration of Basic 500-Man Rectangular R/C Shelter

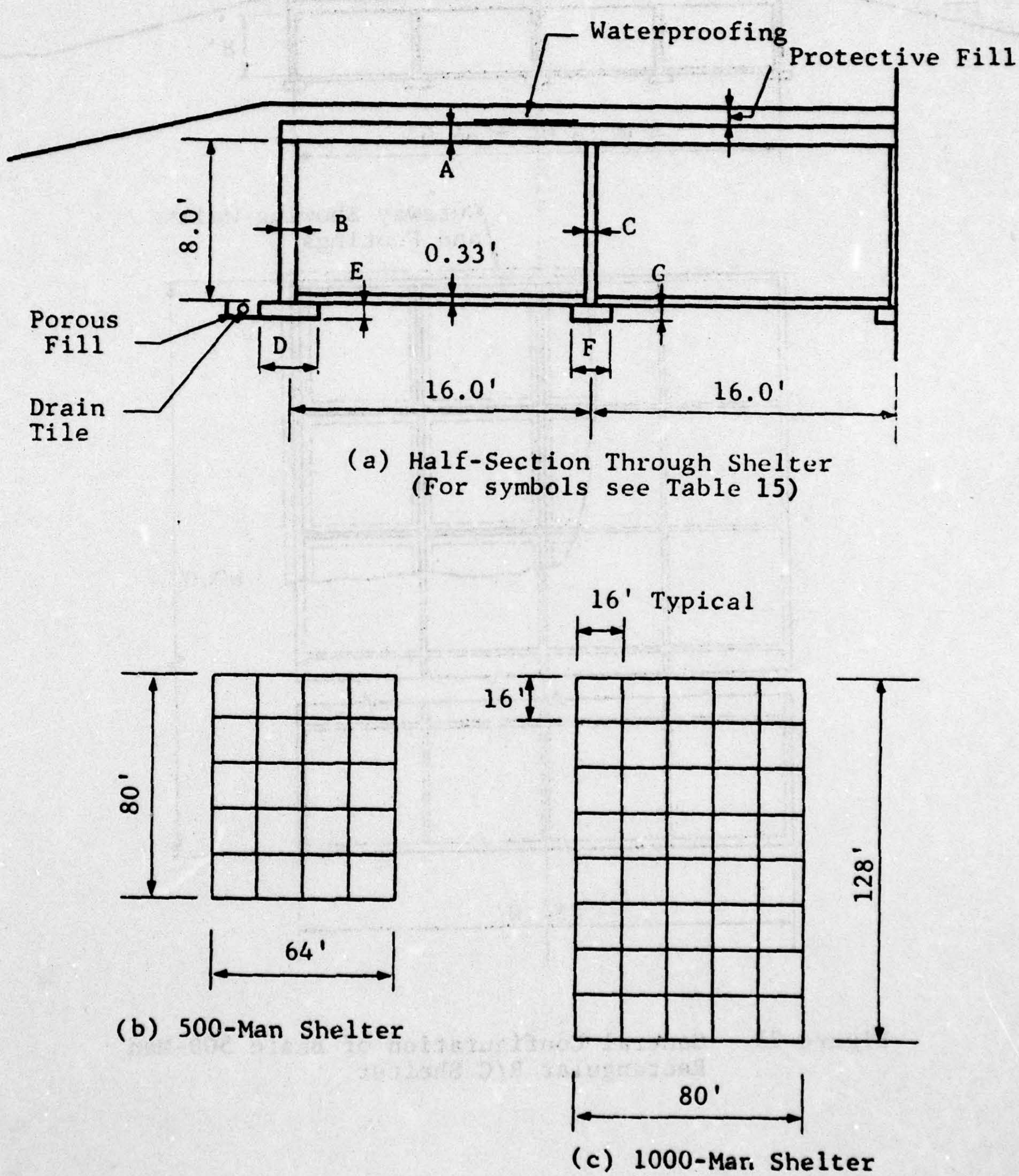


Figure 24. Basic Dimensions of R/C Rectangular Shelter

TABLE 15. BASIC DIMENSIONS OF R/C RECTANGULAR SHELTER

Member	Dimensions for Indicated Design Weapon Environment, in.			
	FRE	10 psi	20 psi	30 psi
Roof Thickness	6	9	12	18
Exterior Wall Thickness	8	8	9	10
Interior Wall Thickness	6	6	6	6
Exterior Footing Width	24	24	27	36
Exterior Footing Depth	8	8	8	8
Interior Footing Width	24	24	24	24
Interior Footing Depth	8	8	8	8

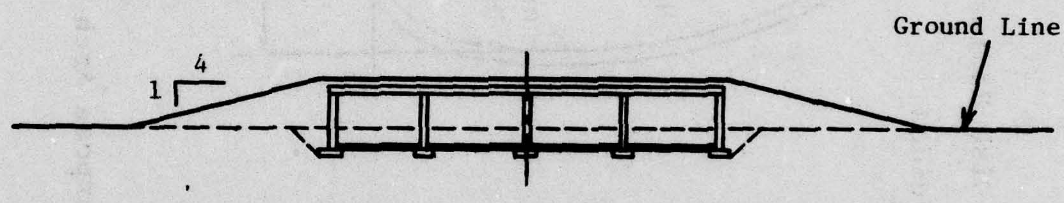


Figure 25. Rectangular Shelter Location Relative to Ground Surface

3.3.3 Entranceways for Arch and Rectangular Shelters

Low Level Weapon Effects Designs - A typical entranceway consists of:

1. an underpass type tunnel,
2. an internal shelter door,
3. an external shelter door (fallout radiation environment only),
4. a bulkhead, and
5. a blast door (no door is provided in the case of a fallout radiation environment).

Entranceway details are shown in Figure 26 and dimensions are given in Reference 59. The tunnel consists of corrugated steel plate section with corrugations 2-in. deep and a pitch of 6 in. The interior door is of standard commercial hollow metal construction, the external door is of stiffened steel plate. Entrance bulkheads

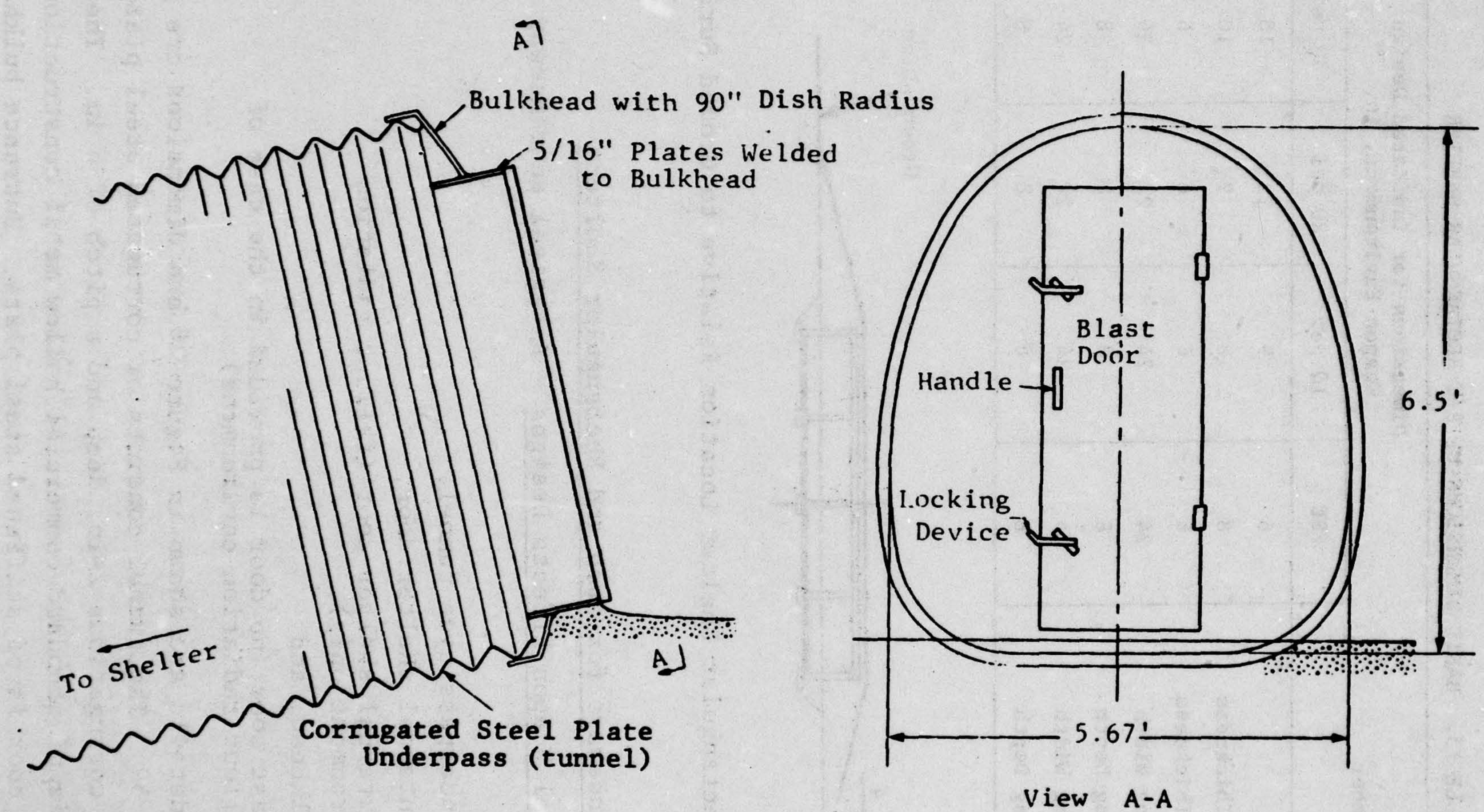


Figure 26. Entranceway Details for Single-Purpose Arch and Rectangular Shelters

are of structural steel plate formed with a 90 in. radius. The exterior blast door is made of two skins of galvanized metal and a core of aluminum honeycomb. The honeycomb is installed with its ribbon direction spanning the 24 in. door width. The design assumes one entranceway for each 500-man shelter unit.

High Level Weapon Effects Designs - Entranceways for the 100 and 150 psi arch shelters are similar to those described earlier except that these consist of RC cast monolithically with the shelter. Due to high overpressures to be resisted the blast doors are also different. A typical entranceway is illustrated in Figure 27. The blast door consists of a structural steel grid filled with concrete. It rests on rails and is mechanically actuated. The blast door detail is shown in Figure 28 which also gives the overall dimensions of the entranceway. Dimensions of the entranceway cross section are given in Figure 29.

3.3.4 People Survivability Estimates

Arch and rectangular shelters considered in this chapter are simple structures in the sense that their survival in a nuclear weapon blast environment is governed primarily by the strength of a single, key structural component. In the case of arches the key structural component is the arch shell, in the case of rectangular shelters it is the roof slab.

Prior to collapse all shelter occupants are assumed to be survivors, after collapse all shelter occupants are assumed to be fatalities. Thus for the shelter, and its occupants the survivability rating can be represented by means of a bilinear function relating survival to overpressure as shown in Figure 30. At overpressure intensity P_A the structure has yielded so that plastic hinges are fully formed in key structural elements. It is assumed, however, that these elements are still connected and are capable of supporting their own weight and the surcharge dead load. At overpressure P_B, key structural elements (roof slabs, arch shells and end walls) are no longer capable of supporting their own weight.

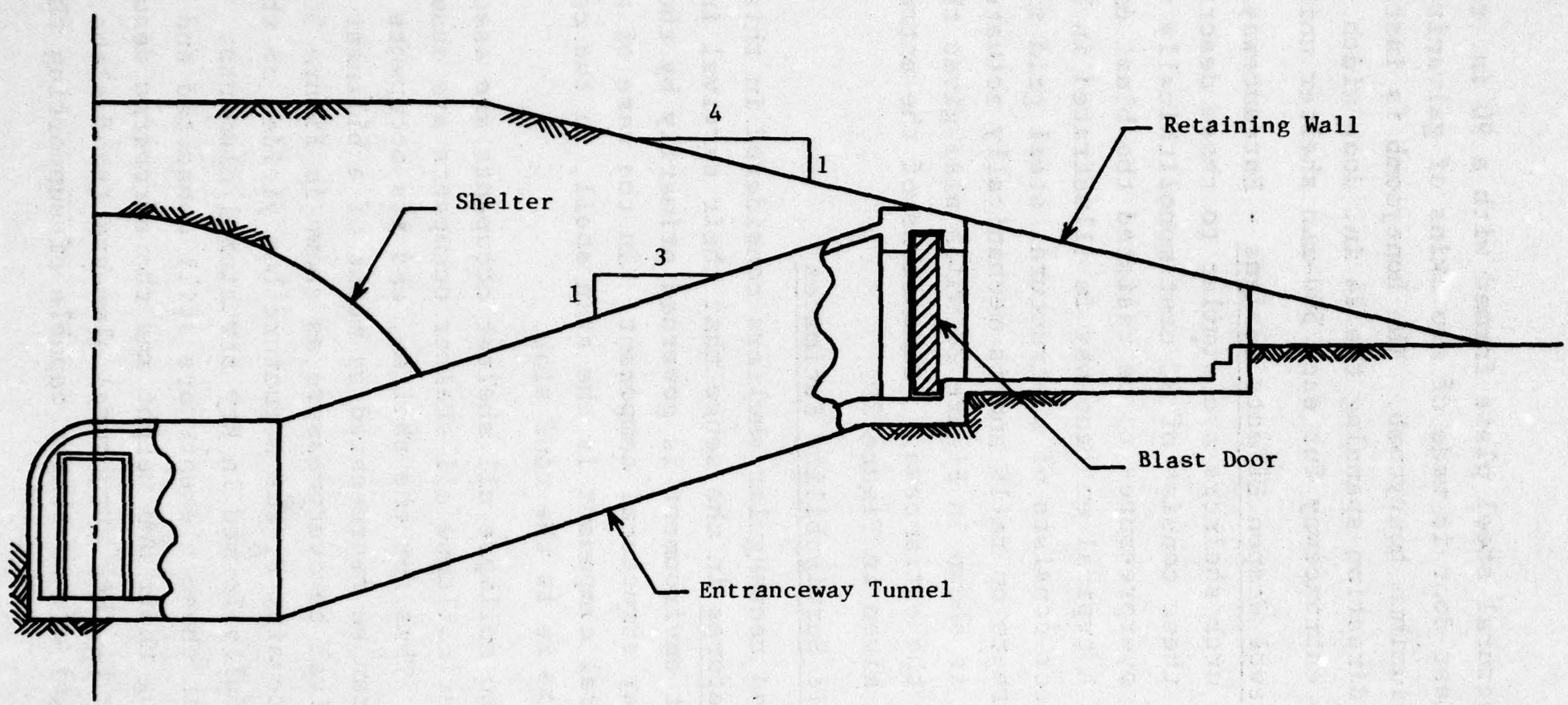


Figure 27. Entranceway for 100 and 150 psi Design Shelters (Elevation)

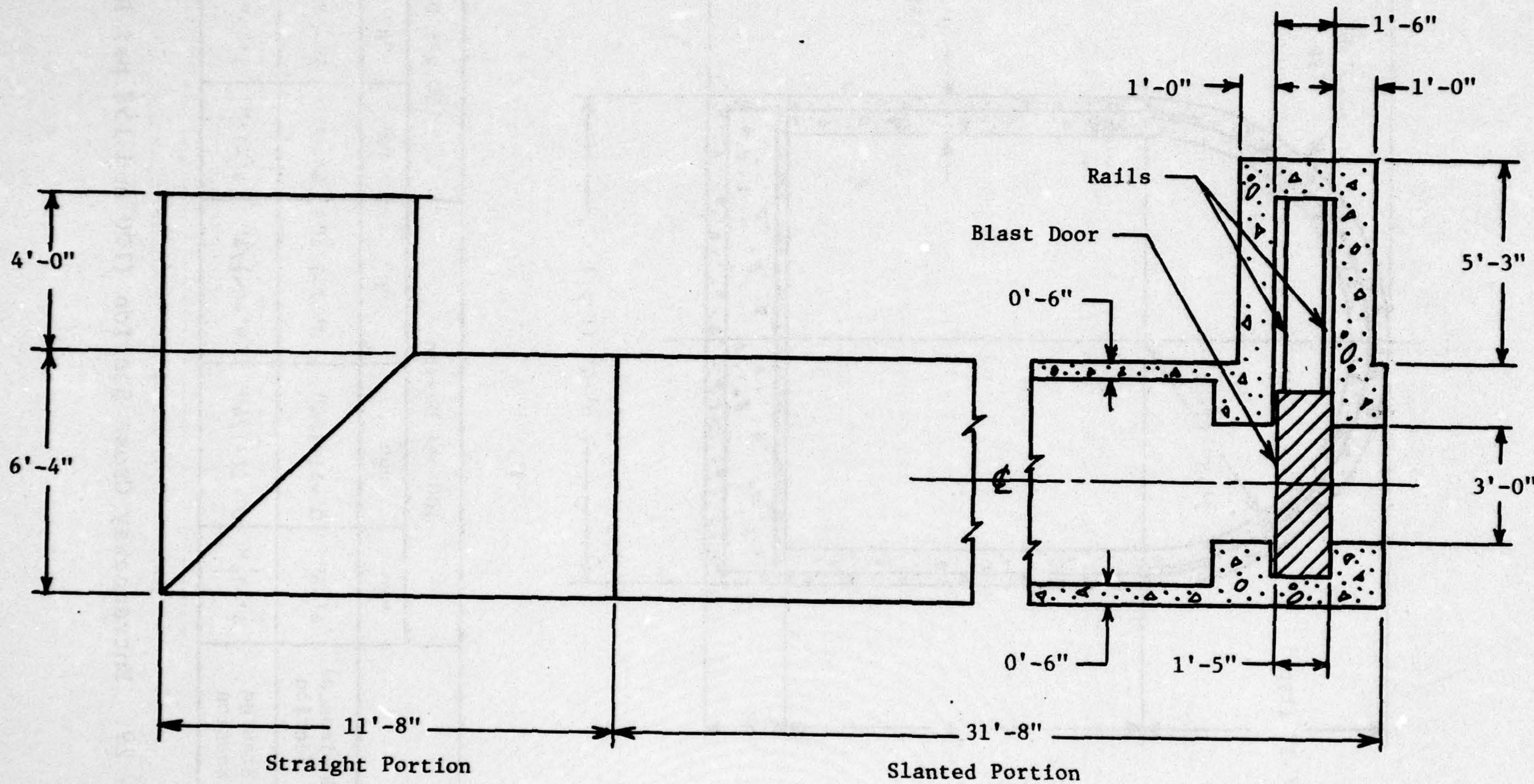
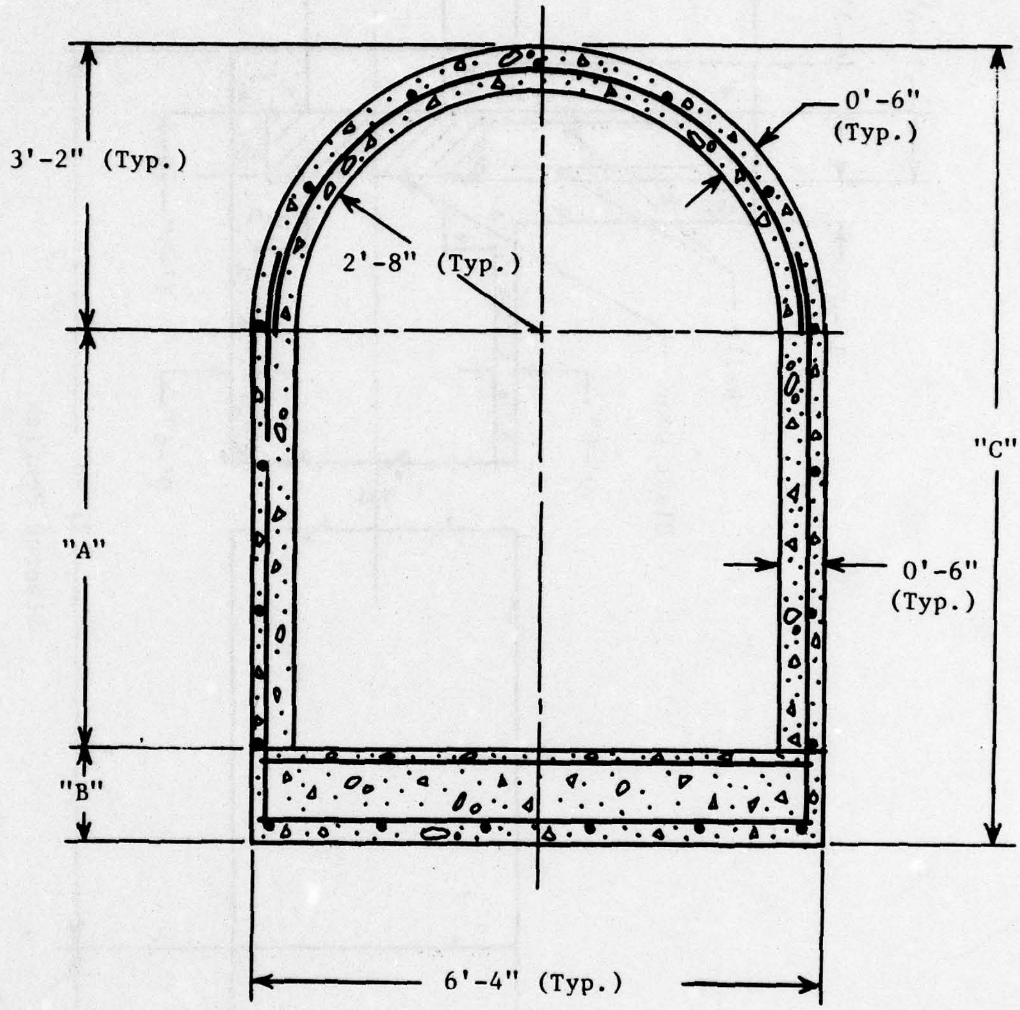


Figure 28. Entranceway Tunnel Plan (100 and 150 psi Design Shelters)



	100 psi Design			150 psi Design		
	"A"	"B"	"C"	"A"	"B"	"C"
Horizontal Section	4'-6"	0'-11-1/4"	8'-7-1/4"	4'-6"	1'-2"	8'-10"
Slanted Section	4'-11"	0'-11-1/4"	9'-0-1/4"	4'-11"	1'-2"	9'-3"

Figure 29. Entranceway Cross Section (100 and 150 psi Designs)

