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CASUALTIES PRODUCED BY IMPACT AND RELATED TOPICS OF PEOPLE SURVIVABILITY IN A DIRECT EFFECTS ENVIRONMENT

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IIT Research Institute

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Final Report

DCPA Contract DAHC20-73-C-0196
DCPA Work Unit 1614D

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FOREWORD

This is the final report on IITRI Project J6306, entitled "Casualties Produced by Impact and Related Problems of People Survivability in a Direct Effects Environment". It was performed for the Defense Civil Preparedness Agency under Contract DAHC20-73-C-0196. The study was initiated on May 18, 1973 and was completed July 31, 1974.

The study was performed in the Structural Analysis Section, Engineering Mechanics Division of IIT Research Institute. The following personnel contributed significantly to this study: A. Longinow, E. Hahn, A. Wiedermann and S. Citko of the Engineering Division and S. Smandra of the Electronics Division. Dr. N. Thomopoulos of the Industrial Engineering Department, Illinois Institute of Technology was consultant on statistical methods.

Respectfully submitted,
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ABSTRACT

This report contains the results of a study concerned with predicting the survivability (relative safety) of people located in conventional buildings when subjected to the direct effects of megaton range nuclear weapons. The emphasis is on impact casualties produced by the effects of blast. Casualty-producing effects considered include 1) dynamic pressures associated with the passage of the blast wave which can cause people to lose balance, be rotated, translated terminating in impact on hard surfaces, and 2) debris produced by the breakup of structural and nonstructural components when interacting with the blast wave. Casualties are divided in three categories, i.e., those produced by debris impact, floor impact and ground plane impact. The latter category includes personnel blown out of the building. The purpose of results is to categorize and rank casualty mechanisms and on this basis identify shelter spaces which are most likely to offer protection against them.

Related topics include a classification of shelter spaces, analysis of a fallout shelter against the effects of blast, feasibility of using large limestone mines as shelters and the analysis of an emergency operating center against the direct effects of nuclear weapons.

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CHAPTER 1

INTRODUCTION

The emphasis of the study described in this report is on the survivability of individuals located in conventional buildings when exposed to the direct effects produced by megaton range nuclear weapons. The reason for the emphasis and the interest in conventional buildings is that these structures, and especially those which contain substantial numbers of people for significant portions of the day, represent the only viable and significant sheltering resource at the present time. It is therefore important to have a clear understanding of their sheltering potential not only against the prompt effects of nuclear weapons but also against the effects of natural disasters such as earthquakes, hurricanes and tornadoes.

The study described is subject-wise a direct follow-on to the study described in Ref 1.1 in which an approximate, formal procedure for the evaluation of existing buildings on the basis of people survivability was formulated. Although still greatly approximate, this study extends the procedure previously developed to include a phenomenon not considered in sufficient detail. Phenomenon referred to is <u>impact</u> which is the primary casualty producer in a blast environment produced by megaton range nuclear weapons.

The impact problem and the corresponding approach to its solution are discussed in Chapter 2 which considers impacts produced in the upper stories of framed buildings when subjected to the blast effects of nuclear weapons. Impact is divided into three distinct categories, i.e., impact of building debris on individuals impact of individuals with rigid surfaces such as floors and walls, and impact of individuals with the ground plane. Ground plane impact is taken as a separate category because it involves those individuals who are swept out from the upper stories by the blast winds.

The computational procedure developed is deterministic and is capable of keeping track of the time dependent debris-people-floor-wall-ground plane interaction process in a reasonably proper sequence of the event. Each upper story occupant is treated on an individual basis keeping track of all impacts experienced by him and the intensity of each. Impacts experienced by individuals are categorized both with respect to source and the portion of body impacted. Each impact experienced by the individual is treated as a separate, independent event. The probability of fatality is determined for each of the basis of casualty criteria. The probability of fatality from combined impacts is determined as a product of the individual impact fatality probabilities.

The major advantage of this analysis process over those used previously (Ref. 1.1) is in the fact that it allows consideration of several different impact categories as part of a single, time-dependent event. It is capable of determining the relative importance of individual impact categories on survivability. It is also capable of determining the relative importance (on survivability) of a variety of different debris producing upper story walls in terms of initial crack patterns, incipient collapse overpressure, time to collapse and window size. Although the process has numerous limitations, it is nonetheless capable of producing credible and useful results.

The capabilities of this procedure are demonstrated by means of an example problem which considers 12 framed, four-story buildings and determines people survivabilities for each. The buildings are identical except that their enclosing walls have a range of different window sizes and types, and therefore different debris-size distributions. Results are analyzed using appropriate statistical methods.