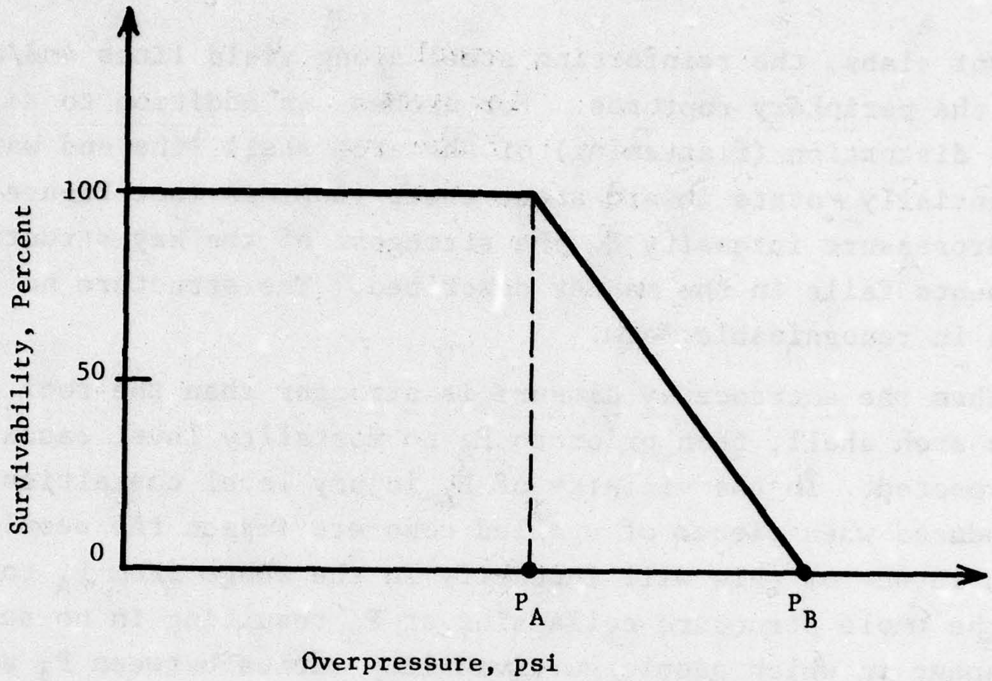


Figure 30. Survivability Rating

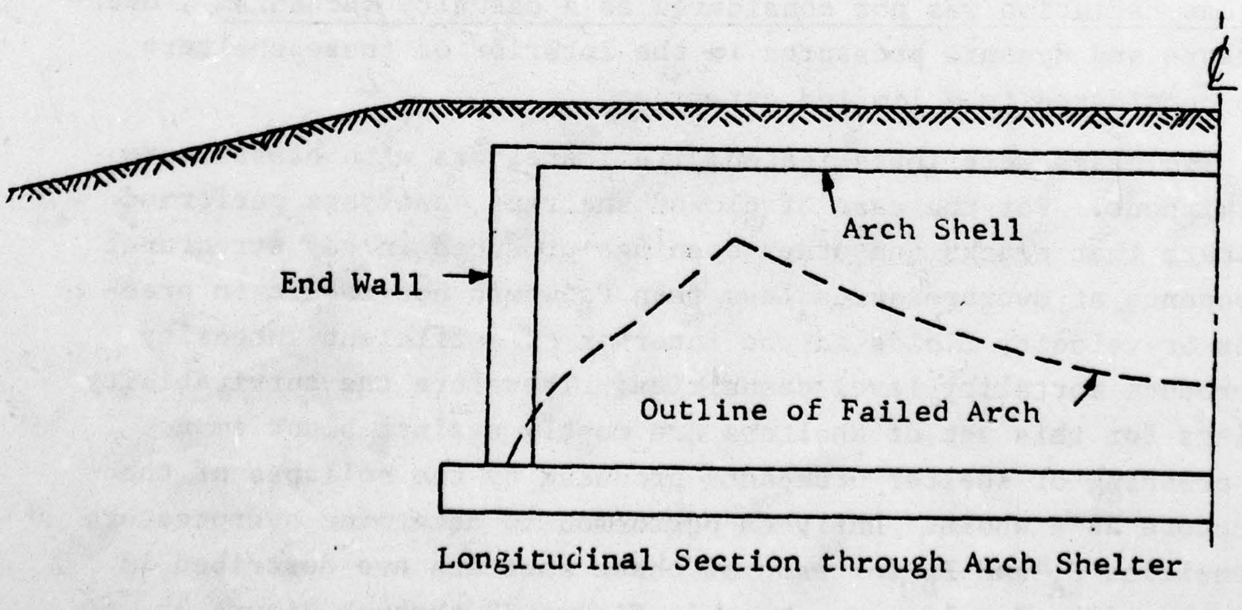


Figure 31. Definition of Arch Structure Failure

For roof slabs, the reinforcing steel along yield lines and/or along the periphery ruptures. For arches, in addition to significant distortion (flattening) of the arch shell, the end walls substantially rotate inward about their footings (see Figure 31). At overpressure intensity P_B the strongest of the key structural components fails in the manner described. The structure no longer exists in recognizable form.

When the entranceway closure is stronger than the roof slab or the arch shell, then prior to P_A no mortality level casualties are expected. In the vicinity of P_A injury level casualties will be produced when pieces of spalled concrete impact the people. The influence of this will intensify in the range from P_A to P_B with the whole structure collapsing at P_B resulting in no survivors. The manner in which people survivability varies between P_A and P_B is not known at this time, thus, the two points are connected by a straight line.

When other casualty mechanisms such as dynamic pressures and prompt nuclear radiation are considered then depending on their intensity, casualties may begin to be produced prior to P_A. Prompt nuclear radiation was not considered as a casualty mechanism. Overpressure and dynamic pressures in the interior of these shelters were considered to a limited extent.

Two cases were investigated, i.e., shelters with blast doors and without. For the case of closed shelters, analyses performed indicate that cracks and other openings produced in key structural components at overpressures less than P_B would not result in pressures or velocity fields in the interior of sufficient intensity to produce mortality level casualties. Therefore the survivability ratings for this set of shelters are mostly against blunt impact and crushing of shelter occupants produced by the collapse of the structure as a whole. Analyses performed to determine overpressure intensities P_A and P_B for each of these shelters are described in Reference 60. Results are shown in Figure 32 through Figure 35.

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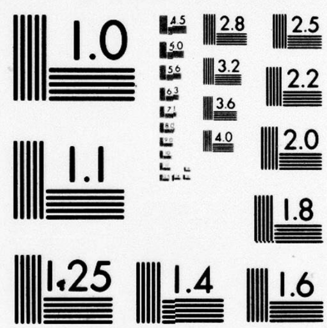

MICROCOPY RESOLUTION TEST CHART

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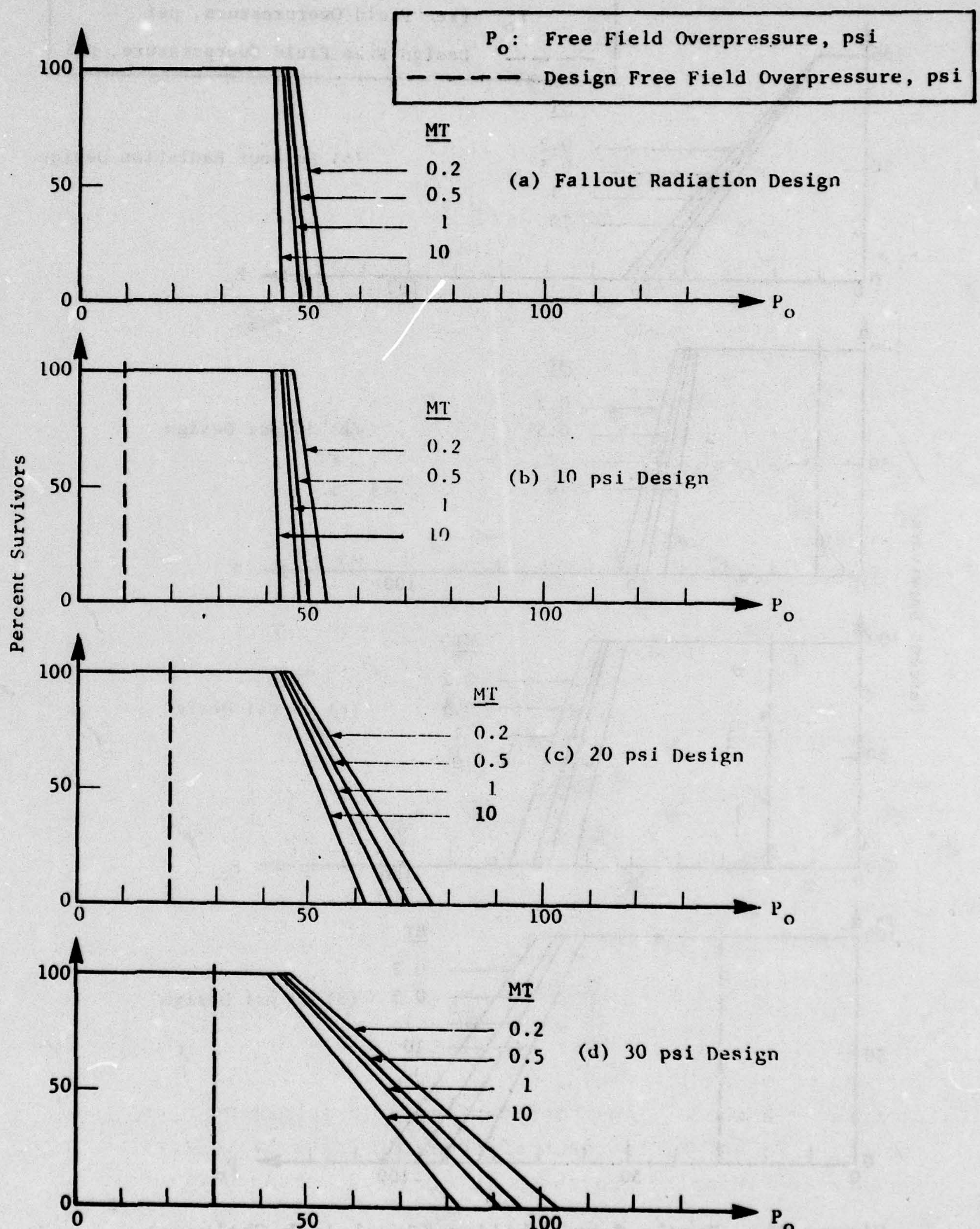


Figure 32. People Survivability (RC Arch Shelters) Low Level Weapon Effects Designs

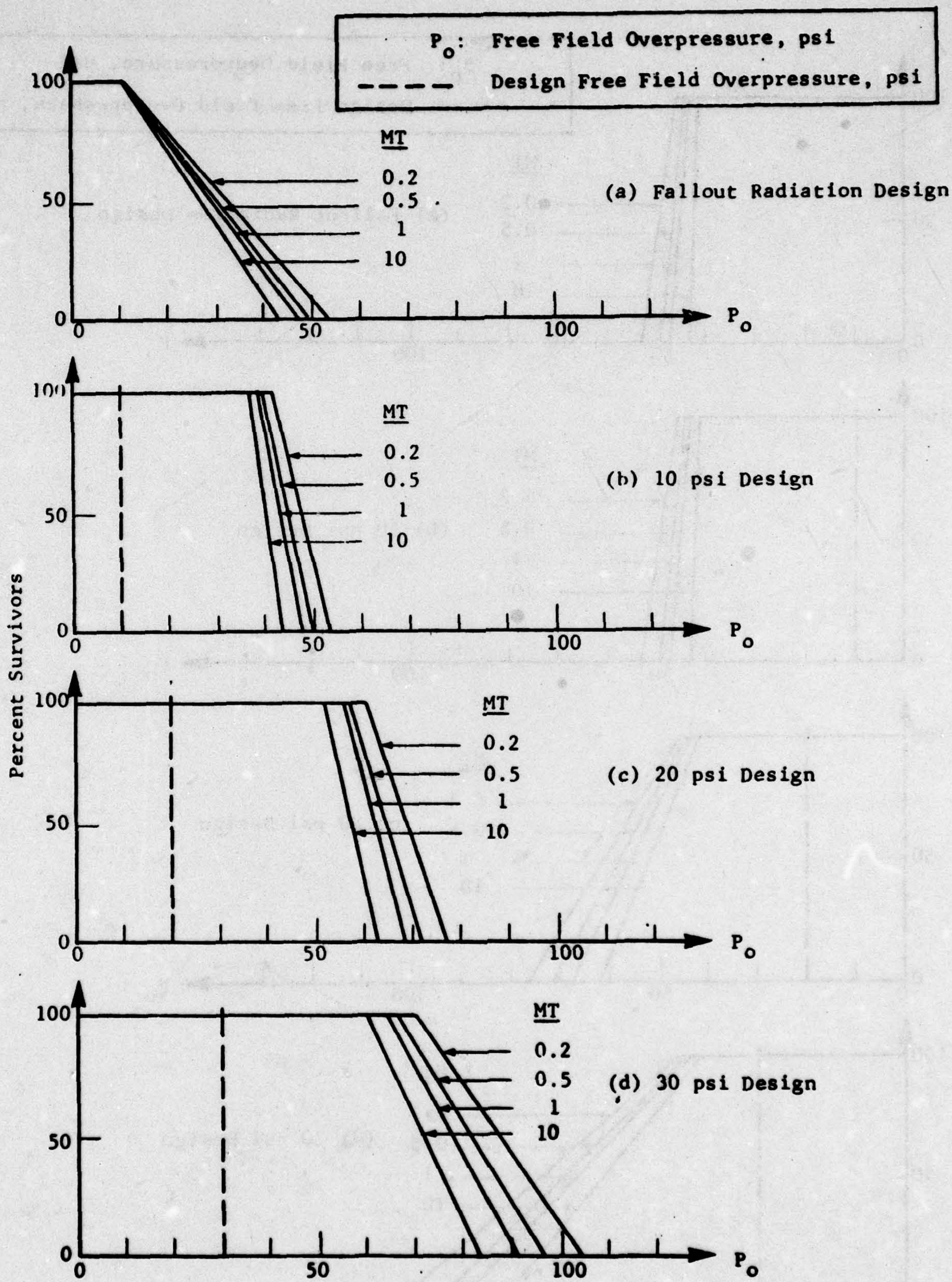


Figure 33. People Survivability (Steel Arch Shelters) Low Level Weapon Effects Designs

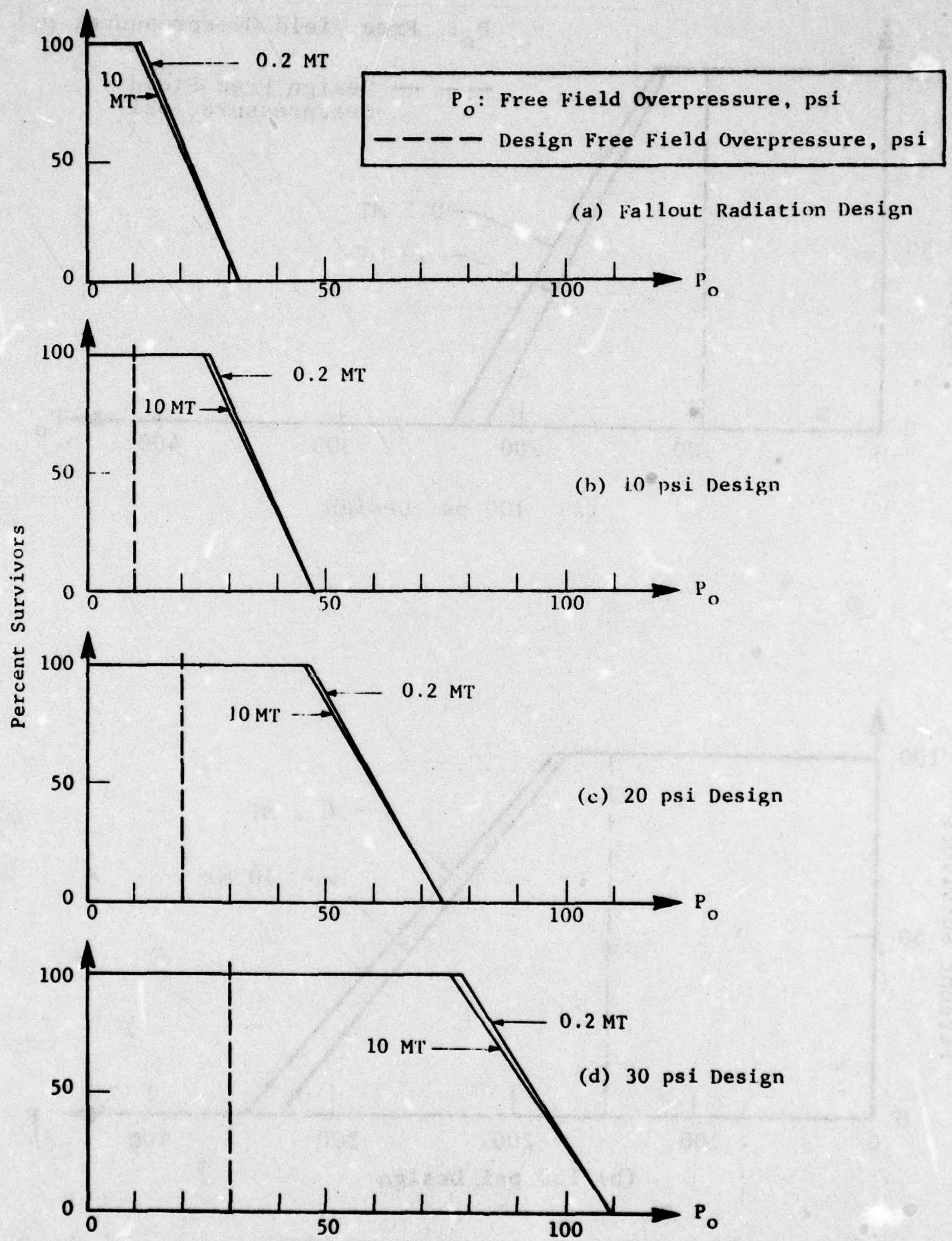
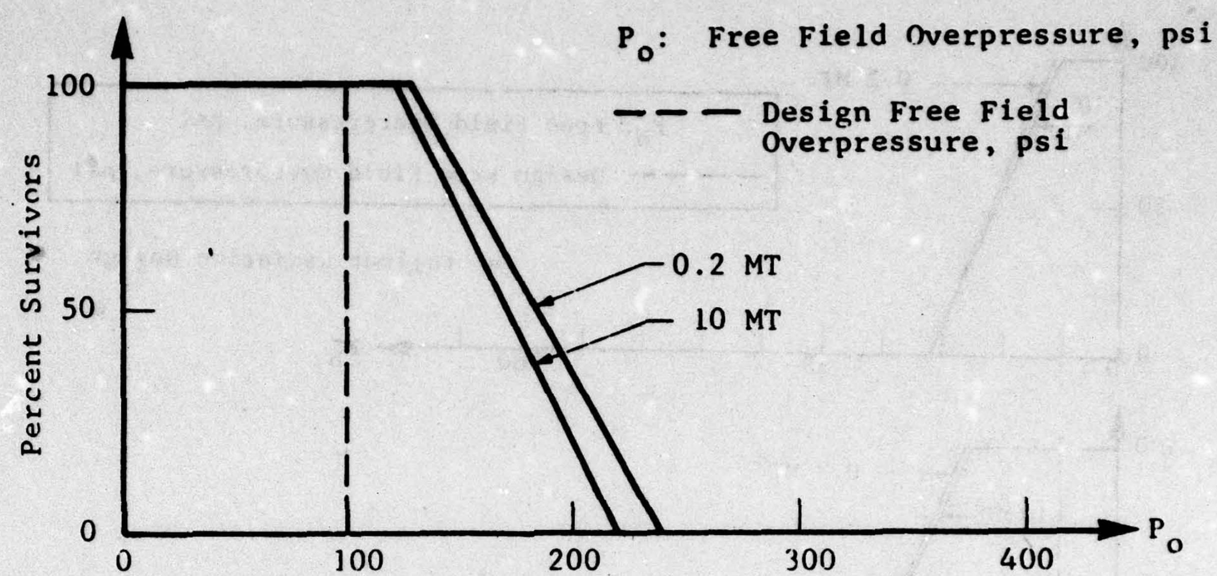
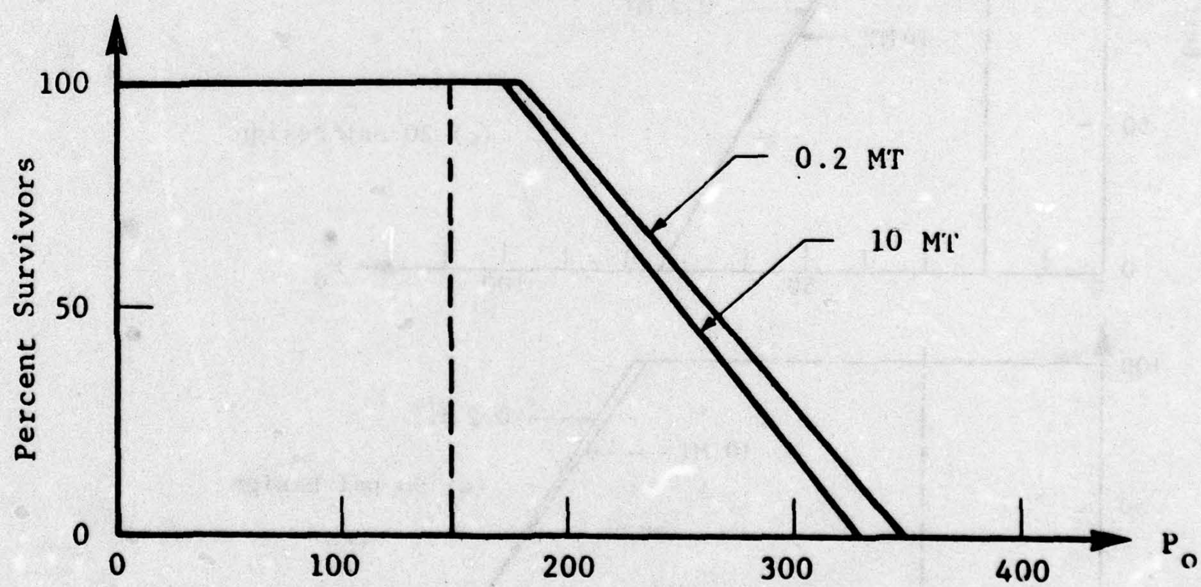


Figure 34. People Survivability (Single-Purpose RC Rectangular Shelters) Low Level Weapon Effects Designs



(a) 100 psi Design



(b) 150 psi Design

Figure 35. People Survivability (High Level Weapon Effects Designs)

From these results it is evident that methods employed in the design of these shelters are generally conservative, the design overpressure is not close to the failure overpressure. This fact was also brought out in field tests (Ref. 4) where no buried structures experienced significant failures. The fact that a structure is labeled a "fallout shelter" does not restrict it from providing blast resistance. The extent of inherent blast resistance depends on the structural system, depth of burial and materials of construction.

An effort was devoted to estimate casualties due to blast winds entering shelter areas when blast doors are not provided. Only arch shelters were considered. The diffraction and drag loading on shelterees was estimated by means of a one-dimensional quasi-steady analysis (Ref. 61). The plan view of the lower level of an arch shelter is shown in Figure 36, which illustrates the area affected by the jet. Shelter occupants were assumed to be located in the area affected by the jet and were simulated using a two-dimensional, rigid block "tumbling man" model illustrated in Figure 37. Blast tumbling calculations were performed for 10, 20, 30 and 50 psi free field (external) overpressures and three initial body positions, i.e., standing, sitting and prone. The end result sought was the head impact velocity of individuals with floor or the back wall. The levels of casualty experienced was estimated on the basis of impact velocity magnitudes (Ref. 20, 2). Assuming that shelterees are uniformly distributed in all shelter areas, i.e., on the upper and lower levels, the survivability estimates for the arch shelters are shown in Figure 38 and Figure 39.

These results indicate that if the occupants are in prone and/or sitting positions and occupy areas away from the jet boundaries at the time of the attack, then blast winds entering the interior of the arch shelters should not pose a serious hazard. This statement also applies to rectangular shelters considered in this chapter.

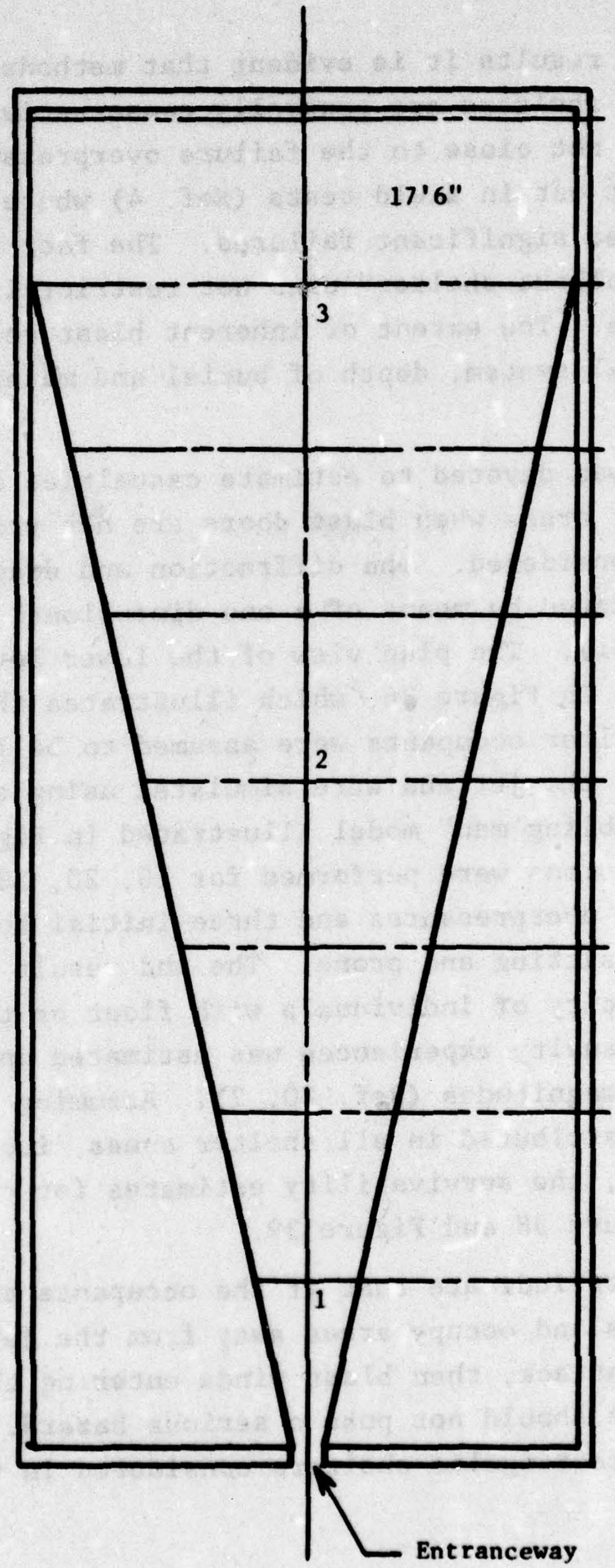


Figure 36. Arch Shelter Plan Showing Jet Boundary

NOTE: Parameter values used are included in Table 16

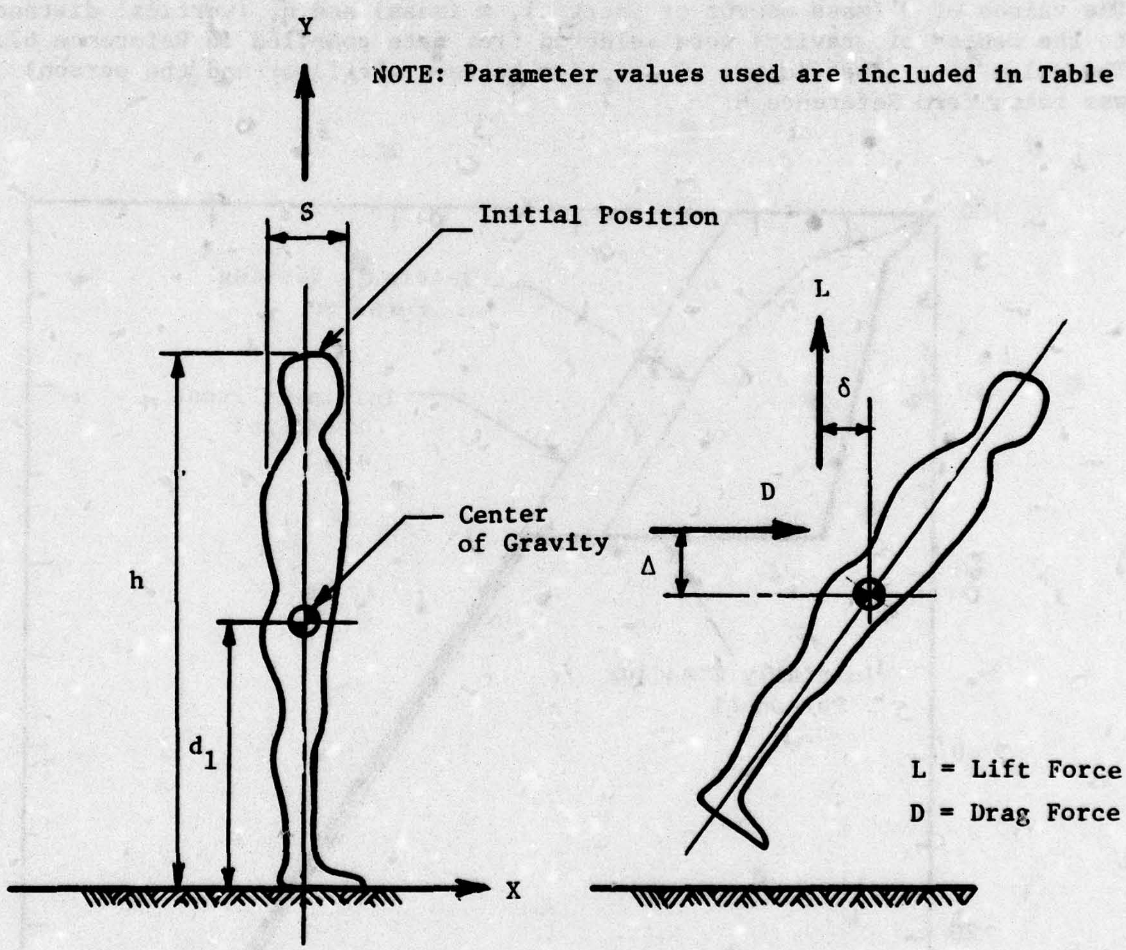


Figure 37. Tumbling Man Simulation Model (Standing Configuration)

TABLE 16. "TUMBLING MAN" PARAMETER VALUES*

Orientation	I lb-sec^2-ft	m lb-sec^2/ft	S ft	d_1 ft	h ft	μ
Standing	8.58	5.16	0.915	3.200	5.770	0.55
Prone	8.58	5.16	5.750	0.458	0.916	0.55
Sitting	3.16	5.16	1.550	1.030	3.280	0.55

* The values of I (mass moment of inertia), m (mass) and d_1 (vertical distance to the center of gravity) were selected from data compiled in Reference 62. The value of μ (coefficient of friction between the floor and the person) was taken from Reference 6.

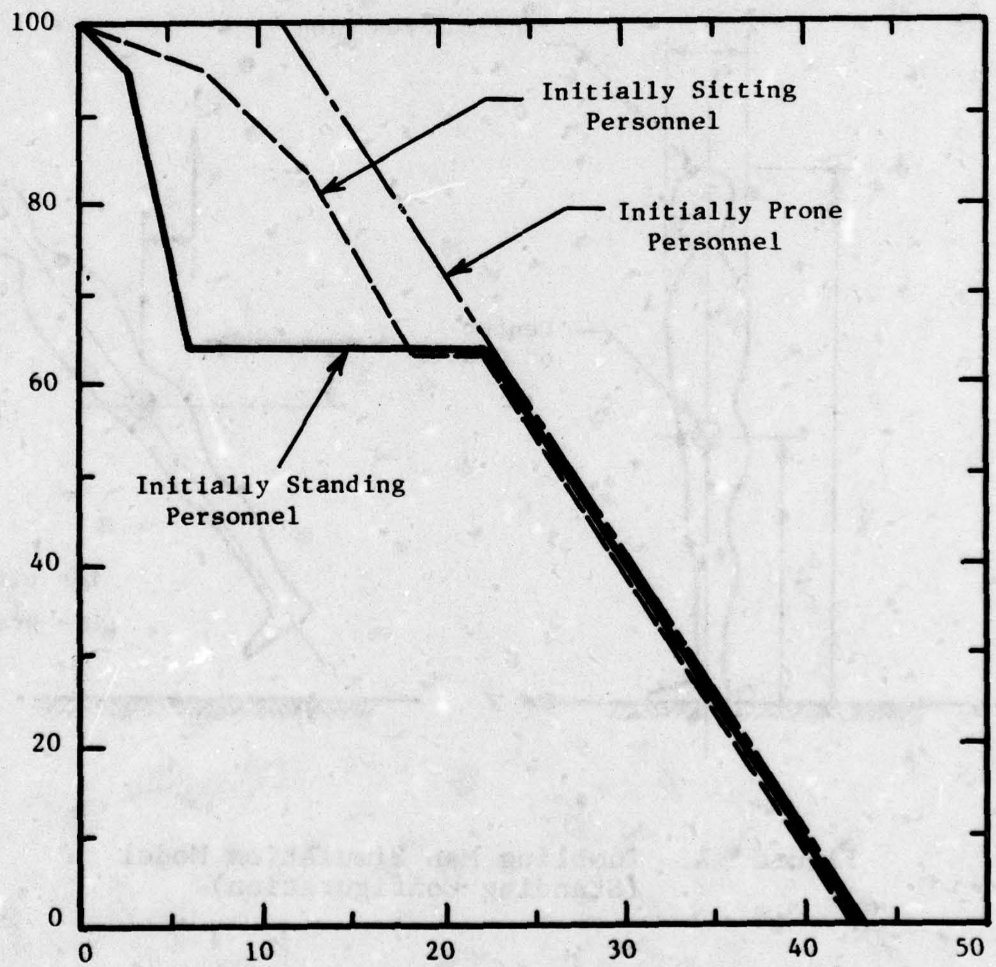


Figure 38. People Survivability Estimate for an Open Steel Arch Shelter (Fallout Radiation Design)

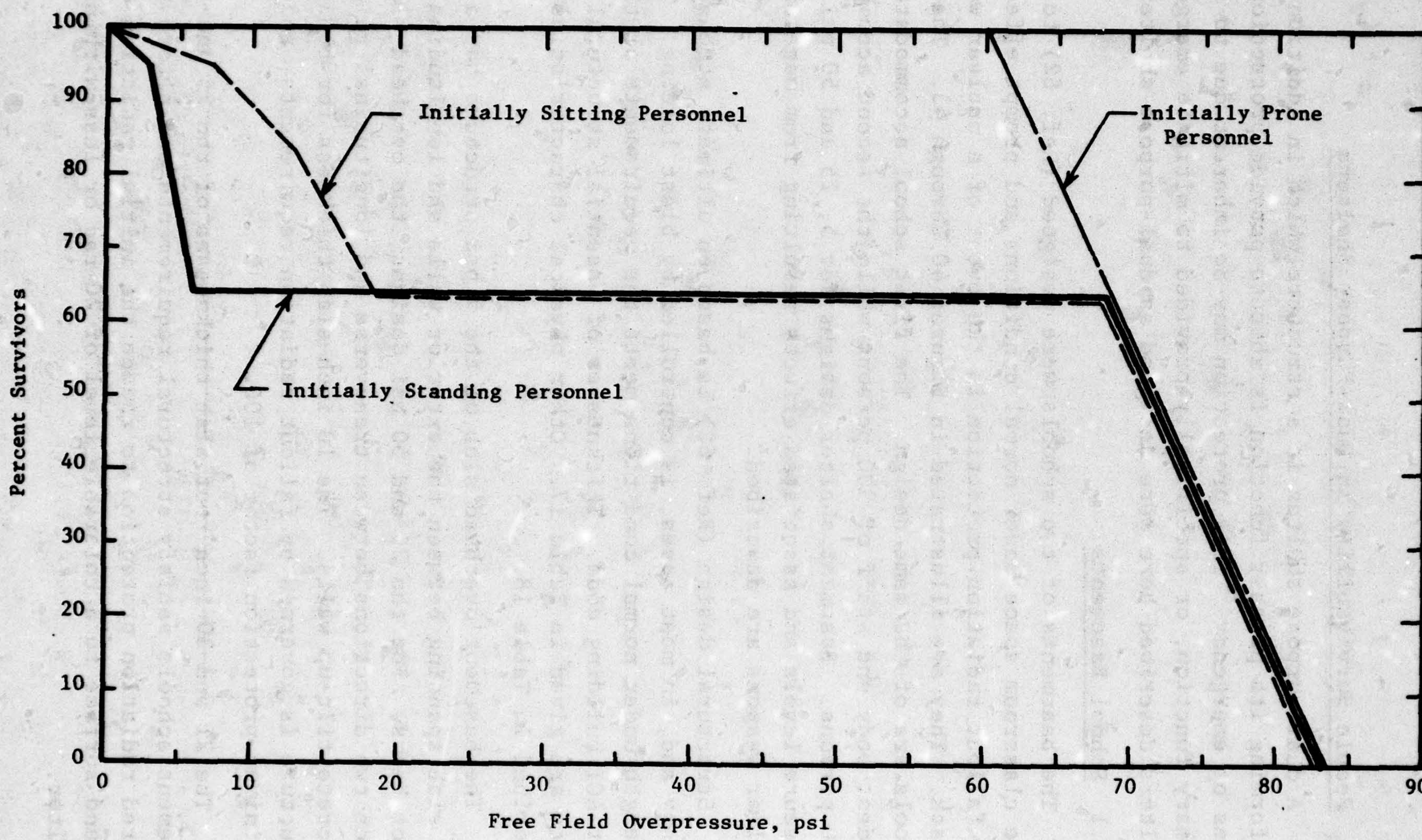


Figure 39. People Survivability Estimate for an Open Steel Arch Shelter (30 psi Design)

3.4 People Survivability in Dual-Purpose Shelters

A dual-purpose shelter is a structure which in addition to performing its primary function is able to provide protection in times of emergency. This protection may be inherent due to the primary function, or specifically provided to mitigate emergencies. Shelters described here were designed as dual-purpose shelters.

3.4.1 School Basements

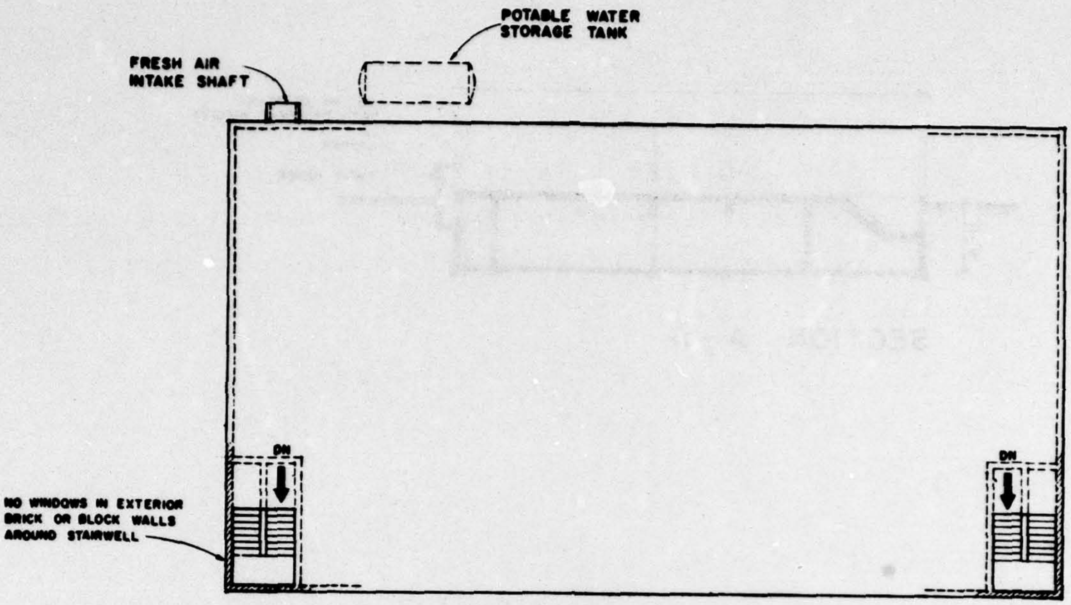
The basements of two schools were designed (Ref. 62) to provide classroom space under normal conditions and prompt effects and fallout radiation protection in the event of a nuclear weapon attack. They are illustrated in Figures 40 through 43. The two schools are of the same design. The first school accommodates a student body and staff of 500 persons while the second accommodates 1100 persons. Basement shelter designs for 5, 25 and 50 psi overpressure levels and associated effects resulting from megaton range nuclear weapons are described.

Structural design (Ref. 62) is based on ultimate strength theory and, in most cases, is controlled by blast loading. The strength under normal conditions meets the requirements of the current ACI building code. Thicknesses of essential structural elements are given in Table 17. Other physical characteristics are described in Table 18.

The basement overhead slab of the 5 psi structure has a one-way slab spanning between the exterior walls and longitudinal corridor beams. For the 25 and 50 psi designs, the overhead slab spans two directions between transverse and longitudinal reinforced concrete tilt-up walls. The 10 inch slab thickness for the 5 psi structure is governed by fallout radiation requirements, and affords a minimum protection factor of 100.

The 21 and 30 inch roof slab thicknesses of the 25 and 50 psi basement schools satisfy structural requirements and afford the required radiation protection to reduce the initial radiation on the ground surface to a tolerable level of 20 rad or less within the shelter.

UPPER LEVEL PLAN



LOWER LEVEL PLAN

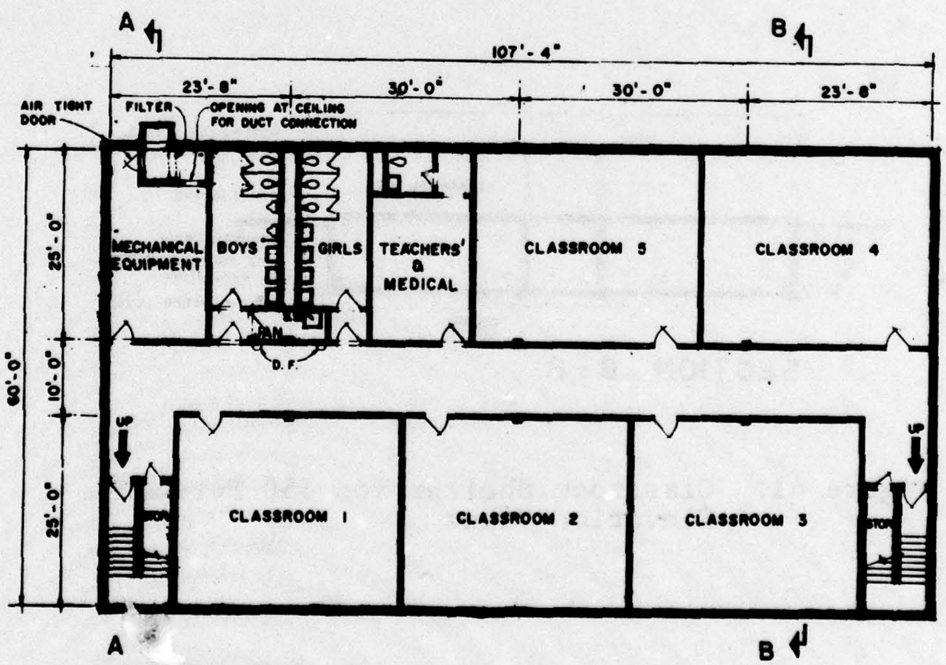
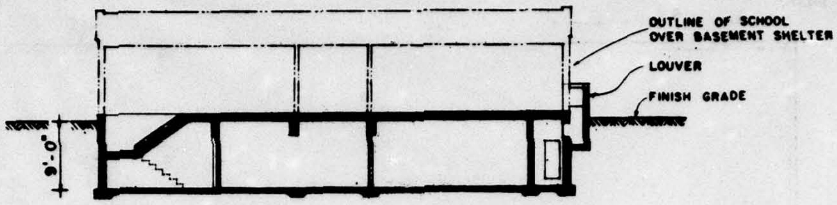
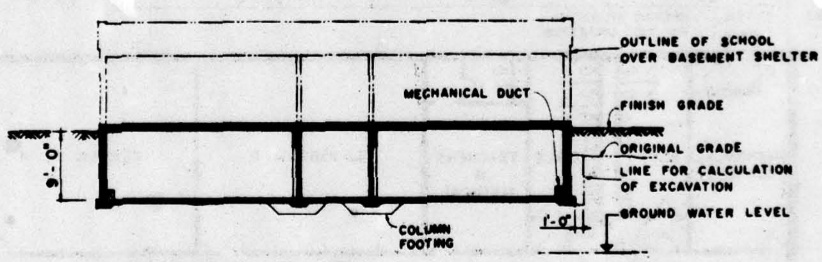