Chapter 3 discusses the feasibility of developing a classification system for conventional buildings in terms of best available shelter space. A purely analytic approach is taken and a table of results for framed buildings is produced. The results are free field overpressures for 90, 50 and 10 percent survivability values, and are expressed in terms of six building parameters one of which is wall strength. Since wall strength is not a commonly available parameter, the applicability of these results is limited

It is demonstrated that in order to be generally applicable, such a classification system cannot be developed without a thorough examination of field data, i.e., detailed survey data of existing buildings. The reason for this is that in order to be generally applicable, the relative protection afforded should be expressed in terms of commonly known and commonly used descriptors. Incipient collapse overpressures for walls and basement overhead slabs are not commonly available. By analyzing field survey data, determining survivabilities of corresponding buildings, and analyzing results using statistical methods, it is possible to eliminate insignificant building parameters and to express survivability in terms of more commonly used descriptors such as wall type and slab type. A pilot analysis effort along these lines has been performed and is described in Ref. 2.2.

An analysis of an existing Emergency Operating Center is described in Chapter 4 Since this is believed to be the first analysis of an EOC to consider direct effects of nuclear weapons on communications, life support equipment and operating staff, the analysis is fairly detailed. The attempt is to consider all potentially critical items and to develop a standard ranking procedure for this class of civil defense facilities.

In Chapter 5 a shelter designed and constructed for fallout radiation protection is analyzed to determine its protection capabilities against prompt effects of nuclear weapons. This analysis adds one more shelter to the catalog of expedient and special purpose shelters originally designed for fallout radiation and analyzed against direct effects. Previous shelters analyzed are described in Ref. 1.1.

Other tasks completed in the course of this study include a review of currently available casualty criteria relative to casualty mechanisms manifested in shelters, i.e., upper stories and basements of conventional buildings, development of an articulated man simulation model, development of a procedure for the analysis of load-bearing and combination buildings, complete update and revision of the people survivability analysis computer program described in Ref. 1.1, estimation of dynamic pressures in a large, existing limestone mine complex. Results and conclusions based on these tasks are discussed in Chapter 6, which also contains a set of recommendations for future studies.

Appendices to this report include a description of the computer program used in generating results presented in Chapter 3 and a preliminary analysis of limestone mines as possible personnel shelters.

REFERENCES

1.1 Longinow, A., et al, People Survivability in a Direct Effects Environment and Related Topics, Contract DAHC20-68-C-0126, Work Unit 1614D, for DCPA, IIT Research Institute, May 1973

1.2 Longinow, A., Survivability in a Direct Effects Environment (Analysis of 50 NFSS Buildings), Contract DAHC20-73-C-0227, for DCPA, IIT Research Institute, July 1974.

CHAPTER 2

CASUALTIES PRODUCED BY IMPACT

2.1 STATEMENT OF THE PROBLEM

In the upper stories of buildings subjected to the direct effects of nuclear weapons casualties will be produced by:

> Thermal radiation when window covering is not provided or is inadequate and when people are in the direct line of sight with the source.
>
> Prompt nuclear radiation when the mass thickness between the people and the source is not adequate or essentially nonexistent as in the case of modern, highrise buildings with large areas of window glass.
>
> Dynamic pressure (high velocity winds) associated with the passage of the blast wave will cause people to lose balance, be rotated, translated terminating in impact on hard surfaces (floor, walls, furniture) with various parts of the body. In addition to setting people in motion, dynamic pressures will also set loose or attached objects in motion. Building components such as window frames and glass, mounted equipment, walls and partitions loosened or separated by the blast wave become moving, lethal debris under the action of blast winds. These can interact with people located in their paths producing impact casualties.

People located in basements face similar casualty mechanisms if windows are provided. In full basements, i.e., those without windows and with the overhead slab at grade, impact is the primary casualty mechanism and is produced by the breakup and collapse of the overhead floor systems. People can thus be impacted as a result of being set in motion by the blast winds; by sliding, airborne or falling debris or some combination of these.

Impact, blunt or penetrating, is an important casualty mechanism for people in the upper stories and in basements. In those instances where thermal and prompt nuclear radiation may be neglected (which incidentally represents a large number of practical cases), impact is the only casualty mechanism.

In previous studies (Ref.2.1) dealing with people survivability, the impact problem was analyzed in two parts. First, casualties produced by impact with floors, walls and ground surface were determined. The resulting probability of survival was then modified by introducing approximate debris effects using results from Ref. 2.2. This approach ignores the interaction of debris and people as each is being translated by the blast winds and is therefore only weakly defensible. This approach considered in this study, although still approximate, takes into account the various impacts described and does so in a reasonably proper sequence of the event.

The objective of the effort described in this chapter was to develop a procedure capable of determining the importance of debris as a casualty producer when compared to other types of impact experienced by people in upper stories. The emphasis is on debris which would be produced by the breakup of external (peripheral) walls in framed buildings. No consideration is given to window glass fragments, furniture items, equipment or interior walls. It is recognized that window glass, furniture, certain classes of building equipment and debris from the breakup of interior masonry walls can be as important in producing casualties as debris from exterior walls. However, due to the complexity of the overall problem it is felt that a more useful purpose is served by gaining a clear understanding into the mechanics of people-debris interaction before studying the effects of the entire spectrum of debris sources. Debris as produced by the breakup of exterior walls was chosen for this purpose.