Figure 40. Classroom Shelter for 550 Persons - Shelter Plan



SECTION A - A



SECTION B - B

Figure 41. Classroom Shelter for 550 Persons - Elevation Views

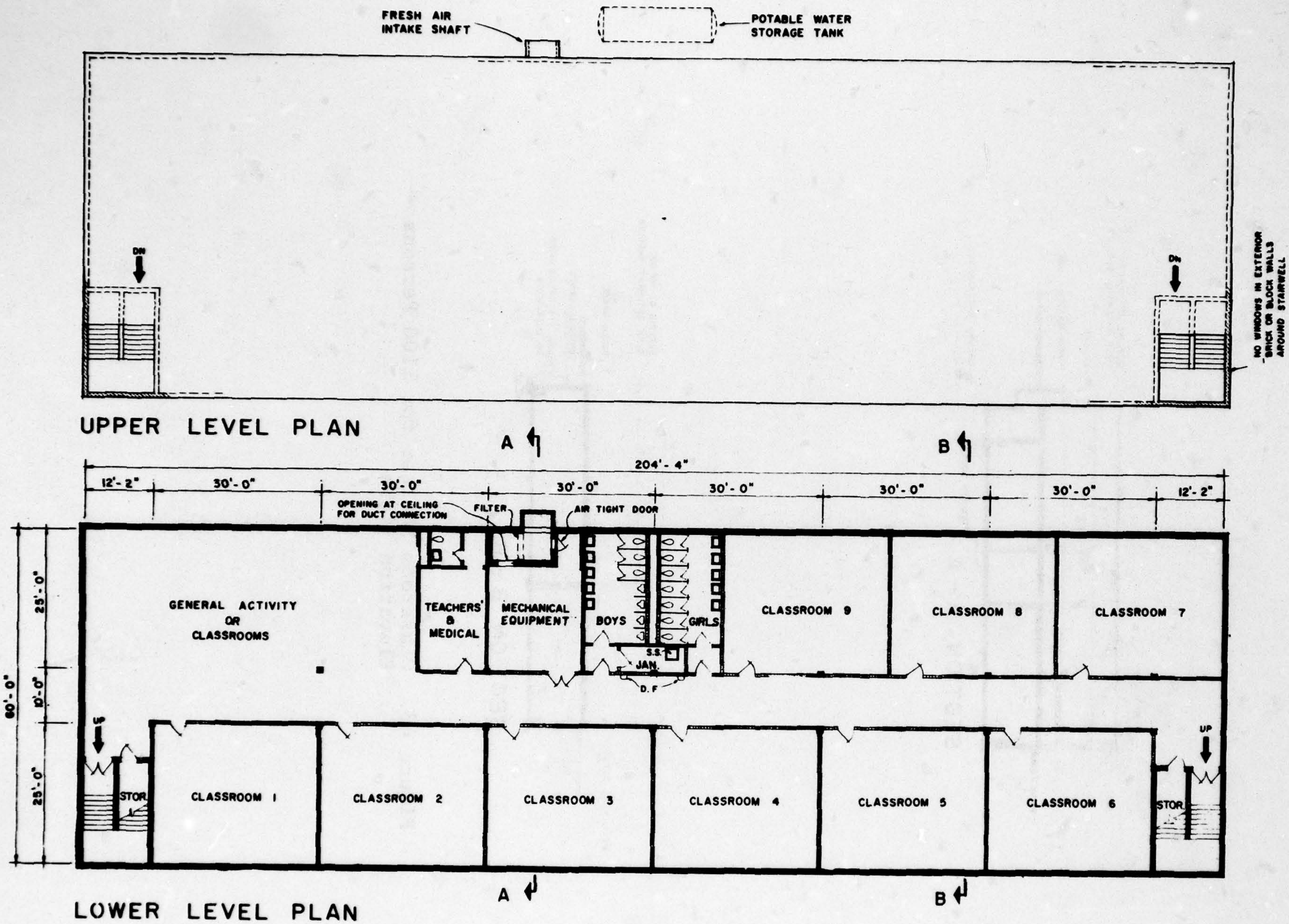


Figure 42. Classroom Shelter for 1100 Persons - Shelter Plan

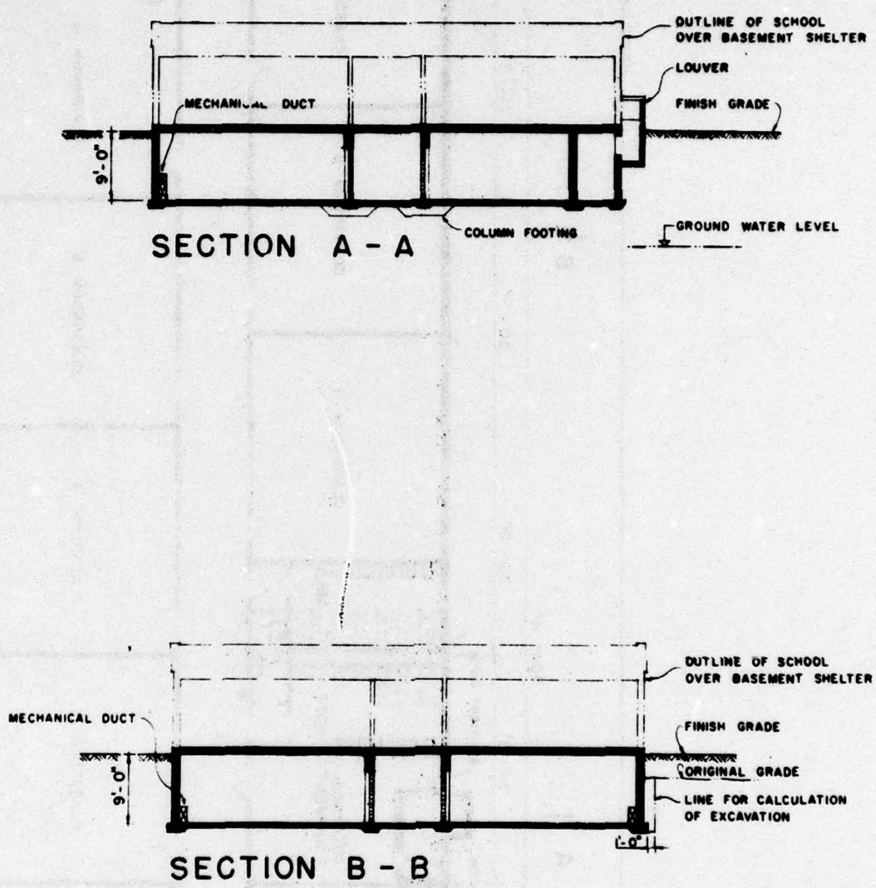


Figure 43. Classroom Shelter for 1100 Persons - Elevation Views

TABLE 17. MEMBER THICKNESSES

Member	Thickness at Indicated Pressure Level 5 psi	25 psi	50 psi
Roof Slab:	10"	21"	30"
Exterior Walls:	10"	10"	10"
Corridor Beam: Width	12"	-	-
Depth	3'-0"	-	-
Concrete Partitions:	-	6"	6"
Columns:	12"x12"	-	-
Exterior Wall Fts. (Width):	1'-10"	2'-0"	4'-0"
Interior Wall Fts. (Width):	1'-6"	3'-6"	6'-6"
Column Fts.:	4'-0"x4'-0"	-	-

TABLE 18. CHARACTERISTICS OF SCHOOL BASEMENT SHELTERS

Characteristic	Design Environments 5, 25 and 50 psi	
	Capacity, persons	
	550	1100
Gross Floor Area (sq ft)	6,440	12,260
Total Volume (cu ft)	57,960	110,340
Headroom (ft)	9	9
Shelter Area per Occupant (cu ft)	11.7	11.1
Shelter Volume per Occupant (cu ft)	105.3	99.9
Fallout Protection Factor	100	100
Maximum Inside Dose of Initial Radiation (rad)	20	20

The 5 psi shelter has cinder block interior partitions; the 25 and 50 psi shelters have reinforced concrete tilt-up bearing walls. Reinforced concrete partitions were selected in the 25 and 50 psi schools for two reasons: to serve as bearing walls and to provide adequate lateral resistance. Blast doors are included for each entranceway for each of the six designs.

The designs are based upon a minimum concrete strength of 3000 psi throughout for the 25 and 50 psi shelters and 3000 psi for the roof and columns, 2500 psi elsewhere, for the 5 psi shelter. The reinforcement conforms to ASTM A432 which has a minimum yield point of 60,000 psi. The live load on the basement roof is taken as 75 psf for the classrooms and 100 psf for the corridors. The dead load and live load from the upper level roof slab is assumed to be 10 and 40 psf, respectively. Debris loading is assumed to be negligible in combination with the blast load. The normal allowable soil bearing capacity is taken as 4 tons/sq ft.

The superstructure that would be located over such basements is not described in Reference 62. However, as shown in Figure 41 and Figure 43 it is at most a one story building. Since the basement is of reinforced concrete, the superstructure is likely to have a reinforced concrete frame with masonry walls. Being a low-rise structure of conventional design, it is not expected to produce any significant damage to the basement when interacting with the blast wave.

3.4.2 People Survivability in School Basement Shelters

People survivability estimates for this set of six shelters are given in Figure 44 and Figure 45. These results represent the case of closed shelters, i.e., the case when the blast doors are at least as strong as the overhead slab. The only casualty mechanism considered in the analysis was debris from the breakup and collapse of the overhead basement slab. Analytic procedure used in arriving at these estimates was the same as that used in the analysis of rectangular, single purpose shelters described in Section 3.3.2.

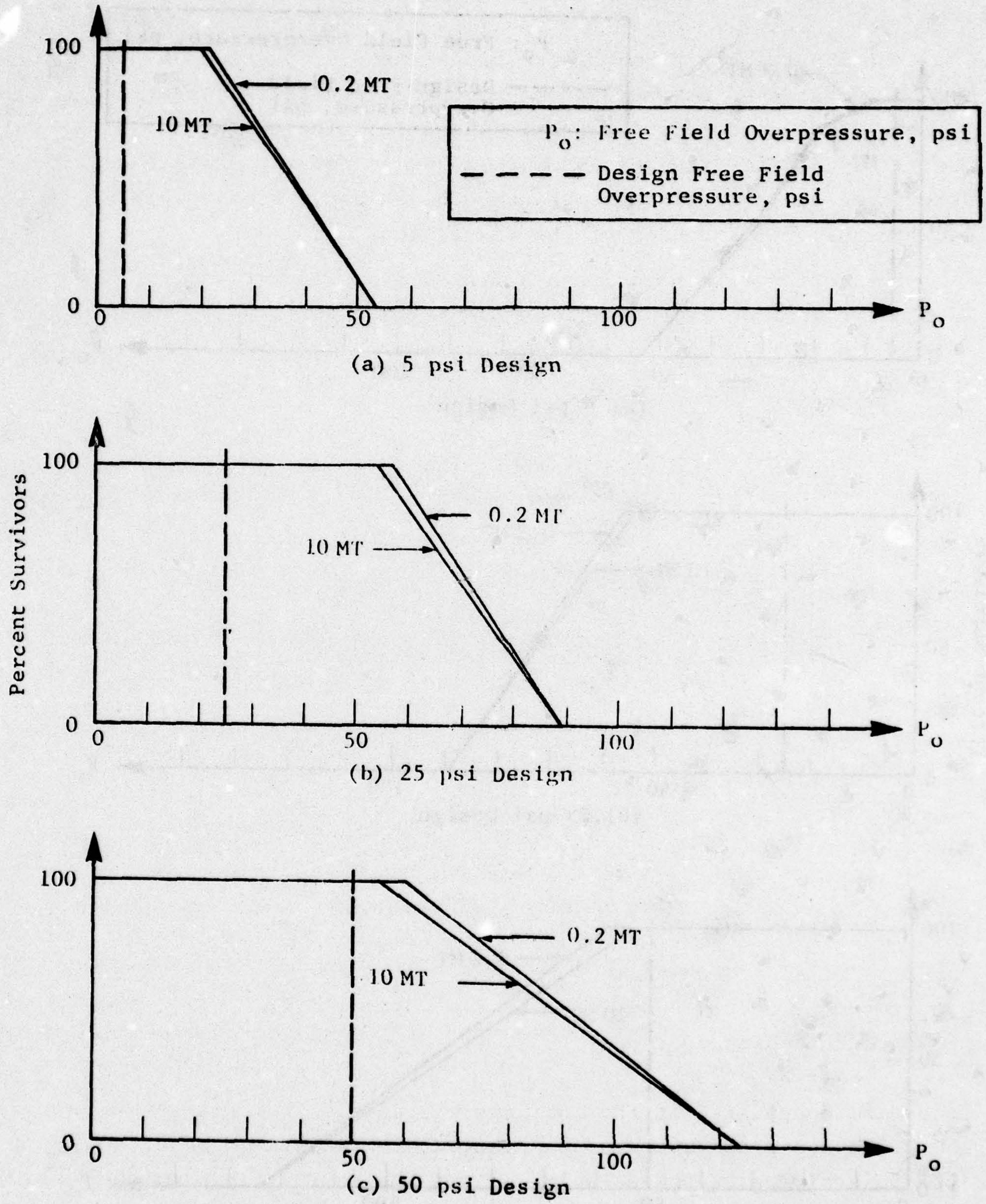


Figure 44. People Survivability (Dual-Use Basement Shelters, Population 550 Persons)

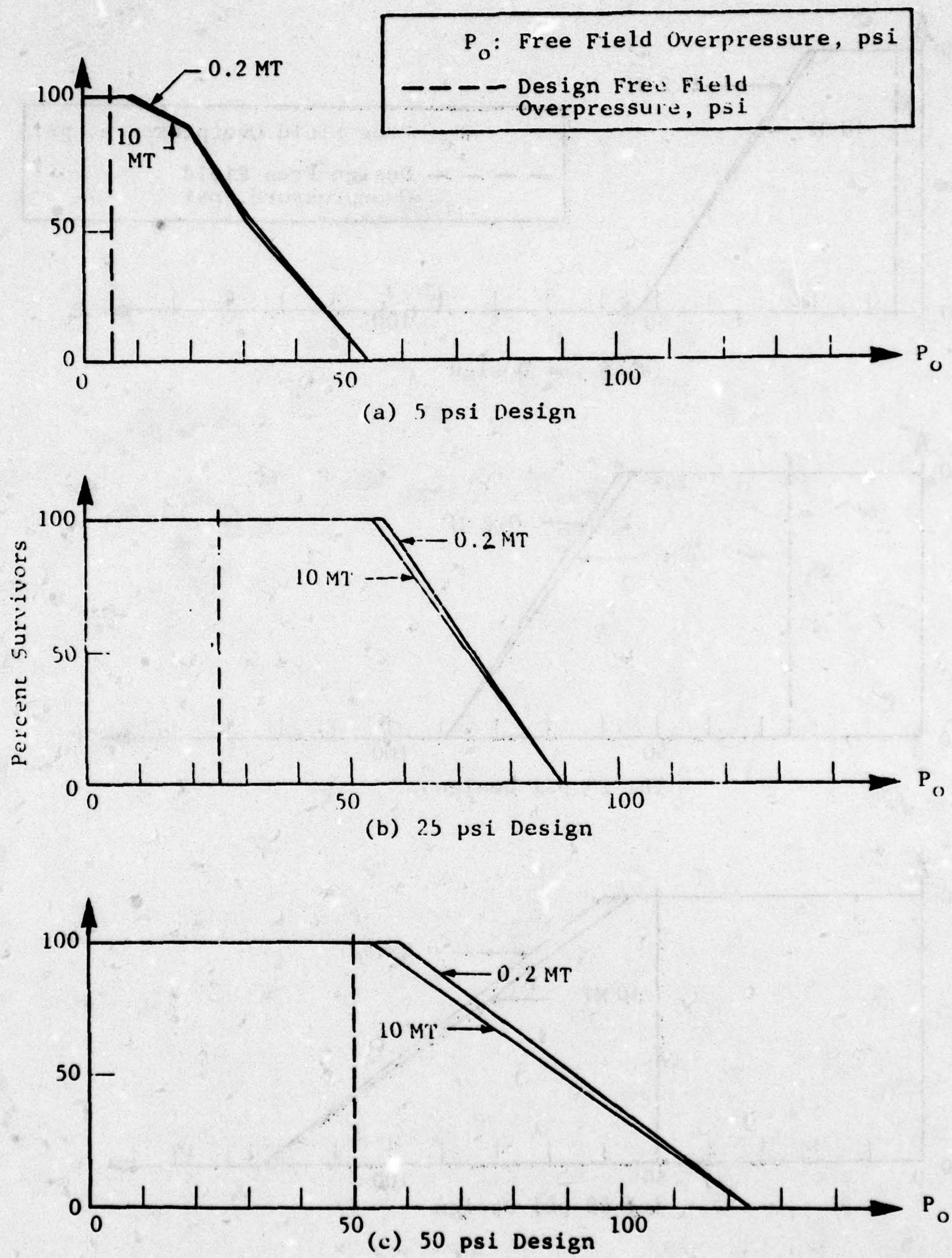


Figure 45. People Survivability (Dual-Use Basement Shelters, Population 1100 Persons)

The effects of prompt nuclear radiation were not considered in arriving at these results. Therefore at higher overpressure levels, i.e., greater than about 25 psi, these estimates will be lower than indicated.

These results also indicate the degree of conservatism inherent in the basic design at low or moderate design overpressures. Thus, a 5 psi design shelter first experiences yielding at about 20 psi and a 25 psi design shelter at about 55 psi.

3.4.3 Parking Garage Shelters

Parking garage shelters (Ref. 63) described are one-story below grade reinforced concrete structures proportioned so as to provide protection against the prompt effects of megaton range nuclear weapons and fallout radiation. They were designed to serve the dual function of parking garage during normal operation and shelter during emergency for each of three design overpressure levels, 5, 25 and 50 psi. These shelters are illustrated in Figures 46 through 48 and their basic physical characteristics are given in Tables 19 and 20. Layout is based on multiples of a 29 by 37 ft bay, proportioned to the dimensions of an average city block, with either parking facilities for 150 cars or shelter space for 5000 persons, as required. Typical locations for this type of shelter are (a) below a street-level parking area, or (b) below a city park site. The structure below the parking lot (Structure I) is designed with a roof slab which doubles as the deck of the parking lot. The structure below a city park site (Structure II) is modified to support 3 ft 6 in. of topsoil over the roof slab for landscaping. The structural design is based on ultimate strength theory and, in most cases, is controlled by the blast loading.

The overhead slab for each of the three design overpressure levels is a two-way flat slab which spans between the exterior walls and the interior columns. A 12 inch slab thickness is used for the 5 psi Structure I to fulfill structural requirements and afford a minimum fallout radiation protection factor of at least 100. This factor is somewhat greater for Structure II.

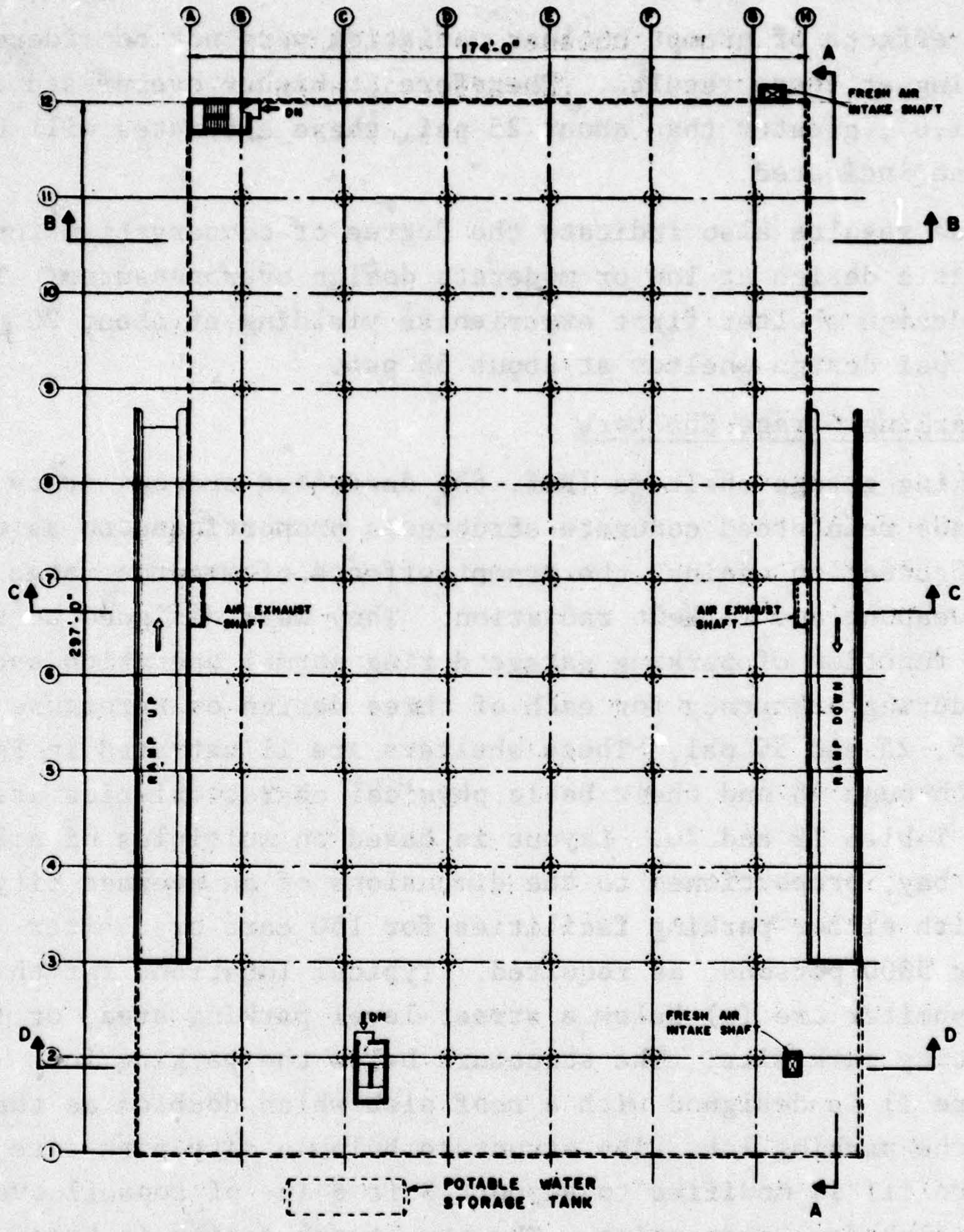


Figure 46. Parking Garage Shelter - Upper Level Plan

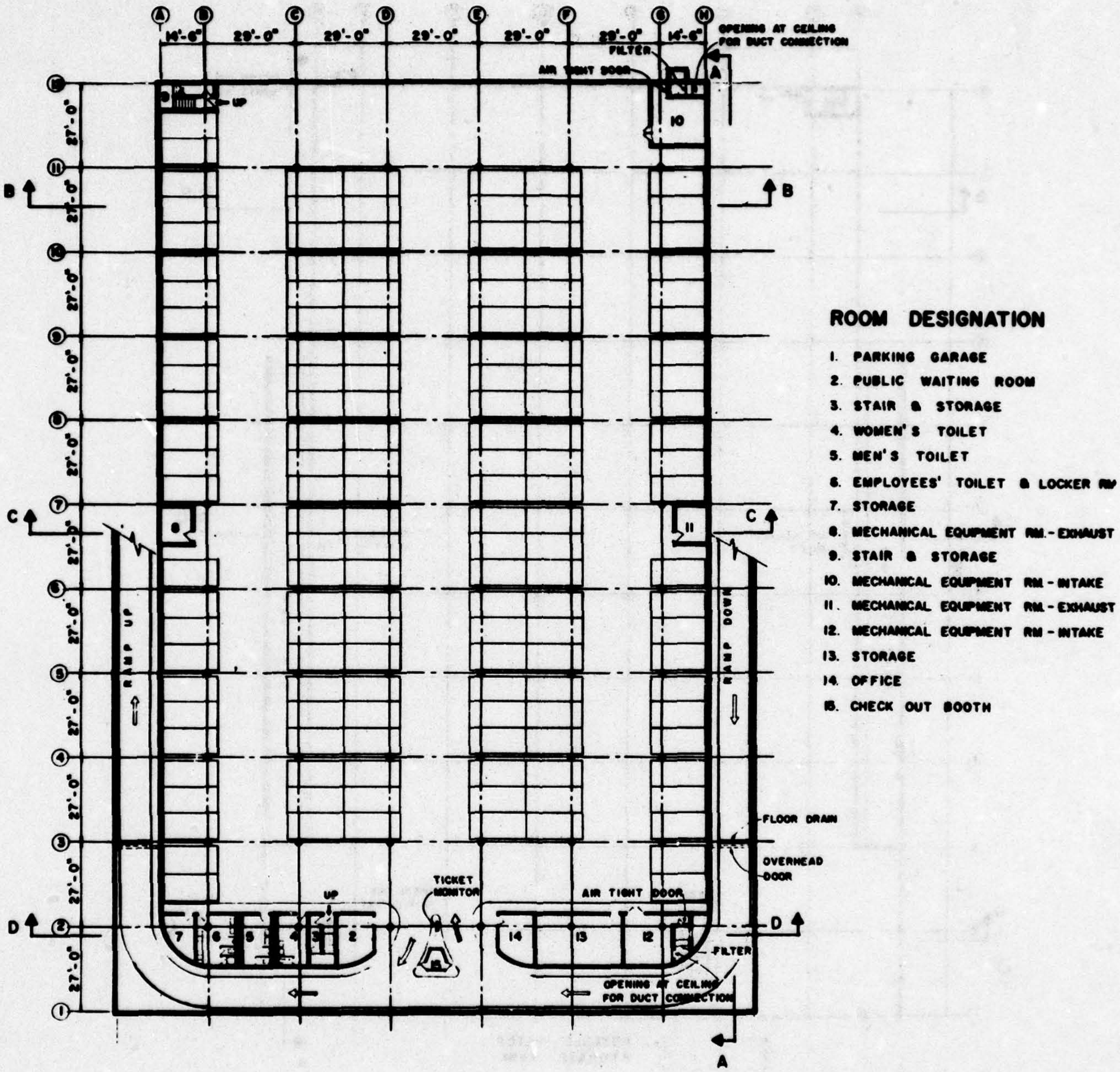


Figure 47. Parking Garage Shelter - Lower Level Plan

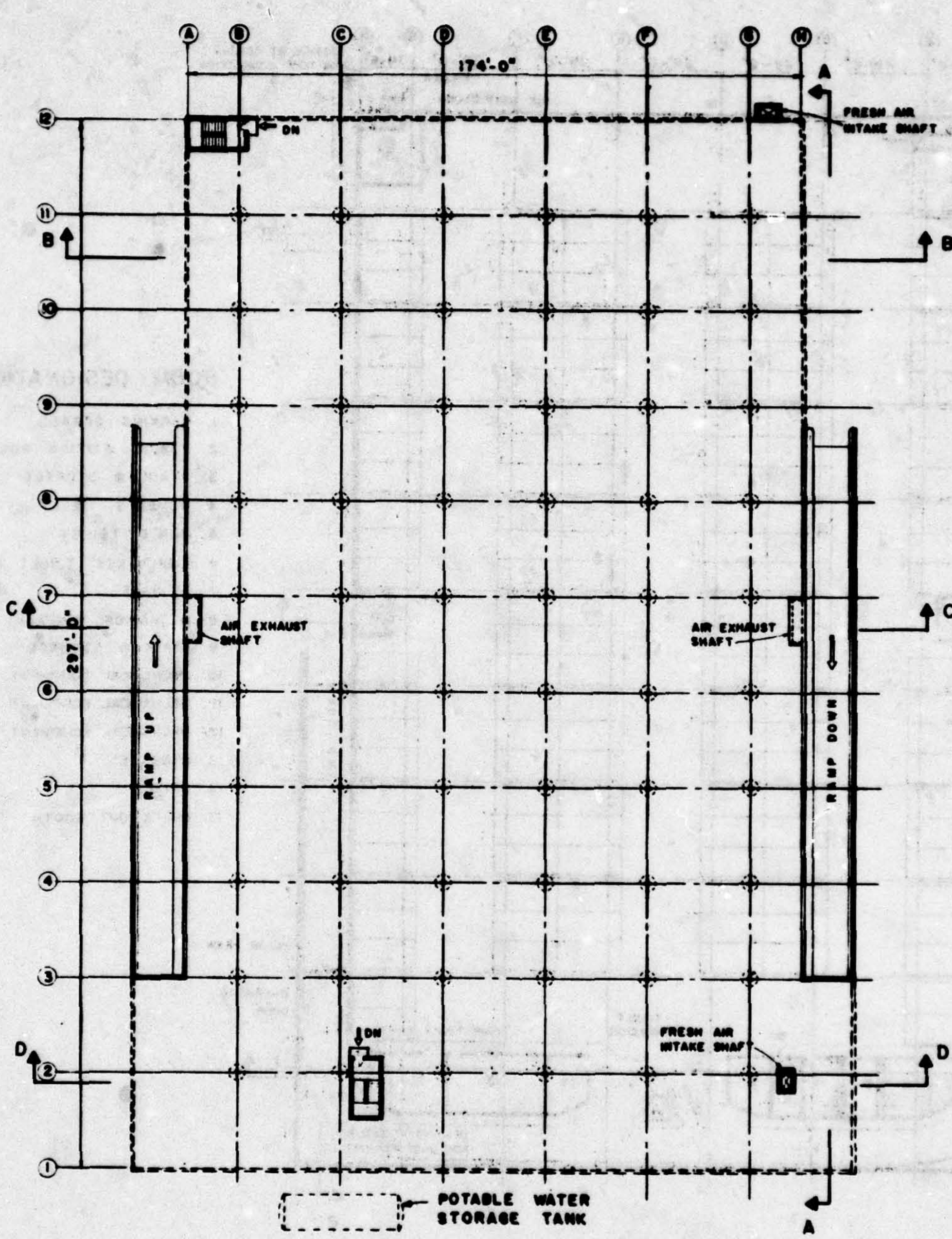


Figure 46. Parking Garage Shelter - Upper Level Plan

TABLE 19. BASIC CHARACTERISTICS OF PARKING GARAGE SHELTERS
(Capacity of 5000 Persons)

Characteristic	Design Hardness Level		
	5 psi	25 psi	50 psi
Gross Floor Area (sq ft)	51,670	51,670	51,670
Total Volume (cu ft)	413,360	473,814	473,814
Headroom (ft)	8.00	9.17	9.17
Shelter Area per Occupant (sq ft)	10.33	10.33	10.33
Shelter Volume per Occupant (cu ft)	82.64	94.73	94.73
Fallout Protection Factor	100.00	100.00	100.00
Maximum Inside Dose of Initial Radiation (rad)	20.00	20.00	20.00

TABLE 20. SIZES OF STRUCTURAL MEMBERS IN PARKING GARAGE SHELTERS

Structural Member	5 psi	25 psi	50 psi
Roof			
Slab Thickness	12"	21"	36"
Drop Panel Thickness	3"	3"	9"
Columns	12"	1'-6"x3'-6"	1'-6"x5'
Column Footings			
Width	6'-9"x6'-9"	14'x14'	20'x20'
Depth	20"	30"	36"
Concrete Partitions			
Thickness	6"	6"	6"
Partition Footings			
Width	18"	18"	18"
Depth	8"	10"	12"
Exterior Walls			
Thickness	8"	8"	8"
Exterior Wall Footings			
Width	20"	22"	46"
Depth	12"	18"	30"

Roof slab thicknesses of 21 and 36 in. are used in the 25 and 50 psi garages which afford sufficient radiation protection to reduce initial radiation on the ground surface to a level of 20 rads or less within the shelter. The interior partitions are of cinder block construction in the 5 psi shelter and reinforced concrete tilt-up walls in the 25 and 50 psi shelters. The reinforced concrete partitions were selected to provide adequate lateral resistance against ground shock.

The designs are based upon a minimum concrete strength of 3000 psi throughout for the 25 and 50 psi shelters, and 3000 psi for the roof system and columns, 25 psi elsewhere for the 5 psi below ground garage. The reinforcement conforms to ASTM A432 which has a minimum yield point of 60,000 psi. The combined live and dead loads on the garage roof of Structures I and II are taken as 100 and 450 psf, respectively, over the entire surface. Debris loading was assumed as negligible in combination with the blast load. The normal allowable soil bearing capacity was taken as 4 tons/sq ft. The equivalent static blast load on the garage roof was taken as equal to the peak incident free field overpressure at all three pressure levels based on allowable maximum deformations 1.3 times the peak elastic value.

The main blast doors at the ramp entrances of the 25 and 50 psi shelters consist of structural steel I-beams with steel cover plates. The hollow interior of the doors is filled with concrete to provide the required radiation protection within the tunnel portion of the ramps. The doors are mechanically (electrical power) rolled open and closed. Blast seals are provided around the door periphery to prevent pressure leakage within the structure. The ramp entrance doors of the 5 psi shelter consist of standard overhead rolling doors reinforced to resist the blast overpressure. These doors are operated manually.

3.4.4 People Survivability in Parking Garage Shelters

People survivability estimates for this set of three shelters are given in Figure 49. As with the school basement shelters described previously, these results represent the case of closed shelters, i.e., the case when the blast doors are at least as strong as the overhead slab and the exposed ramp wall. The only casualty mechanism considered in the analysis was debris from the breakup and collapse of the overhead slab and the exposed ramp wall. Analytic procedure used in arriving at these estimates was the same as that used in the analysis of rectangular, single purpose shelters described in Section 3.3.2.

The effects of prompt nuclear radiation were not considered in arriving at these results. Therefore at higher overpressure, i.e., greater than about 25 psi these results will be lower than indicated.

Although the design overpressure is still considerably lower than the corresponding yield overpressure (see Figure 49a), this is no longer true in the case of the 25 psi and the 50 psi designs.

3.5 Expedient Personnel Shelters

Expedient shelters are those that may be constructed in a relatively short period of time, several days, using locally available materials (lumber, logs from felled trees, soil, etc.), none or few specialized tools and mostly unskilled local labor. In geographic areas where basements are not constructed, such as in areas with a high watertable, expedient shelters represent the only means to provide protection for the population against prompt effects of nuclear weapons.

Over the years a number of different expedient shelter concepts such as covered trench shelters, metal and wood arch shelters have been devised. Two typical examples are shown in Figure 50 and Figure 51. Some of these concepts, in particular covered trench shelters and metal and wood arch shelters have been built and tested (Ref. 74, 75) in the early days of nuclear weapon effects tests. Results of these tests indicate that expedient shelters are capable of providing protection against the effects of blast at least up to 10 psi.

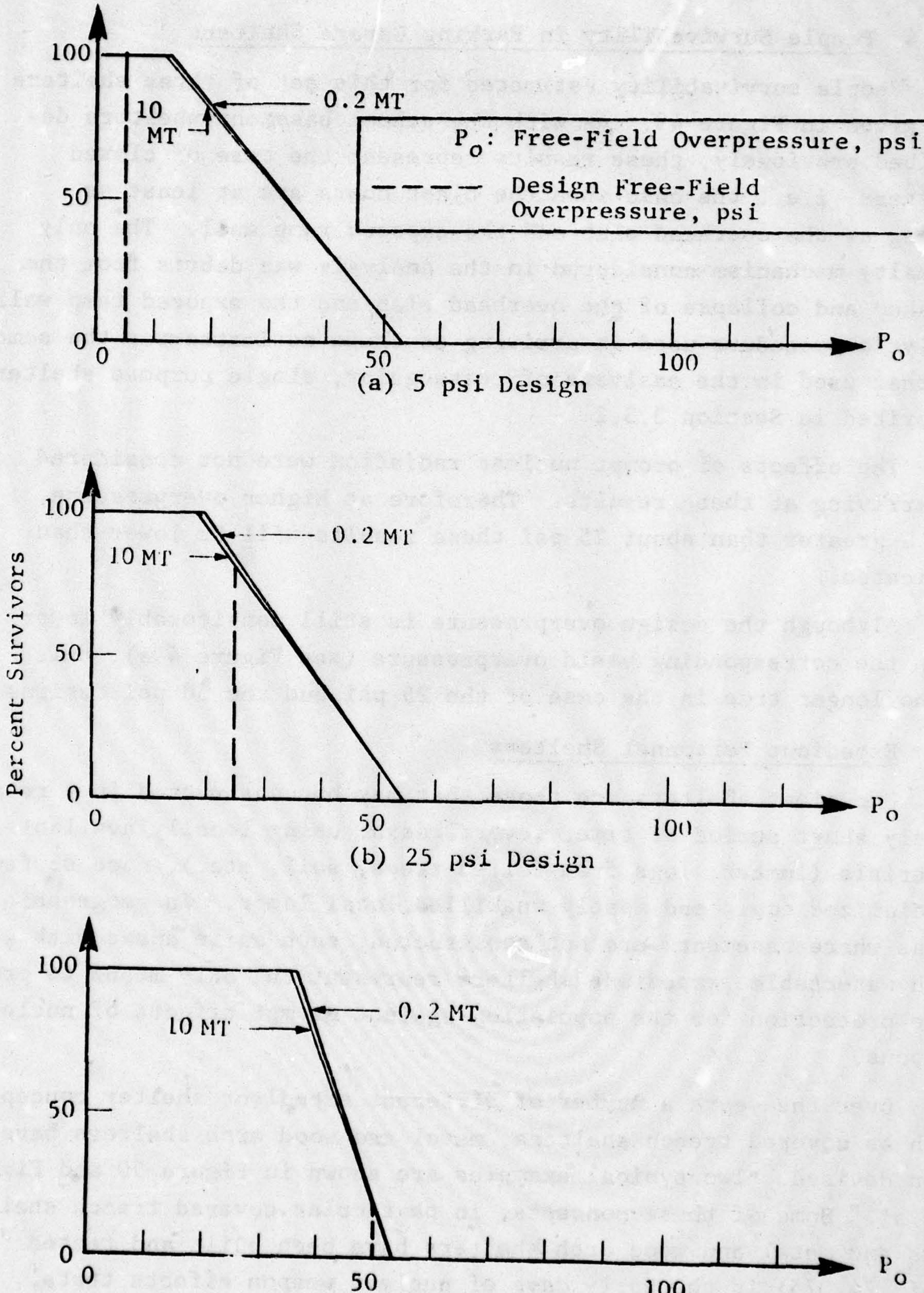


Figure 49. People Survivability (Parking Garage Shelters Structures I and II)

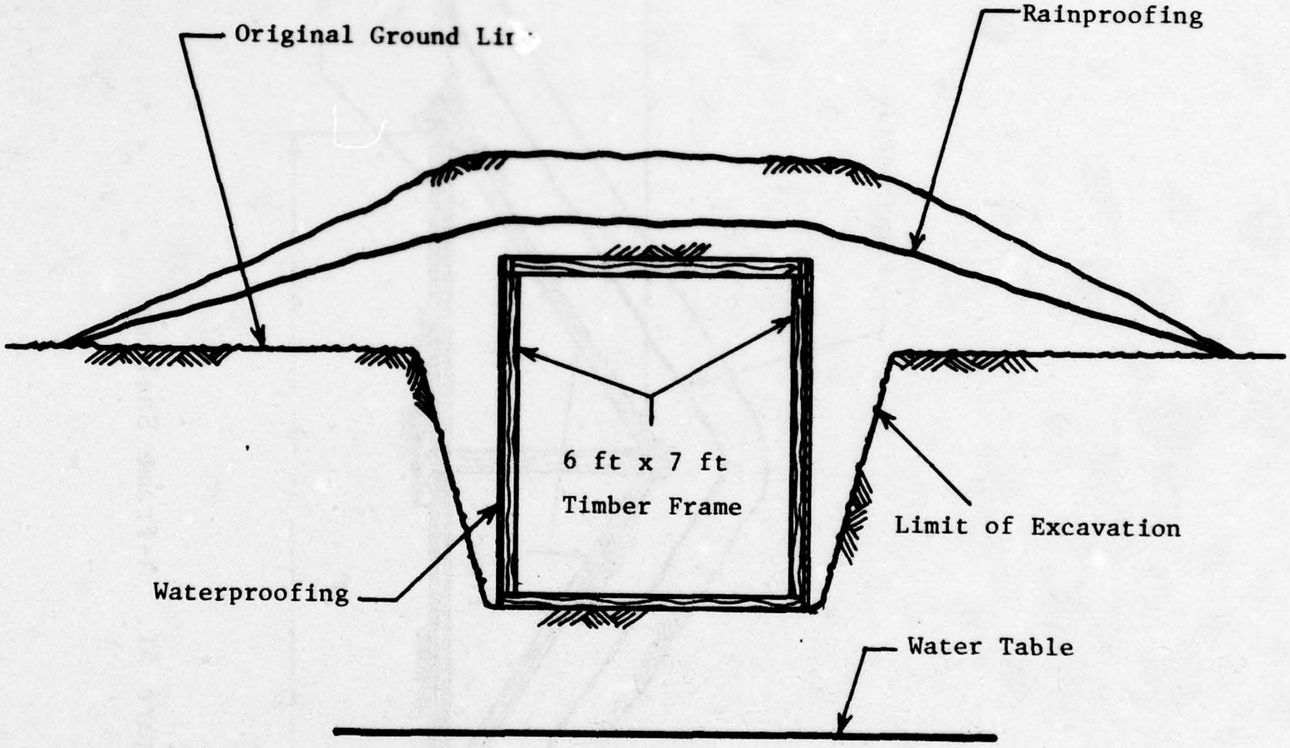


Figure 50. Timber Frame Trench Shelter

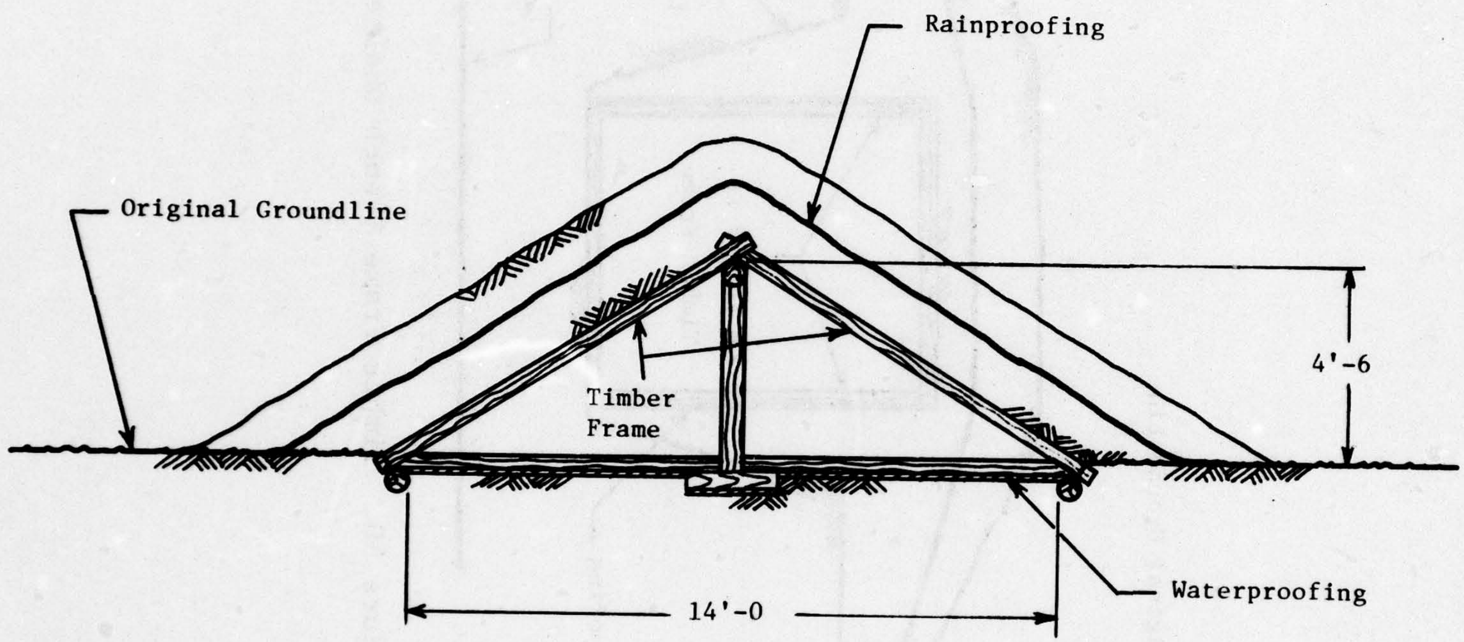


Figure 51. A-Frame Shelter

In a more recent (October 1976) weapon effects test, the DICE THROW Event, a number of different expedient shelter concepts were tested (Ref. 67). The main event of the DICE THROW series was a 628-ton ANFO (ammonium nitrate-fuel oil) explosion which produced surface air-blast effects about equivalent to a 1-kiloton nuclear surface burst. Eighteen expedient personnel shelters (including four half-scale models) were subjected to blast overpressures ranging from 53 psi to 5.8 psi. Expedient shelters tested included pole shelters, unshored trench shelters with different types of structural covers, ridge pole shelters, etc.

Although most results obtained in this test are of interest, the shelter of particular interest was the "small pole shelter" located at the range of 53 psi, i.e., 540 ft from ground zero. It is illustrated in Figure 52.