The method used in predicting impact casualties is described in the following section. Three types of impact are considered, i.e., impact of debris with people, impact of people with the floor and impact of people with the ground plane.

2.2 PROCEDURE FOR THE ANALYSIS OF IMPACT CASUALTIES

2.2.1 Summary of the Process

To determine the relative importance of the various categories of impact to which people in the upper stories may be subjected when exposed to the blast effects of nuclear weapons, the following analysis method was adopted. The process is illustrated in Figure 2.1.

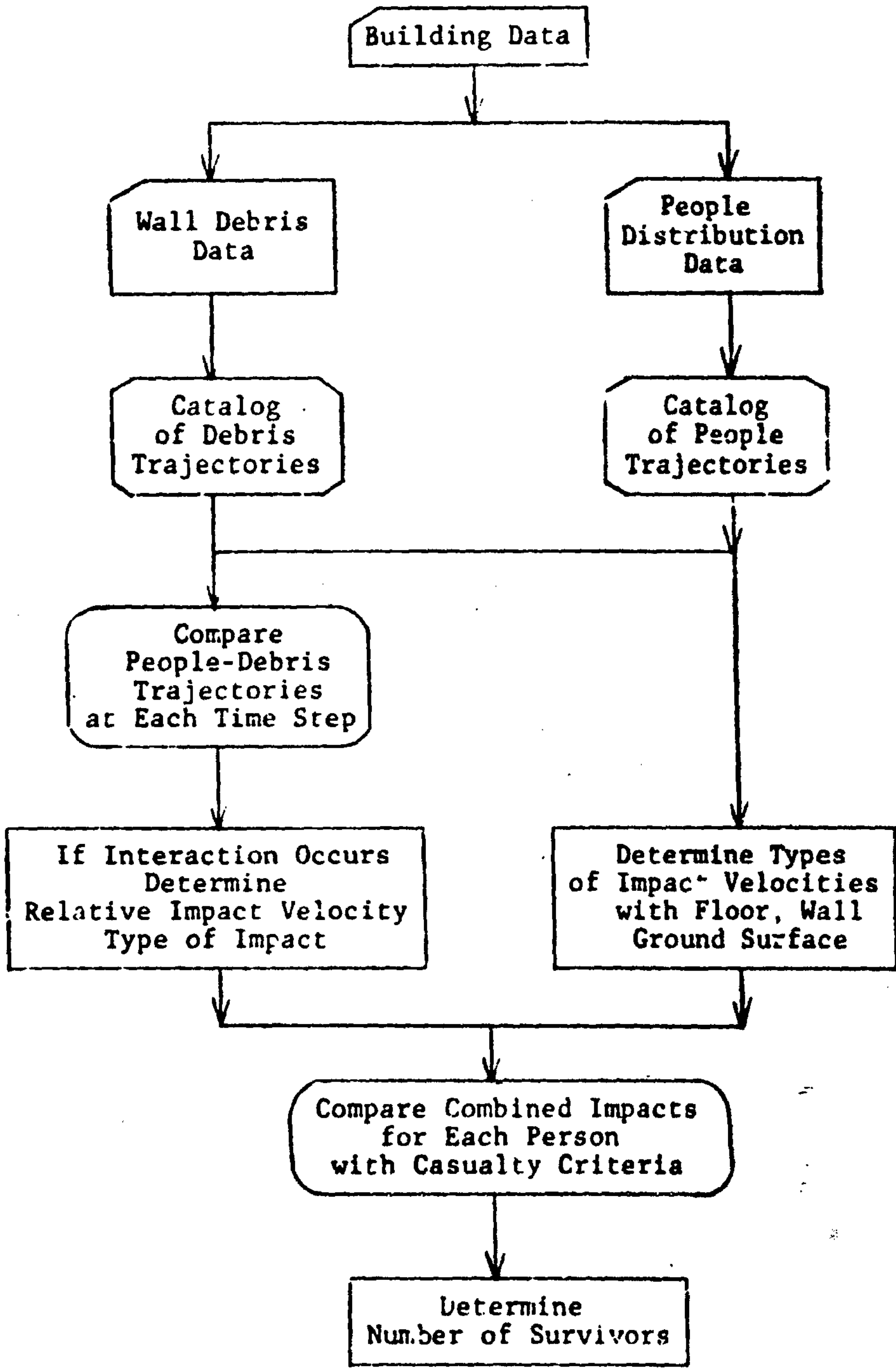


Figure 2.1 Impact Casualty Analysis Process

As indicated in this figure, for a given building portion and a given distribution of people within, the procedure makes use of stored information, i.e., a catalog of debris trajectories and a catalog of people trajectories.