Untrained groups of families, using only muscle-powered tools, have succeeded in constructing this type of shelter in approximately 48 hours elapsed time from the time they received instructions (Ref. 76).

In this test the roof poles of the boxlike shelter were at ground level. The length of the shelter was perpendicular to the radius from ground zero. The roof of the shelter was covered with 5 ft of mounded earth. Both entrances were protected by expedient blast doors. Each door (48x42 in.) was made of five thicknesses of 3/4 in. exterior plywood.

The measured overpressure at the shelter location was 53 psi and a calculated wind velocity of about 950 mph. The shelter survived intact including the blast doors. It displaced as a whole about 4 in. downward. This movement caused some earth to flow into the shelter, however, over 80 percent of floor area was undisturbed. About 12 in. of soil in the vicinity of blast doors was blown away by the blast winds. Measured peak pressure within the shelter was 1.5 psi.

Shelters of this type are difficult to analyze structurally in any rigorous fashion. Structural properties of freshly cut wood are not well documented and the strength of connections is difficult

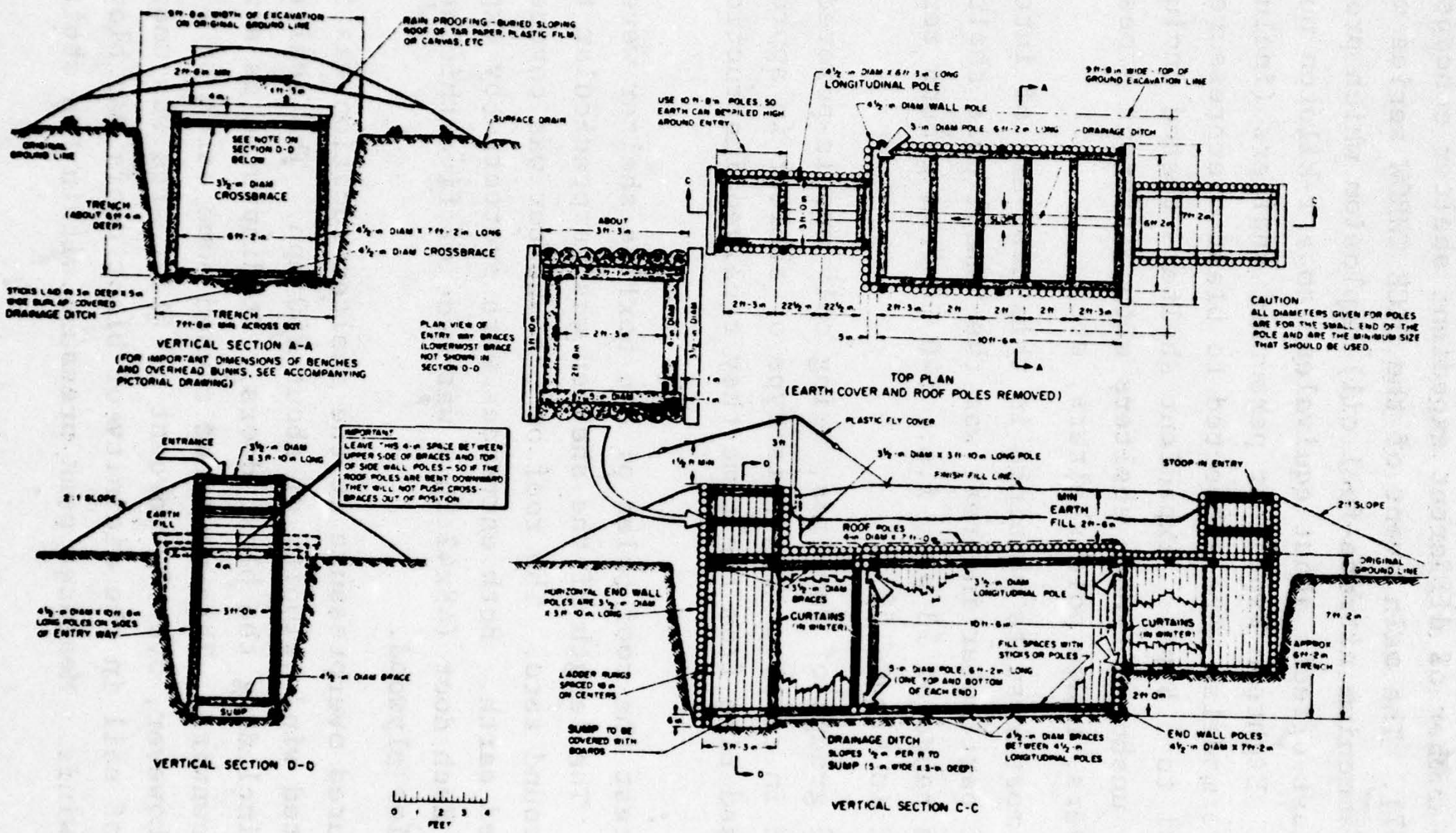


Figure 52. Plan and Elevation of Small-Pole Shelter

to estimate. Structural integrity depends on the quality of wood and soil, strength of connections, quality of workmanship in constructing the shelter and integrity of the backfill. No structural analysis was performed in the course of this study. However, based on the results of the test reported it is estimated that an MLOP of at least 53 psi from an MT weapon can be achieved by this type of shelter in stable soils with good quality wood and good workmanship. This statement is not limited to the "small pole shelter", but to any expedient shelter of similar construction.

3.6 Special Purpose Shelters

Over the past two decades a number of different family and community shelter concepts have been produced, both against fallout radiation and the effects of blast. To distinguish them from expedient shelters, they are labeled as "special purpose" shelters. These categories are not always distinct. Although both categories require careful planning, expedient shelters are generally limited to two or three materials (soil, logs, etc.) and basic construction techniques (see Figures 50, 51). Special purpose shelters, on the other hand, (see Figures 53 to 60) may consist of a variety of construction materials, may require specialized hardware and contemporary construction techniques.

Eight shelter concepts were selected from available sources and analyzed to determine their protective capabilities against the effects of blast produced by the detonation of a megaton nuclear weapon. Results are presented in Reference 65 and are summarized here. Two types of special purpose shelters are included.

1. Basements shelters, i.e., shelters that may be constructed in basements of family residences. This includes the following.

    1. Concrete block shelter (unreinforced) (Ref. 68)
    2. Lean-to shelter (Ref. 69)
    3. Rigid frame shelter (Ref. 69)
    4. Reinforced concrete block shelter (Ref. 69)