The debris trajectory catalog was generated by selecting a set of representative debris sizes, assigning a set of initial coordinates to each and computing trajectories for each piece of debris at each initial coordinate. Overpressures used in the calculations were for a 1 MT weapon and ranged from 2 psi to 20 psi in increments of 2 psi. A total of 47 debris size initial coordinate combinations were used. This resulted in 470 individual trajectories. Trajectory information stored includes time-dependent center of gravity displacements, velocities and accelerations. Calculations were performed using the rigid block, three-degree of freedom model described in Chapter 3, Ref. 2.1.

By selecting various debris size-coordinate combinations from this catalog it is possible to put together a wall (with or without a window) which on failure produces the given number of debris pieces. A fairly large number of 10 ft by 11 ft external, windowed walls having different failure patterns and number of debris pieces can be constructed using this set of stored information.

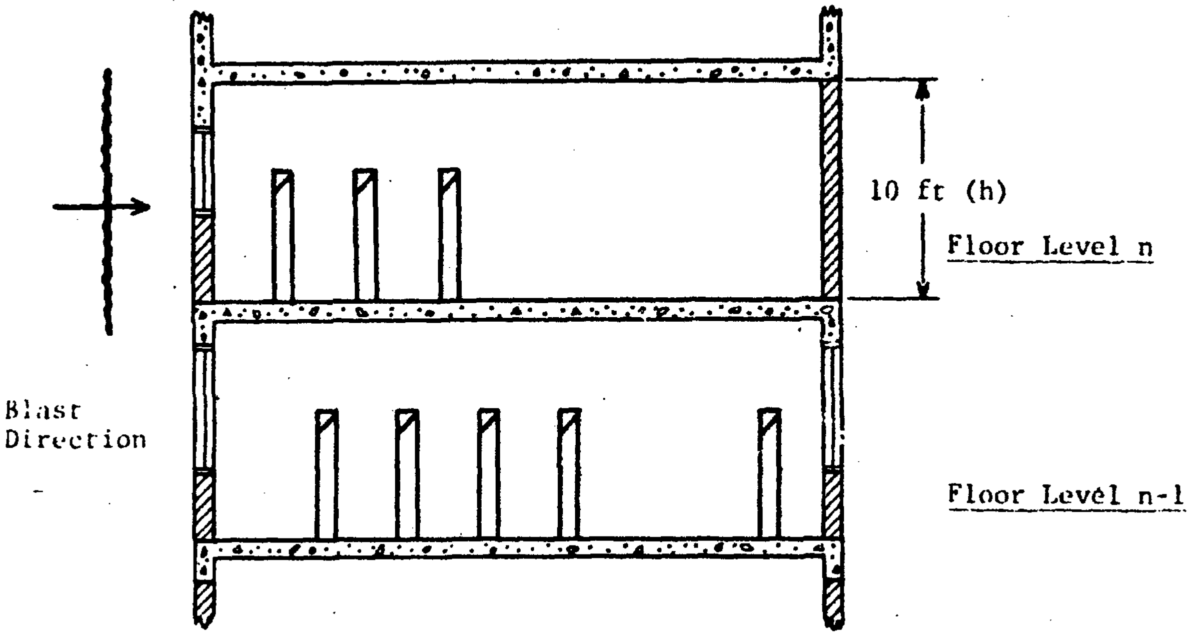
People trajectories were calculated by first positioning individual, simulated people at specified coordinates on a floor level 11 ft wide and 100 ft long. People were simulated using the three degrees of freedom, rigid block model described in Ref. 2.1. Each simulated person was loaded by diffraction, drag and lift forces. Magnitudes of this loading were computed by modifying the free field loading at the position of the windward wall as a function of window area, aperture produced by the breakup of the wall and the distance of the person from the windward wall. On this basis 44 trajectories were calculated for each of three initial body positions, window area and overpressure level; one trajectory for each 2 ft interval from the windward wall for a length of 98 ft. The three initial body positions included standing, prone (parallel to the direction of blast), and prone (perpendicular to the direction of blast). Window percentages were 15, 50 and 100. Overpressures used were for a 1 MT weapon and ranged from 2 to 20 psi in increments of 2 psi.

Since the trajectories are for individual people, this set of calculated information allows one to define a fairly large number of different building or room population distributions.