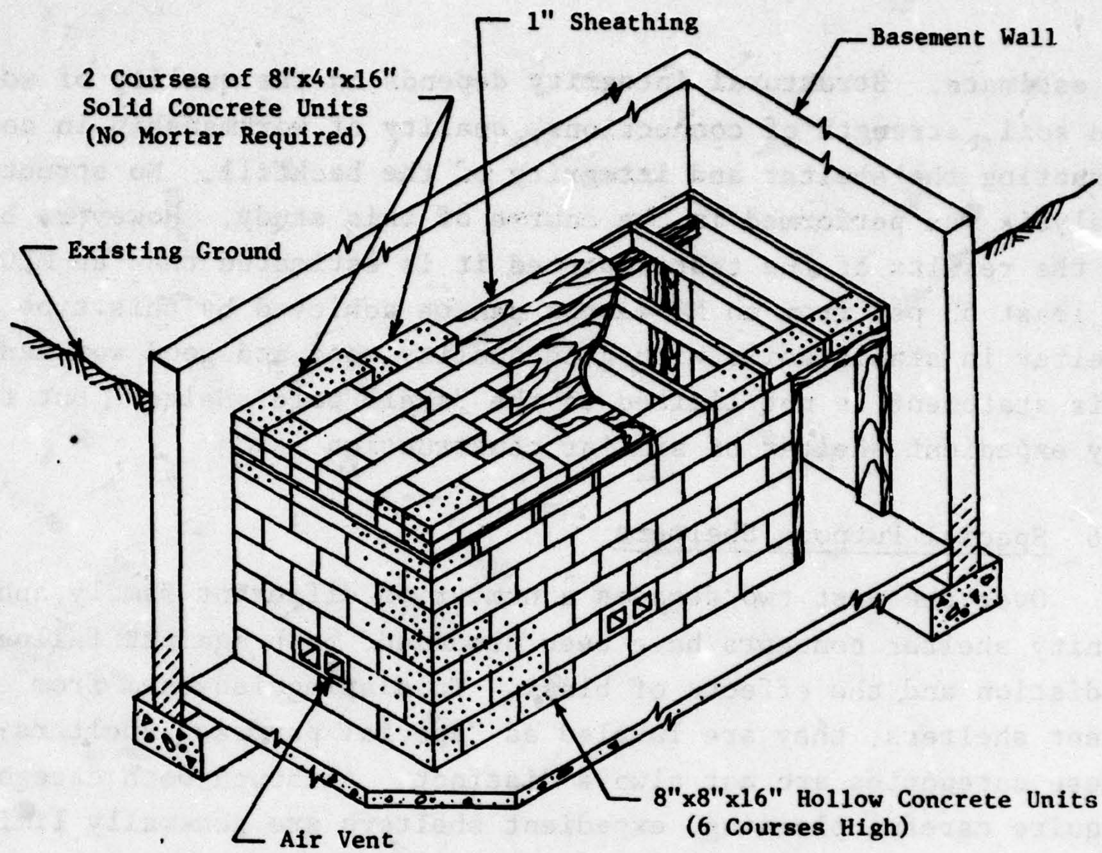


Figure 53. Concrete Block Shelter

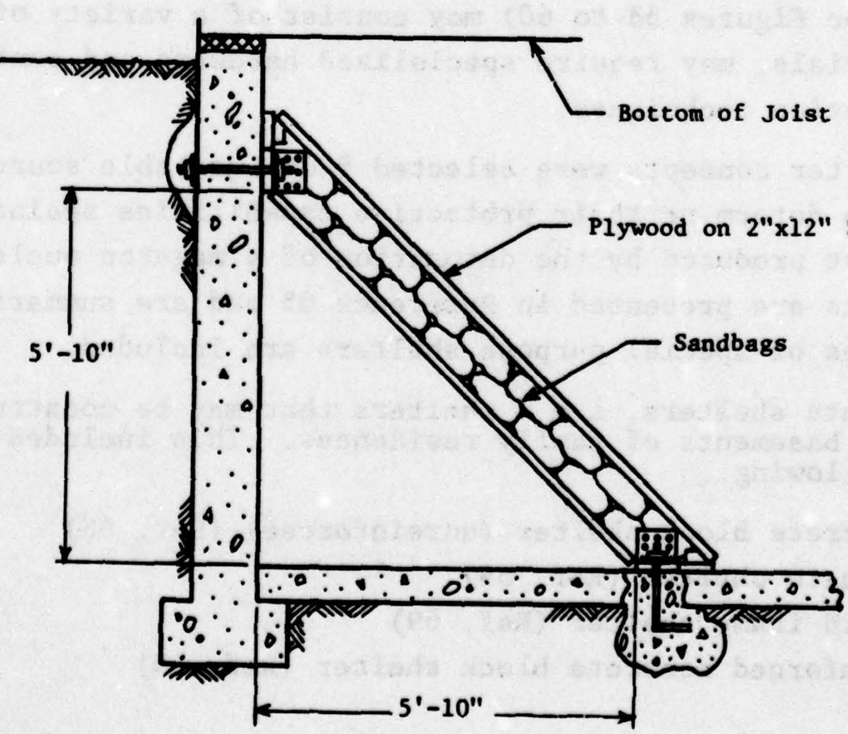


Figure 54. Lean-To Shelter

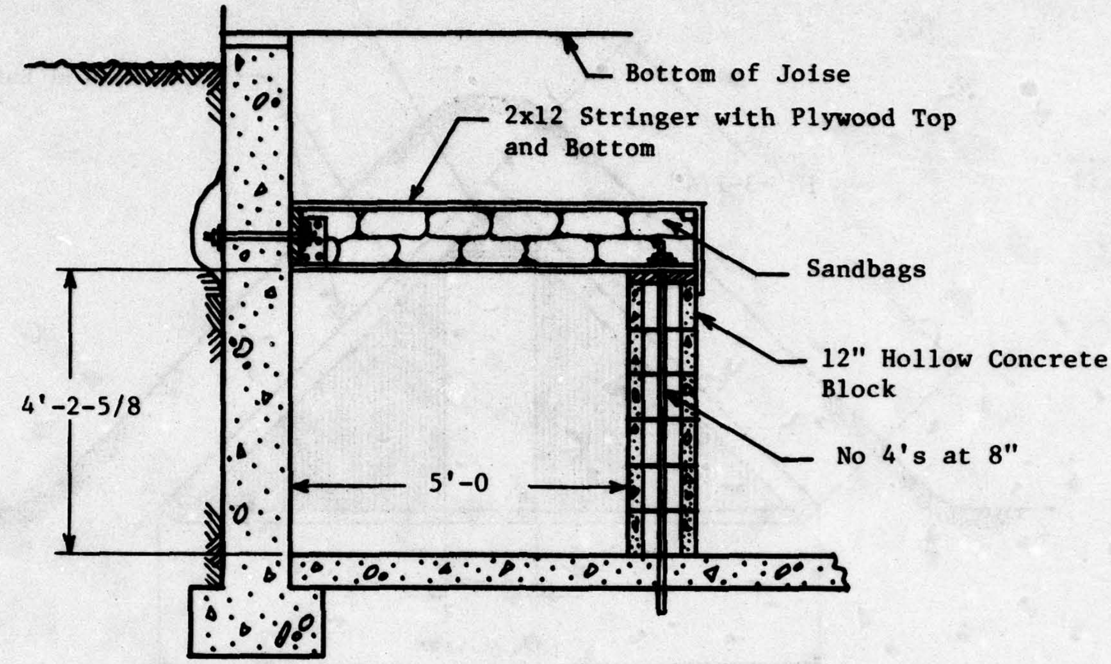


Figure 55. Reinforced Concrete Block Shelter

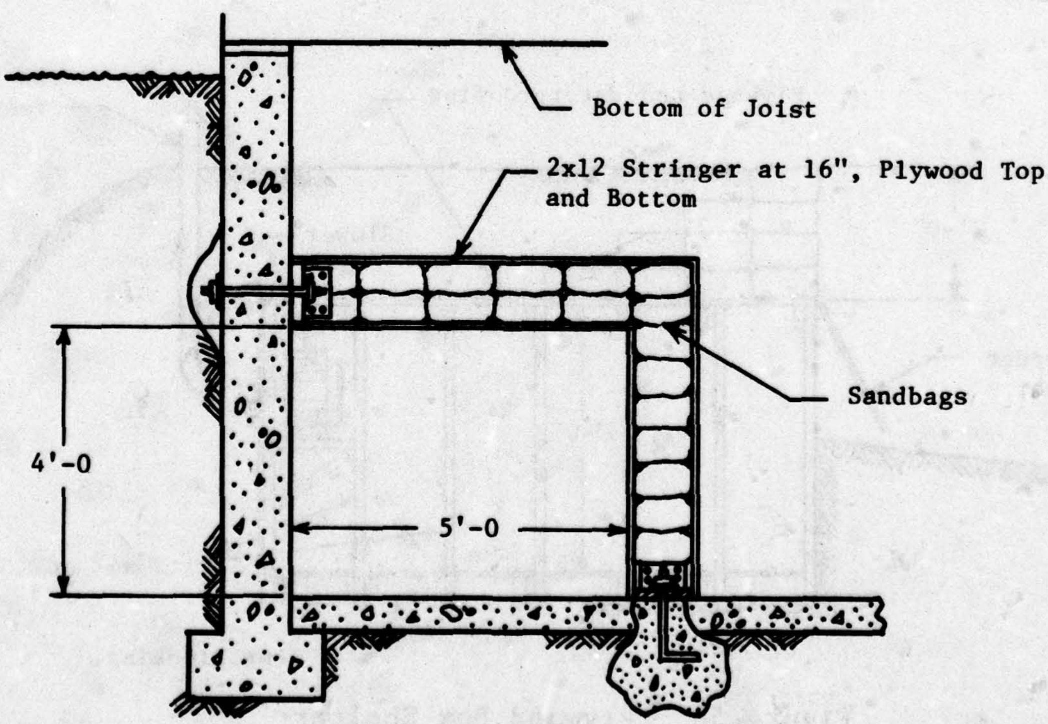


Figure 56. Rigid Frame Shelter

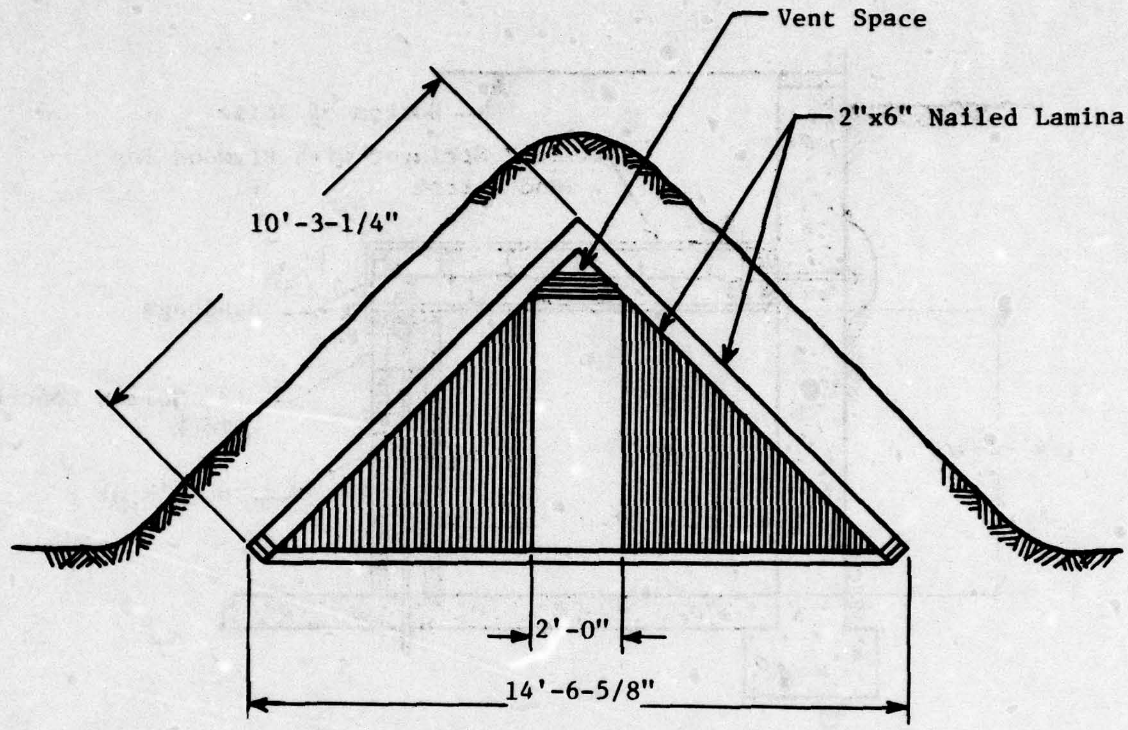


Figure 57. Aboveground A-Frame Shelter

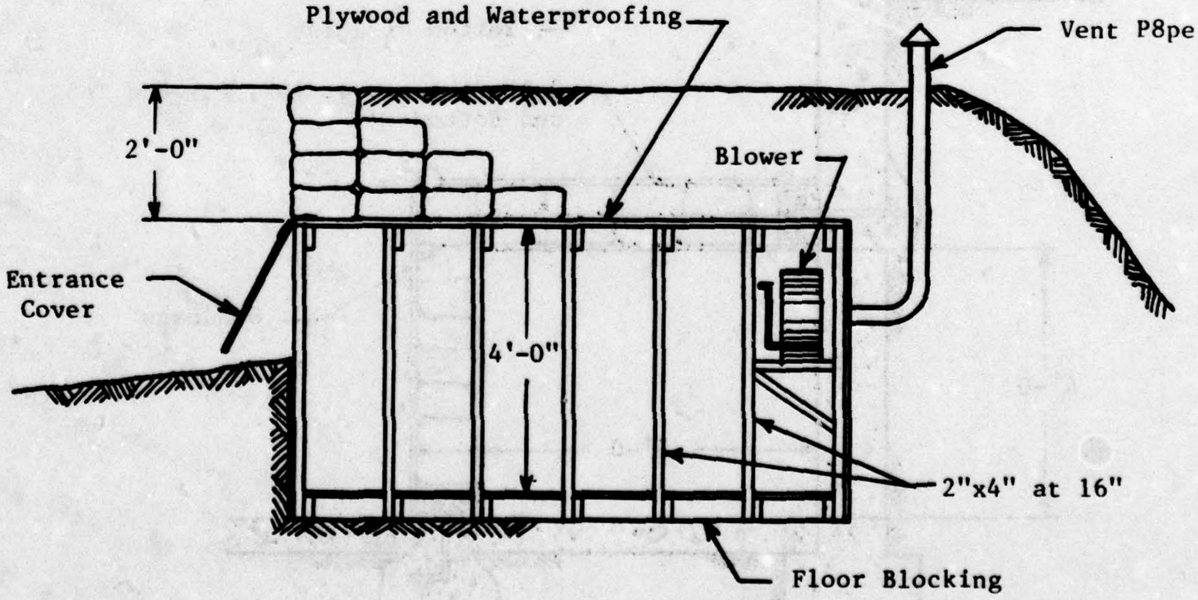


Figure 58. Plywood Box Shelter

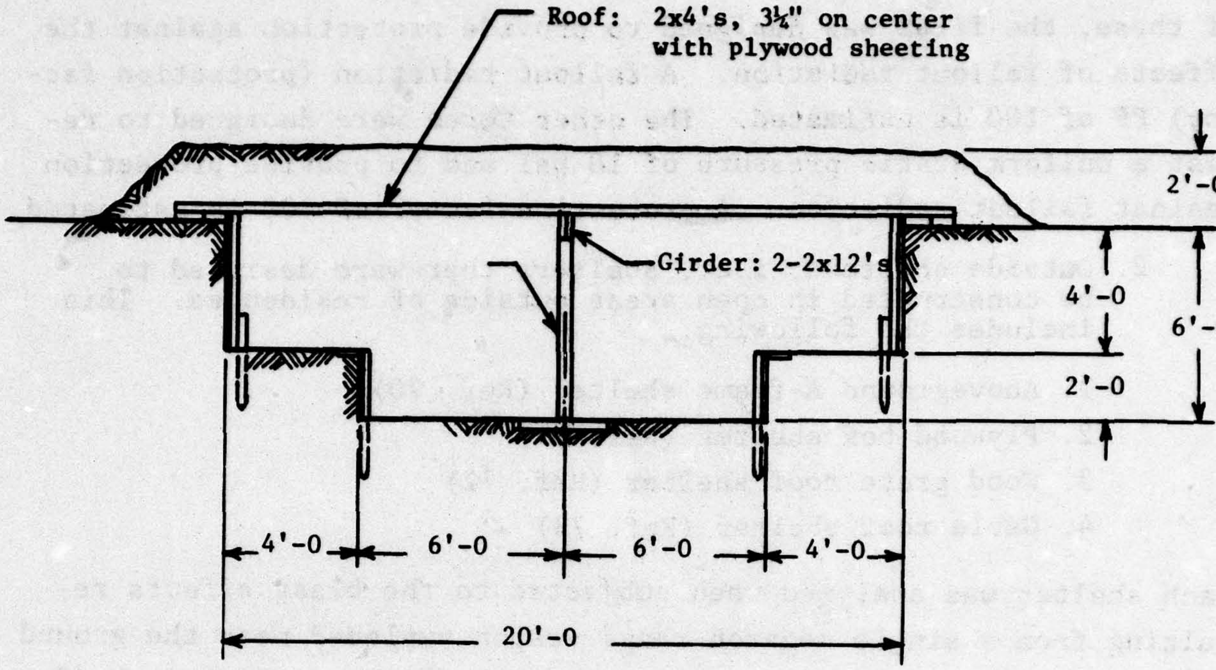


Figure 59. Wood Grate Roof Shelter

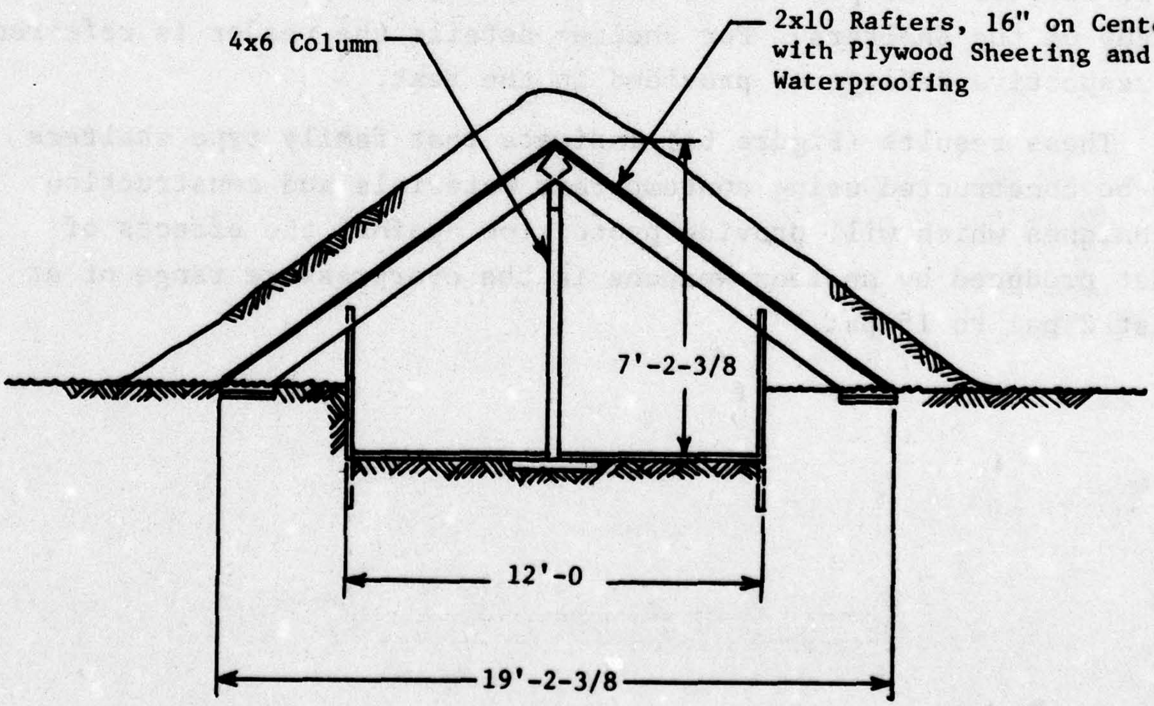


Figure 60. Gable Roof Shelter

Of these, the first was designed to provide protection against the effects of fallout radiation. A fallout radiation (protection factor) PF of 100 is estimated. The other three were designed to resist a uniform static pressure of 10 psi and to provide protection against fallout radiation. A protection factor of 100 is estimated.

2. Outside shelters, i.e., shelters that were designed to be constructed in open areas outside of residences. This includes the following.

   1. Aboveground A-frame shelter (Ref. 70)
   2. Plywood box shelter (Ref. 71)
   3. Wood grate roof shelter (Ref. 72)
   4. Gable roof shelter (Ref. 73)

Each shelter was analyzed when subjected to the blast effects resulting from a single megaton range weapon exploded near the ground surface. These shelters are illustrated in Figures 53 through 60. People survivability estimates are given in Figure 61.

In Figures 53 through 60 the attempt is to illustrate the basic shelter concepts rather than to provide any details on the makeup of the shelters. For shelter details the reader is referred to respective references provided in the text.

These results (Figure 61) indicate that family type shelters can be constructed using contemporary materials and construction techniques which will provide protection against the effects of blast produced by nuclear weapons in the overpressure range of at least 2 psi to 15 psi.

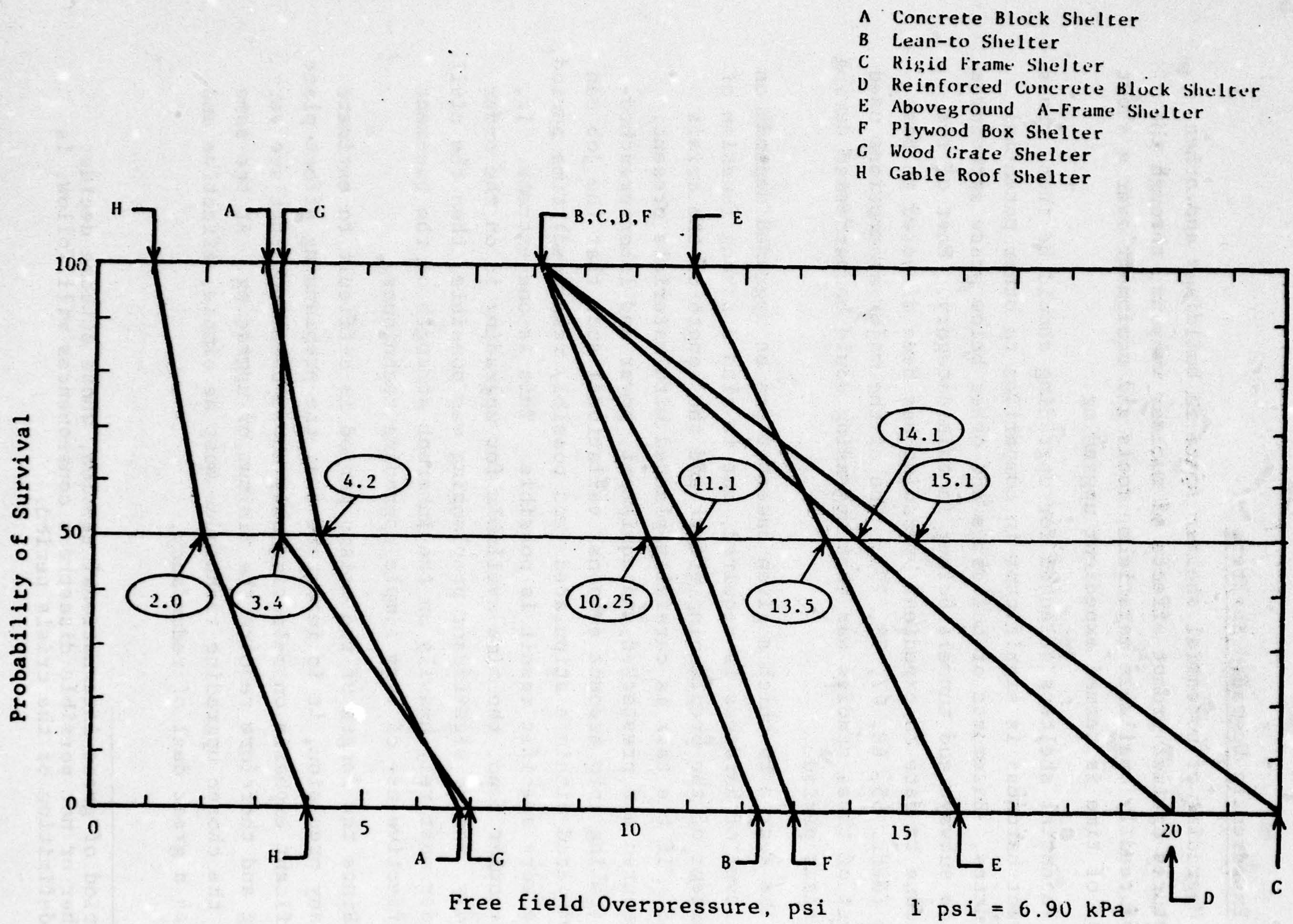


Figure 61. People Survivability Estimates, Special Purpose Shelters

3.7 Expediently Upgraded Shelters

Upgrading of potential shelter space in buildings and other structures against prompt effects of nuclear weapons, through the use of readily available materials, tools and equipment over a short period of time is termed expedient upgrading.

Potential shelters selected for upgrading should be those whose inherent hardness is significant in comparison to other potential candidates. Basements of buildings and other below grade structures such as subways and tunnels belong in this category. Most of the work done to date on expedient upgrading has been directed to basements (Refs. 65, 66, 77, 78, 79). One of the major assumptions used in most of these studies was that upgrading would be performed during the crisis period.*

The degree to which a given basement can be upgraded depends on what level of hardness is required, but is also a strong function of the extent of the preplanning effort and the length of the crisis period. If the task is carefully planned with materials present, premeasured and prestocked and equipment, power and labor prescheduled (taking into account seasonal variations) such that the job can be completed within a stipulated (and possibly rehearsed) time period, then a very specific result is possible. This is one extreme. If, on the other hand, the time available for upgrading is on the order of a day, and no significant preplanning was possible, then the civil defender must rely heavily on the inherent strength of the basement and effective use of very simple upgrading techniques.

Since the length of the crisis period is difficult to estimate with any precision, it is important that the preplanning effort place significant emphasis on selecting only those basements that are very strong and therefore require the minimum of upgrading. At the same time, the chosen upgrading techniques must be simple, effective and possess a great deal of redundancy.

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*A period of great international tension, whose outcome decides whether or not possible disastrous consequences will follow, is one definition of the crisis period.

Upgrading Methods - Each structure needs to be considered on an individual basis. However, in general, the following methods or combinations thereof would need to be used for increasing the strength (hardness) of a potential shelter.

For Overhead Floor Systems in Basements

Reduce spans by providing beams, columns or support walls (see Figure 62).

Provide additional end supports for beams (see Figure 63).

Strengthen columns (see Figure 64).

For Openings (Entranceways, Utility Openings, etc)

Replace weak doors with stronger ones and provide additional supports at hinges.

Introduce practical baffles where possible.

Reduce size of opening.

Introduce blast closures at stairwells, elevator shafts, utility openings and windows (see Figure 65).

Interior Load-bearing Walls

Provide continuity.

Increase thickness.

Add pilasters and columns, etc.

The number and size of openings into the shelter should be reduced to a level consistent with reasonable egress, safety and other operational requirements.

As a minimum requirement for upgrading, good "housekeeping" conditions should be implemented and maintained. These include the removal and/or securing of all nonessential objects and the application of padded surfaces in certain regions of the shelter. Furthermore, depending upon shelter size, geometry, size of openings and their location, certain regions of the shelter should be marked off and not used whenever possible.

Upgrading Materials - Although the materials shown in the previous upgrading examples are wood, obviously expedient upgrading will not be limited to this material alone.