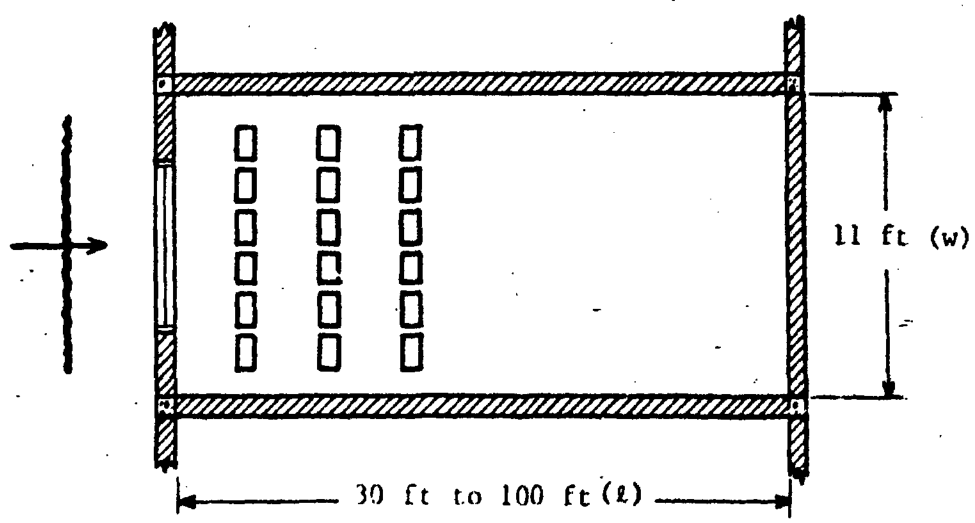
Referring back to Figure 2.1 the overall analysis process can now be described in terms of a typical application illustrated in Figure 2.2.

The process allows for the analysis of individual building bays. Building data are specified by providing the following information: bay length (30 ft to 100 ft in increments of 10 ft), floor level (story height), sill height, window percent and wall failure overpressure. Floor to ceiling distance is taken as 10 ft, and bay widths, 11 ft. These values are built in the computation process. Wall data are specified by identifying a set of debris sizes and their center of gravity coordinates on the wall. People data are specified by providing the following information: number of people, body position, and coordinates for each person.

Designations provided by these data allow the program to identify the correct debris and people trajectories in the two data catalogs. Respective trajectories are then compared at each time step to determine if interactions occur. If interactions occur, points of contact are determined and relative velocities between the person and debris at the point of contact are computed. This is done for each person and each piece of debris providing that impact occurs within the building (bay) length. By the location of the contact point, three types of impact are identified, i.e., head impact, thorax-abdomen impact, lower limbs impact. Relative velocity values for each impact and person are compared with casualty criteria to establish the level of casualty.



a. Elevation



b. Plan (Floor Level n)

Figure 2.2 Typical Application of Impact Casualty Analysis Process

Having completed the debris interaction analysis, the process goes to determine floor and ground plane impact velocities. These are determined using people trajectory data. Results are compared with casualty criteria and corresponding levels of casualty are combined with those determined for debris impact.

Probabilities of survival for individual people are determined using the following relationships.

$$S_{j1} = \prod_{i=1}^{i=n} (1 - f_{1i}) \tag{1}$$

$$S_{j2} = \prod_{i=1}^{i=o} (1 - f_{2i}) \tag{2}$$

$$S_{j3} = \prod_{i=1}^{i=p} (1 - f_{3i}) \tag{3}$$

In these equations S_{j1}, S_{j2}, and S_{j3} are individual probabilities of survival of person "j" due to debris impact, floor impact and ground plane impact respectively. f_{1i}, f_{2i}, and f_{3i} are probabilities of fatality (levels of casualty) corresponding to computed impact velocities in the three impact categories. Since in any impact category an individual can be impacted more than once, the index "i" is used to keep track of the number of impacts received in each case. On the basis of these relationships, the probability of survival of person "j" with respect to the three types of impact (k=1,3) is determined using the following expression:

$$S_j = \prod_{k=1}^{k=3} S_{jk} \tag{4}$$

The average probability of survival for an arbitrary individual in a given population of "m" persons becomes

$$S = \frac{1}{m} \sum_{j=1}^{j=m} S_j \tag{5}$$

Similarly, the total average percent survivors for a population of "m" persons is

$$S_t = \frac{100}{m} \sum_{j=1}^{j=m} S_j \tag{6}$$

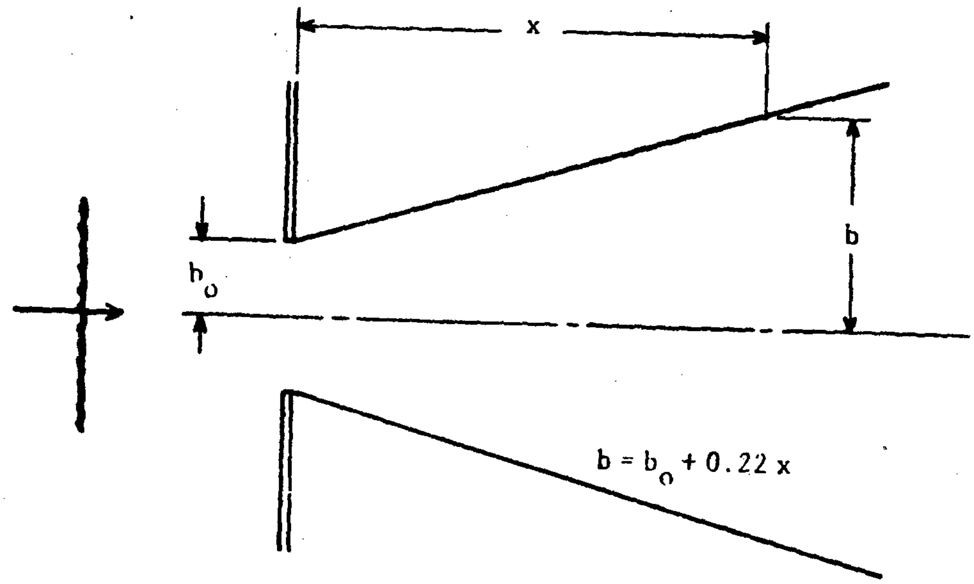
On the basis of these equations the procedure for computing people survivability can also be expressed in matrix form as follows:

Individual probabilities of survival for each person and each impact category	Probabilities of survival for each person	Average probability of survival for an arbitrary individual	Total, average percent survivors

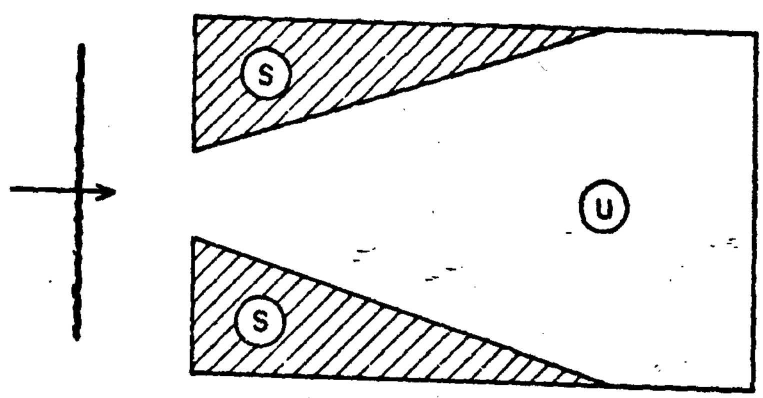
$$\begin{array}{c} \underline{\text{Individual}} \\ 1 \\ 2 \\ \cdot \\ j \\ \cdot \\ \cdot \\ m \end{array} \begin{array}{c} \underline{\text{Impact Category}} \\ \begin{array}{ccc} 1 & 2 & 3 \end{array} \\ \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ \cdot & \cdot & \cdot \\ S_{j1} & S_{j2} & S_{j3} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ S_{m1} & S_{m2} & S_{m3} \end{bmatrix} \end{array} \rightarrow \begin{bmatrix} S_1 \\ S_2 \\ \cdot \\ S_j \\ \cdot \\ \cdot \\ S_m \end{bmatrix} \longrightarrow S \longrightarrow S_t \tag{7}$$

2.2.2 Blast Loading of Building Occupants

The loading is described in Figures 2.3, 2.4, and 2.5. In any given room a person may be located in the shaded area, i.e., outside the blast jet, or in the unshaded area, i.e., within the blast jet. Blast jet velocities, at any x-coordinate (see Figure 2.3) are assumed to vary such that they are zero at the jet boundary. With this assumption, people located in shaded areas are therefore "translation safe" as long as the windward wall remains standing.