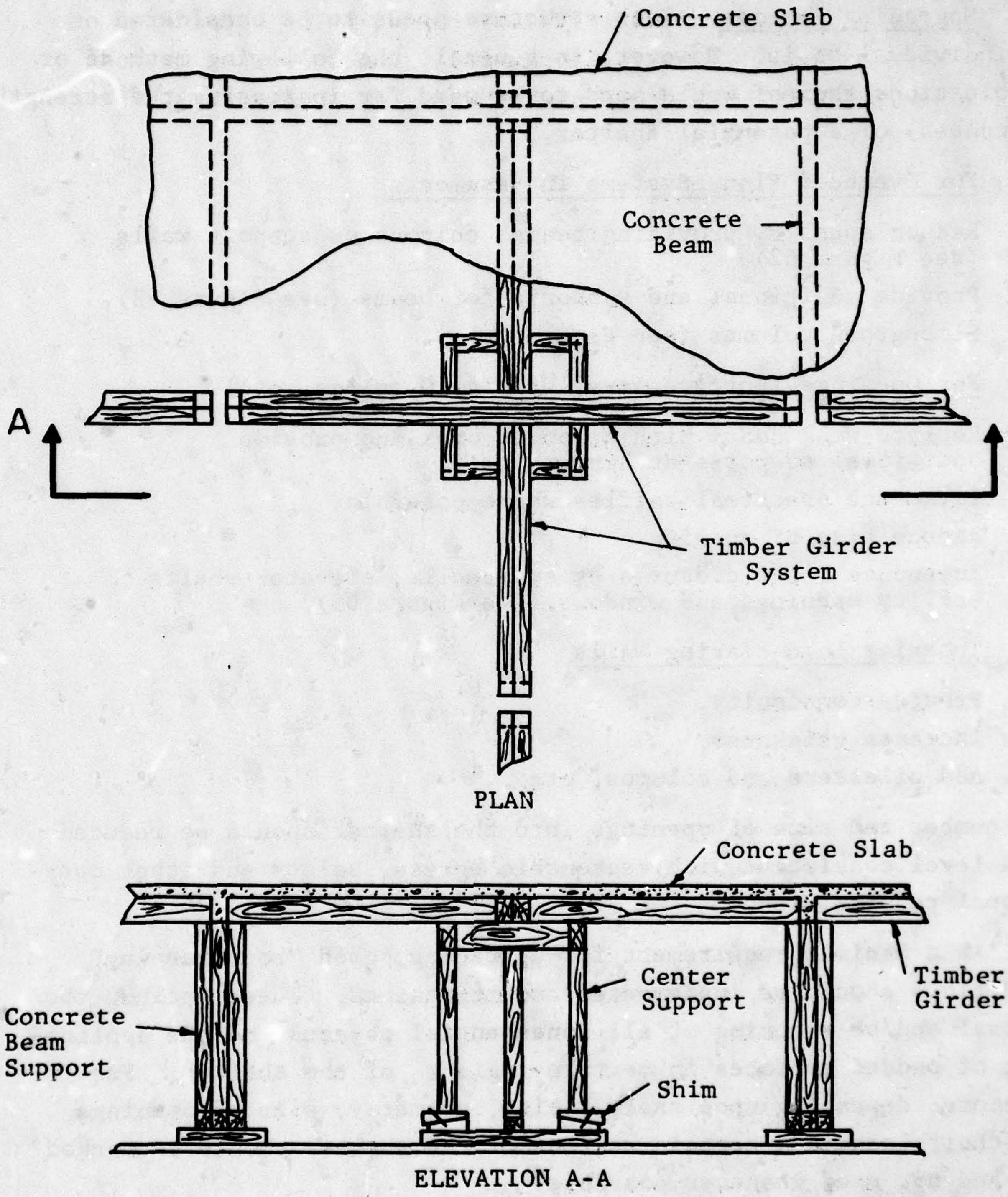


Figure 62. Two-Way Slab Upgrading System

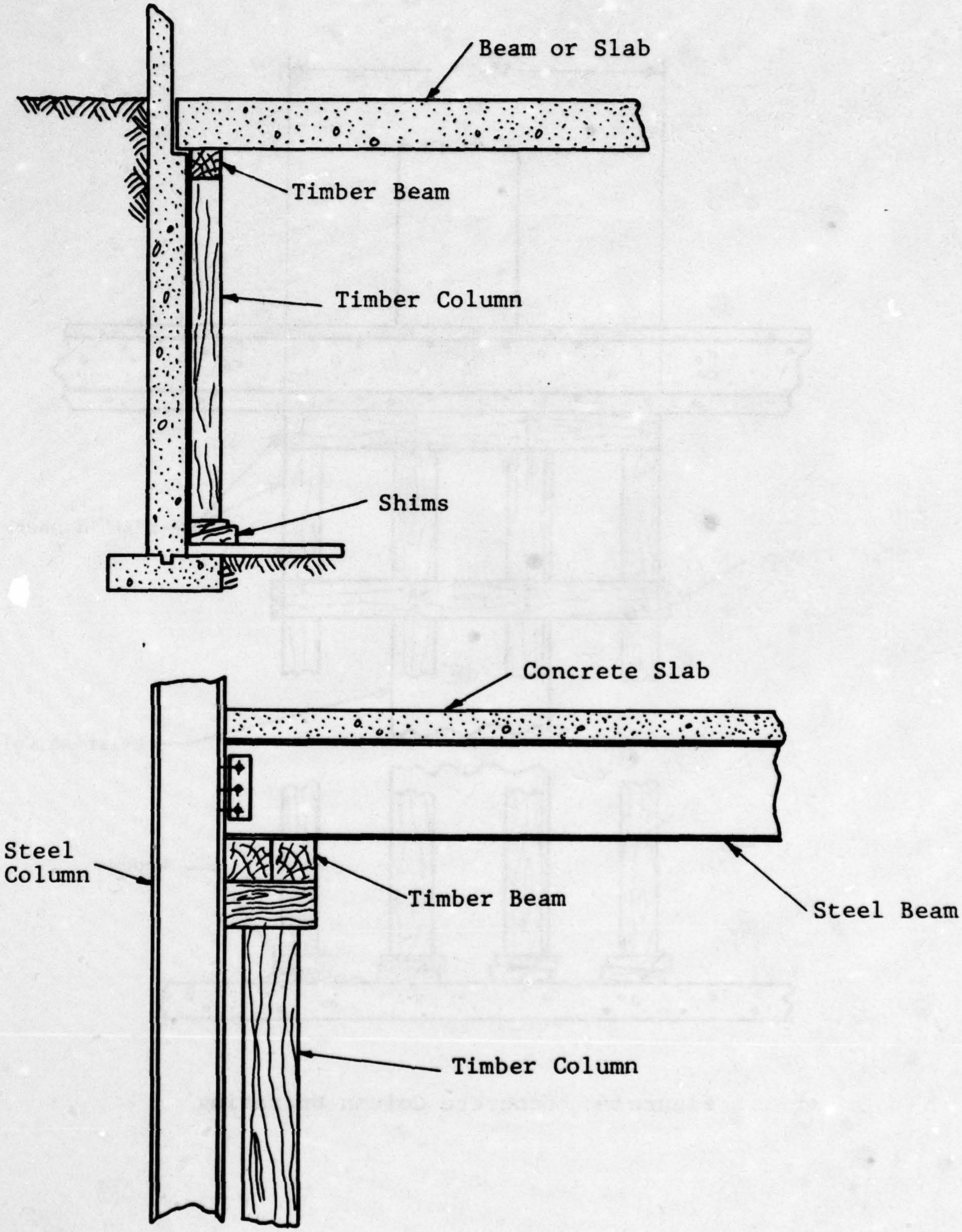


Figure 63. End Support Expedient Upgrading Concepts

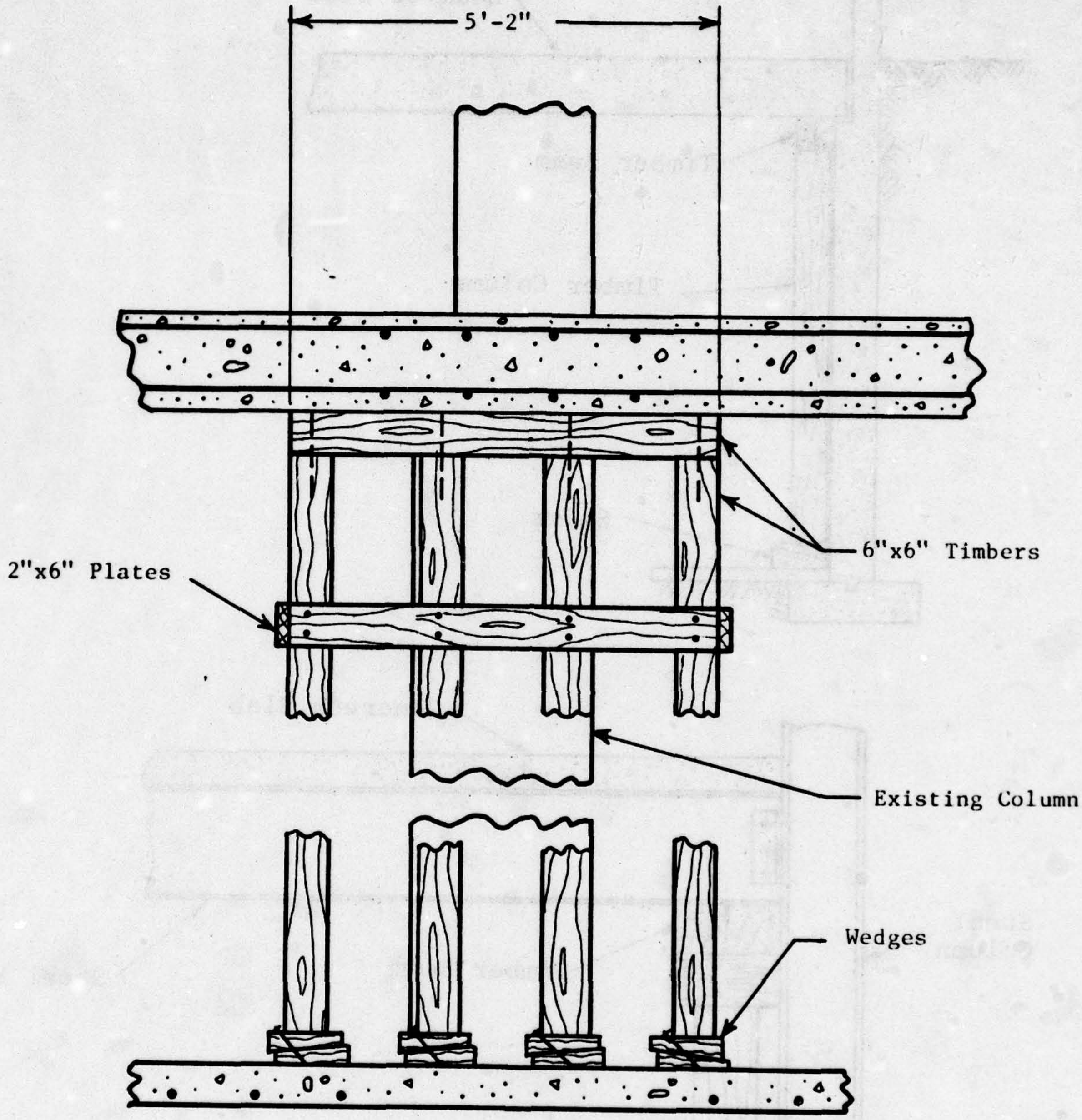
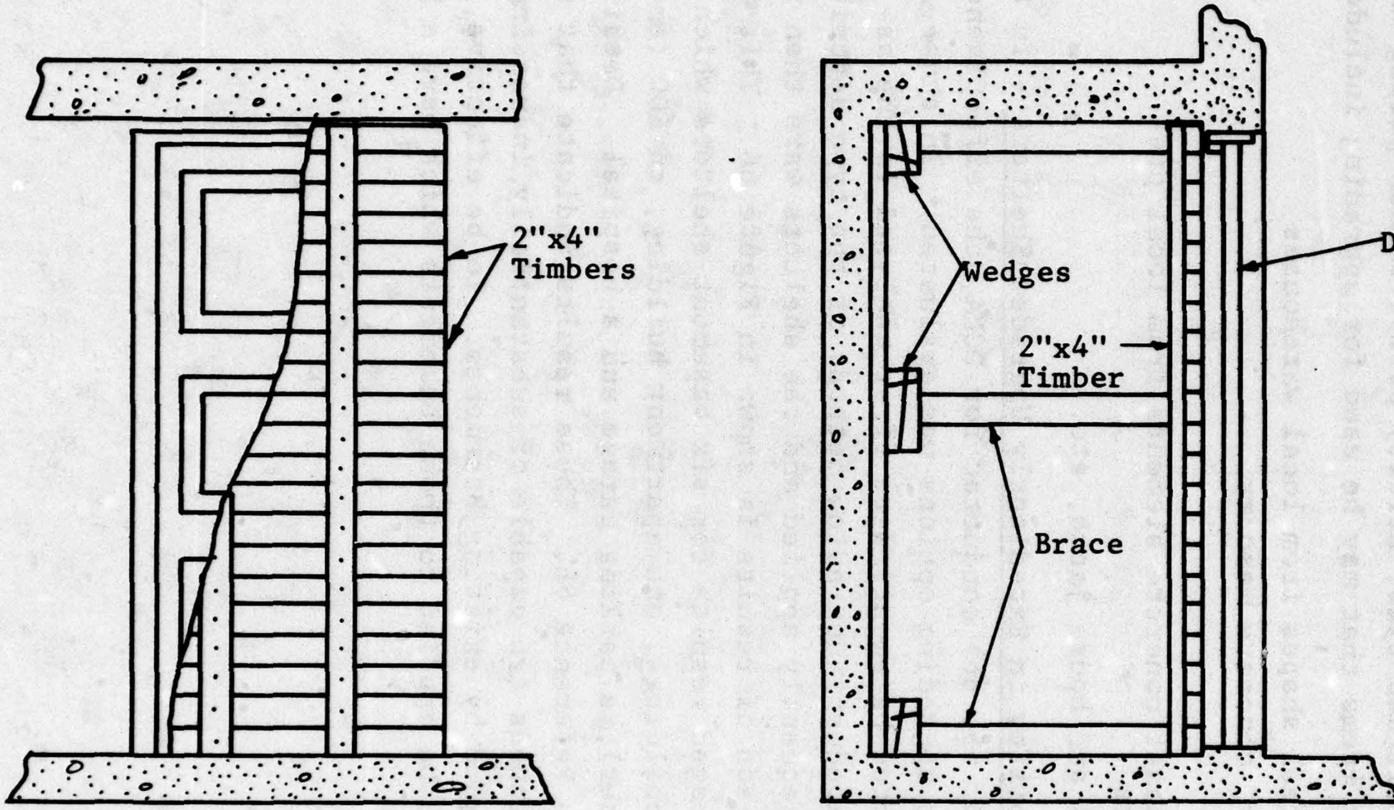


Figure 64. Concrete Column Upgrading



(a) Front View

(b) Side View

Figure 65. Expedient Blast Closure for a Basement Door

Due to the versatility of application, wood in various forms is expected to be a popular upgrading material. This will include structural timber, railroad ties, utility poles, timber piling and felled trees. Other items that may be used for upgrading include

- Structural steel shapes from local warehouses
- Brick masonry, concrete masonry
- Steel Plates
- Available precast concrete elements from local precasting plants
- Utility jacks and house jacks, etc.

People Survivability in Expediently Upgraded Shelters - In two recent studies (Refs. 65, 66) conducted for DCPA, the effectiveness of several expedient upgrading options was evaluated. In these analytic studies, selected basements were first analyzed in the as-built condition. Expedient upgrading methods of the type described previously were subsequently applied and the shelters were then reanalyzed. A comparison of results is shown in Figure 66. This is a comparison of averaged results for six basement shelters which include two office buildings, one apartment building, an EOC (emergency operating center), a parking garage and a hospital. Detailed results are given in Reference 66. These results indicate that expedient upgrading methods are capable of substantially increasing the protection afforded by existing basements. To be effective, these methods should be applied to those basements which have a high inherent strength.

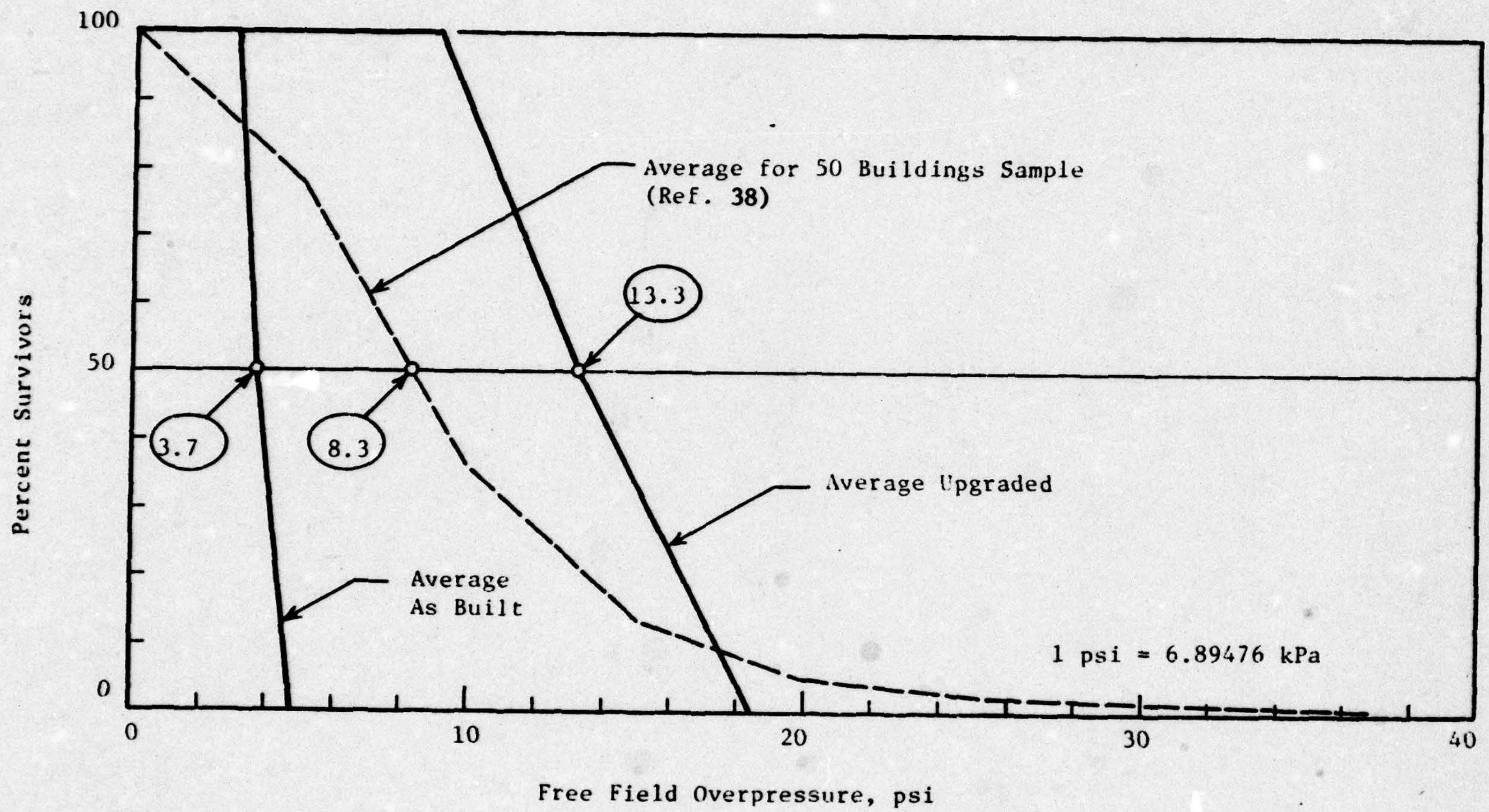


Figure 66. Comparison of People Survivability Estimates (Average Values)

4. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary and Conclusions

This report contains information on protective capabilities of a variety of different personnel shelters against prompt effects of nuclear weapons. Protective capabilities are given in terms of "people survivability functions" (Figure 1, pg. 3) which relate the probability of survival (or percent survivors) to the free-field overpressure at the location of the shelter. Respective shelters are described in terms of their geometry and construction materials. The following shelter categories are included.

1. Existing, Engineered Buildings (Upper Stories and Basements)
2. Designed Basements
3. Single Purpose Shelters
4. Dual Purpose Shelters
5. Expedient and Special Purpose Shelters
6. Expediently Upgraded Shelters

Results were summarized in Chapter 3. They were collected in the course of this effort from previous studies performed for DCPA in this subject area.

These results may be used as a <u>guide</u> for effectiveness analysis of alternative shelter systems, development of shelter plans, damage assessment studies, etc., provided that personnel shelters used in each case are the same as those described in this report, or very similar to them. In addition to this, the following special considerations and deficiencies should be noted.

Results for shelter categories 1, 2, 5 and 6 are against the effects of a single megaton range nuclear weapon detonated near the ground surface. Results for shelter categories 3 and 4 are against the effects of 0.2-, 0.5-, 1.0- or 10-MT nuclear weapons detonated near the ground surface. The effects of multiple weapon attacks were not specifically considered in arriving at these results. Laws for scaling these results to other weapon yields do not exist and are therefore not included.

All results are for individual shelters located in the open and away from neighboring buildings. Shielding against the effects of blast and radiation that may be provided by neighboring buildings is therefore neglected. Damage and casualty producing effects of debris from the breakup of neighboring buildings are also neglected. For urban areas directly outside of central cities, for suburban and rural areas and in general for all areas having a low building density this is a reasonable assumption.

Results are for the most part based on deterministic models which did not take into account variabilities in weapon effects parameters, material and geometric properties of shelter structures or variations in the physical makeup of the sheltered population. Material properties used in the analysis were the same as those used in design. Design properties are generally less than the mean values of respective populations of properties and therefore the results are conservative, i.e., these shelters are likely to be stronger against the effects of blast than these results indicate. Although variations in the physical makeup of the population can be considered to some extent, available casualty criteria are crude and for the most part are not capable of accommodating such refinements.

In preparing survivability estimates for people in the upper stories of large engineered buildings, possible overturning (collapse) of the building frame was considered in a very approximate manner. The level of uncertainty associated with predicting casualties from this effect is greater than that associated with most of the other casulaty mechanisms considered. This means that for highrise buildings (approximately ten stories and higher), the number of people surviving in the upper stories may be somewhat less than indicated here.

The interaction of the building superstructure with the basement and foundation when subjected to blast loading was not considered. Since such interaction can initiate damage in the basement overhead slab, foundation and peripheral basement walls, then for strong-wall buildings, approximately ten stories and higher, the number of people surviving in basements may be less than that indicated by the estimates given here.

People survivability estimates for people in single- and dual-purpose shelters do not consider prompt nuclear radiation as a casualty mechanism. These results are therefore applicable to situations for which this effect can be neglected. This effect can be neglected for MT size nuclear weapons producing free-field overpressures less than 20 psi. For other weapons sizes additional soil cover would need to be provided to keep the survivability estimates approximately the same as given here.

This report does not contain specific procedures whereby casualty estimates for people in shelters may be made. Casualty estimation is still mostly a research area and procedures which may be used on a routine basis by engineers and planners for the purpose of evaluating the effectiveness of shelter systems have not been developed. Evaluation of the effectiveness of alternative shelter systems is currently best accomplished by practitioners in this area.

4.2 Recommendations

The following recommendations are made with the object of improving casualty prediction capabilities, and data on the performance of shelter systems in a nuclear weapon environment.

Blast Loading Experienced by Buildings - In a city complex, the blast loading experienced by a building is a function of the extent to which other buildings in the area provide shielding prior to their collapse, and the extent to which the flow is channeled by the streets and other separation distances between surviving buildings. Experiments with model city complexes subjected to high velocity winds have demonstrated significant shielding effects; both increases and reductions in wind loading can result. The effect is dependent on the length and width of open channels and on the relative heights of buildings. Similar response is expected to be produced in a nuclear weapon blast environment. Studies should be conducted to bound the loading on individual buildings in typical city complexes.

Building Frame Response and its Interaction with the Basement Structure - People survivability analyses performed over the past several years have demonstrated that basements provide the better shelter space of most available options in an urban area. An exception is made for basements in buildings with flat plate framing systems. Flat plates over basements, by virtue of their construction, are expected to fail suddenly and at relatively low overpressures and should therefore be avoided. It is also felt that another exception may be necessary. This refers to basements in tall, framed buildings. Highrise buildings, and especially those with strong walls, are expected to collapse due to the failure of the frame at overpressures less than 10 psi (free-field)(Ref. 58). The number of stories and the ratio of length to width that distinguishes low-rise from high-rise buildings, as far as response in blast load environment is concerned, is not known at this time. When a highrise building interacts with the blast, the interaction of the superstructure with the basement, i.e., the overhead basement slab, foundations, peripheral walls, etc., may be of sufficient extent to damage these components. The result is that the basement loses a portion of its strength to resist the imposed airblast loading. The interaction referred to is illustrated in Figure 67. Evaluation of the extent of this interaction has been neglected in previous studies dealing with the analysis of basements subjected to blast loads. It is recommended that a study be conducted to include the following objectives.

1. Determine what categories of buildings are expected to collapse when subjected to blast loadings in the range of overpressures of interest to civil defense. This should be expressed in terms of building height, plan area of the building, building plan aspect ratio, type of walls (arching, nonarching), percent apertures, type of framing system, type of foundations.
2. Determine to what extent and under what conditions the interaction of the framing system with the basement is important in significantly damaging the basement structure.
3. Develop simplified procedures for predicting the strength of basements taking into account the interaction of the basement with the framing system.

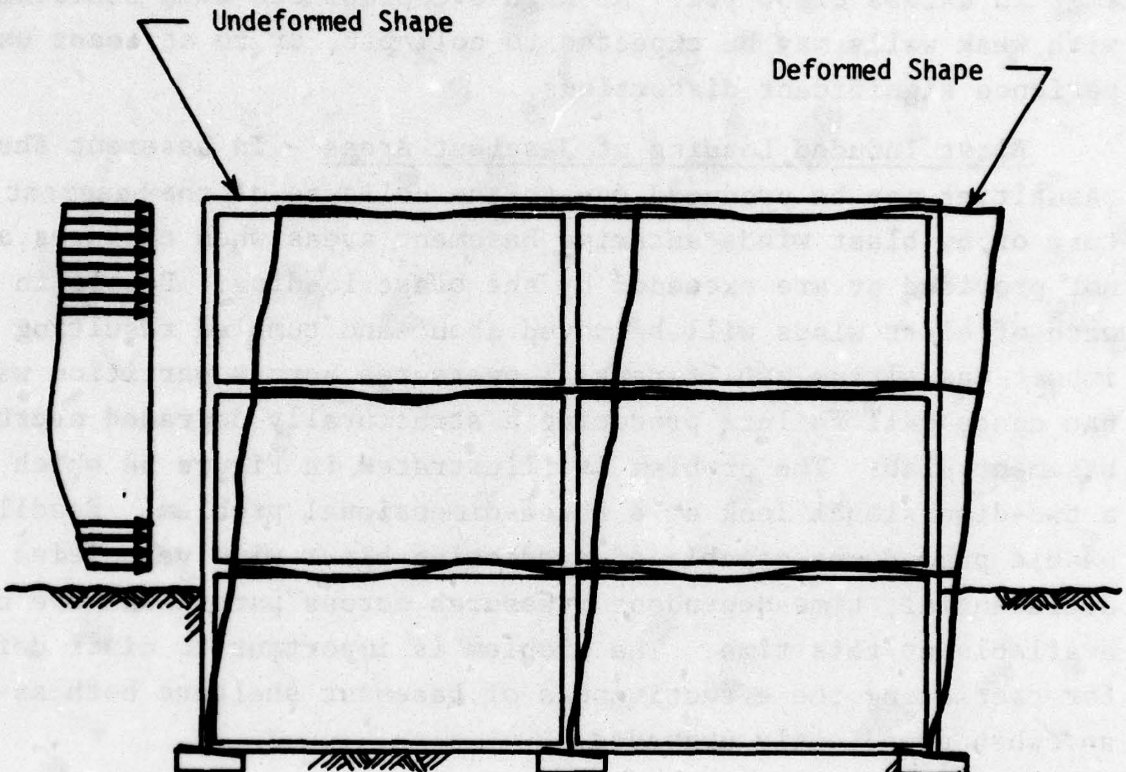


Figure 67. Building Frame Deformation Due to Lateral Load

4. Develop procedures for expediently upgrading basements so as to minimize the building frame/basement interaction effects.

The building frame/basement structure interaction may be especially important when dealing with inherently hard basements, i.e., basements capable of being upgraded to withstand blast loadings in excess of 30 psi. At high overpressures even buildings with weak walls may be expected to collapse, or to at least experience significant distortions.

Blast Induced Loading of Basement Areas - In basement shelters casualties may be produced due to the collapse of the basement structure or by blast winds entering basement areas when closures are not provided or are exceeded by the blast loading. People in the path of blast winds will be moved about and tumbled resulting in impact casualties. Differential pressures across partition walls can cause wall failure producing a structurally degraded overhead basement slab. The problem is illustrated in Figure 68 which is a two-dimensional look at a three-dimensional problem. Readily usable procedures capable of predicting blast wind velocities and differential, time-dependent pressures across partitions are not available at this time. The problem is important to civil defense for predicting the effectiveness of basement shelters both as-built and when expediently upgraded.

We recommend that a study be initiated to develop a procedure capable of generating the following information.

1. Distribution and intensity of time-dependent velocity fields in basement areas of engineered buildings as a function of the number and size of openings into the basement, basement volume and pressure-time history of the incident blast wave.
2. Distribution of time-dependent pressure on vertical and horizontal basement surfaces and across partitions.

Casualty Criteria - Criteria, on the basis of which casualties are predicted against the individual effects of nuclear weapons are in need of being reviewed in the light of the information and capabilities of the current state of the art. It is therefore recommended that a study be initiated to review and update casualty criteria in the following categories:

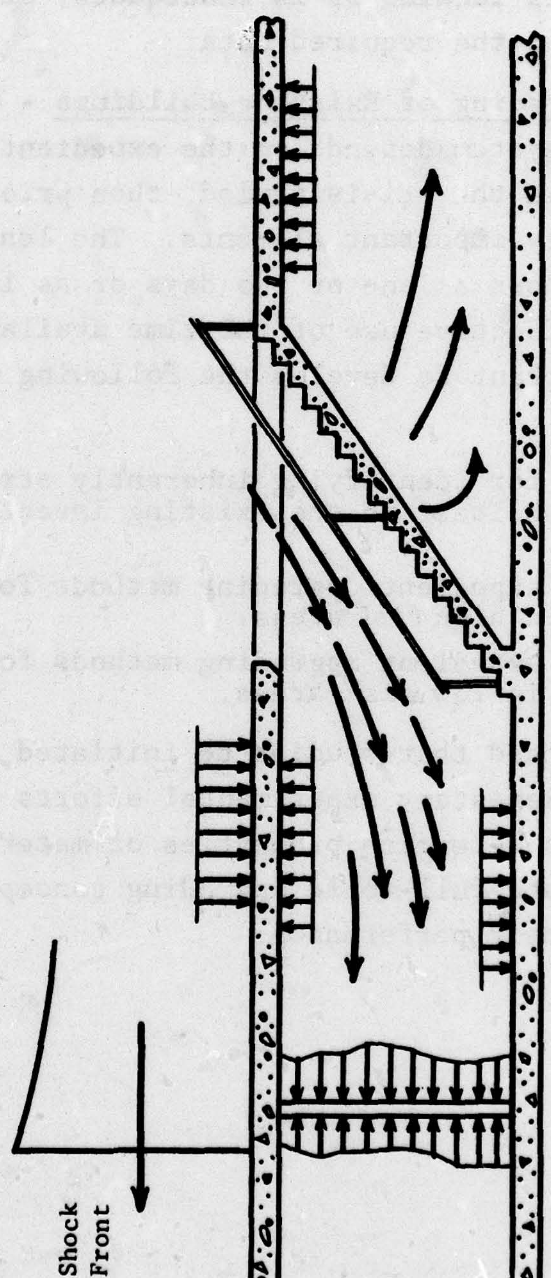


Figure 68. Blast Loading of Basement Areas

1. Thermal radiation
2. Nuclear radiation
3. Impact (blunt and penetrating)

Where information is lacking or is inadequate, studies should be initiated to develop the required data.

Expedient Upgrading of Existing Buildings - When the development of a shelter system depends on the expedient upgrading of existing facilities in the crisis period, then prior planning and preparation are very important elements. The length of the crisis period may be as short as one or two days or as long as several months.* To make effective use of the time available for implementation, it is important to develop the following ready to use information.

1. Procedures for identifying inherently strong and effective shelters in the existing inventory of buildings.
2. Catalog of expedient upgrading methods for "key worker shelters" in high risk areas.
3. Catalog of expedient upgrading methods for evacuated population in low risk areas.

It is recommended that studies be initiated to develop such information. Supplementary experimental efforts should include laboratory tests to determine properties of materials useful for upgrading. Candidate full-scale upgrading concepts should be tested to verify their performance.

*The extreme case of no crisis period, i.e., a surprise attack is not considered since under the given conditions no expedient upgrading would be implemented.

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Work Unit 1621H May 1979

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