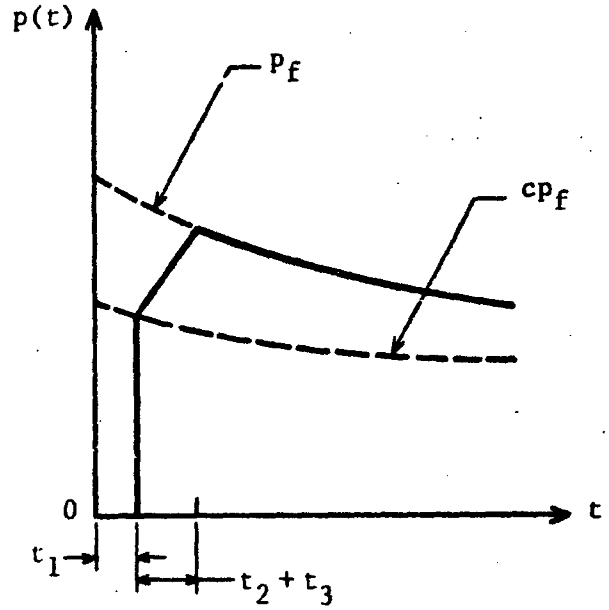


a. Assumed Jet Profile

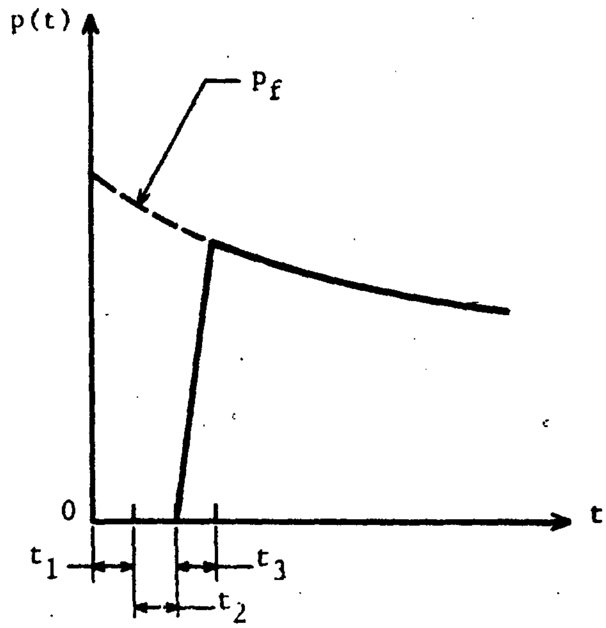


b. Room Plan - Shaded and Unshaded Areas

Figure 2.3 Definition of Shaded and Unshaded Areas

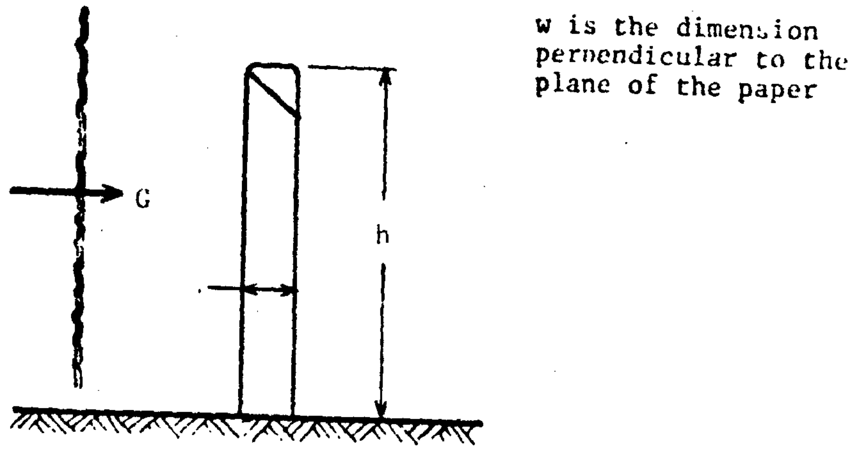


a. Pressure-Time History in Unshaded (U) Area

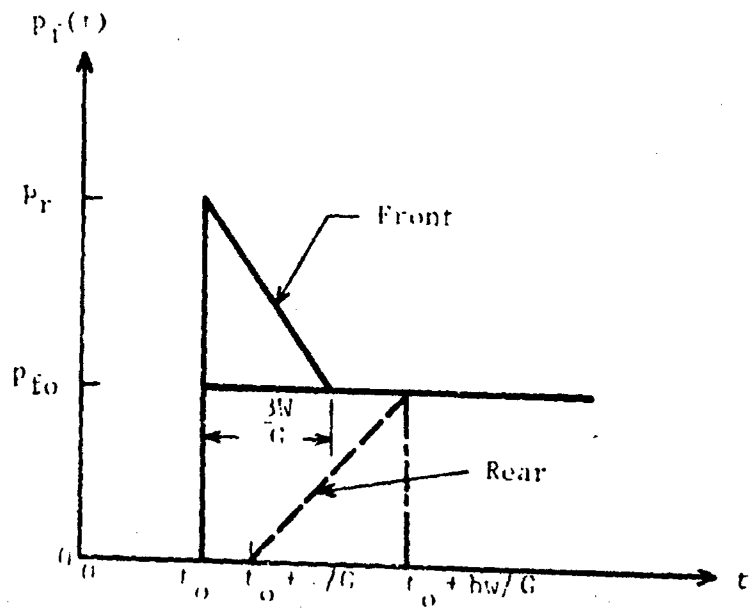


b. Pressure-time History in Shaded (S) Area

Figure 2.4 Pressure-Time Histories in Initially Unshaded and Shaded Areas of a Room



a Simulated Person



b. Diffraction Loading

Figure 2.5 Diffraction Model for Shock Impulse

Pressure-tire histories for unshaded and shaded areas in a given room are illustrated in Figure 2.4. At time t=0, the blast wave is at the face of the windward wall. At any point in the unshaded area the pressure is zero for the time (t_1) required for the blast wave to transverse the distance from the windward wall to the point considered, at which time it rises to $p(t_1) = cp_f(t_1)$. Coefficient "c" is a pressure reduction factor (Ref. 2.2) which is related to the ratio of window area to the total windward wall area of the room under consideration. If the wall does not fail, the pressure varies along the dash line labeled cp_f. If the wall fails pressure follows the solid line where t_2 is the time required for the wall to fail (time to separation of the individual debris pieces) and t_3 is the time for it to be removed. In the demonstration problem described in Section 2.3 all walls have an incipient collapse pressure of 2 psi. For these walls t_1 was assumed to range from 100 msec at 2 psi to 55 msec at 20 psi. A constant value of 0.8 sec is used for t_2 in each case. This is the free-fall time of a piece of debris from a height of 10 ft (room height). At the end of time increment "t_3" the area occupied by the windward wall is assumed not to provide any obstruction to the blast jet.

The pressure-time history at any point in the shaded area is assumed as shown in Figure 2.4. Pressure is zero until the wall fails and separation occurs, i.e., at the end of time increment t_2. The pressure rises linearly to the free field pressure during the time increment t_3 which is again the time required for the wall to be removed.

Pressure-time histories shown in Figure 2.4 are used in determining the loading experienced by individual room occupants. This consists of diffraction followed by a drag phase. An idealized diffraction loading is shown in Figure 2.5. In the drag phase a person is subjected to drag (D) and lift (L) forces which are computed as follows:

$$D = q(t)\ A_d(\theta) \tag{8}$$

$$L = q(t)\ A_{\ell}(\theta) \tag{9}$$

where q(t) is the dynamic pressure of the flow and $A_d(\theta)$ and $A_{\ell}(\theta)$ are position dependent drag and lift areas which are expressed as follows:

$$A_d = A_{dmin} + (A_{dmax} + A_{dmin})\ \sin^2(\theta - \frac{\pi}{2}) \tag{10}$$

$$A\ = A_{\ell max}\ \sin(2\theta - \pi) \tag{11}$$

A_{dmin}, A_{dmax} and $A_{\ell max}$ are respectively the minimum drag area, the maximum drag area, and the maximum lift area of the translated individual.

As indicated previously, the velocity in the jet varies with room position x (see Figure 2.4a) and at any x is maximum at the centerline and zero at the jet boundary. In this analysis process such variations were not used. At any given overpressure, the loading at any point within the blast jet was assumed to be the same, with variation shown in Figure 2.4a. In this figure p_f - p(t) + q(t) where p(t) is the free field overpressure which is used in the diffraction phase loading.

2.2.3 Debris Produced by the Breakup of Masonry Walls

2.2.3.1 Experimental Debris Data

The wall debris trajectories catalog described in the following section was assembled after a review of a number of references including that contained in Refs. 2.3 and 2.4. A brief discussion of this information is given in this section. Table 2.1 is a summary of some basic experimental data on full-scale masonry walls subjected to blast loading. A total of 19 walls are summarized. Ten of these had simple beam support conditions, i.e., simple supports top and bottom. The remaining nine were simply supported along their four edges with corners restrained against displacement and rotation. This information is plotted in Figure 2.6.

Table 2.1

WALL DEBRIS DATA (Ref. 2.3)

	Wall No.	Boundary Conditions	Peak Reflected Overpressure psi	Number of Pieces	Location of Initial Cracks
1	1	Simple Beam Supports	3.0	2	Essentially horizontal, 5.5 ft from floor
2	2	Simple Beam Supports	~3.5	2	Staggered horizontal, ~4 ft from floor
3	3	Simple Beam Supports	~3.5	2	Horizontal, 4 ft from floor
4	4	Simple Beam Supports	10.0	3	Horizontal, ~4 ft and 5.3 ft from floor
5	5	Simple Beam Supports	3.6	*	*
6	6	Simple Beam Supports	10.1	3	Horizontal, 4 ft and 6 ft from floor
7	7	Simple Beam Supports	3.6	2	Horizontal, 4 ft from floor
8	20	Simple Beam Supports	10.3	3	Essentially horizontal, 3 ft and 5 ft from floor
9	21	Simple Beam Supports	3.5	2	Near the middle
10	22	Simple Beam Supports	10.0	3	Horizontal, ~3 ft and 6.5 ft from floor
11	23	Simple Plate Supports	10.9	*	*
12	24	Simple Plate Supports	3.2	4	Near the center. Form: essentially classic yield lines
13	25	Simple Plate Supports	3.6	7	Similar to 12
14	26	Simple Plate Supports	~15.0	*	*
15	27	Simple Plate Supports	3.5	7	Similar to 12
16	28	Simple Plate Supports	4.0	*	*
17	29	Simple Plate Supports	3.8	5	Similar to 12
18	30	Simple Plate Supports	~15.0	10	Similar to 12
19	31	Simple Plate Supports	15.0	6	Similar to 12

*Information not available.

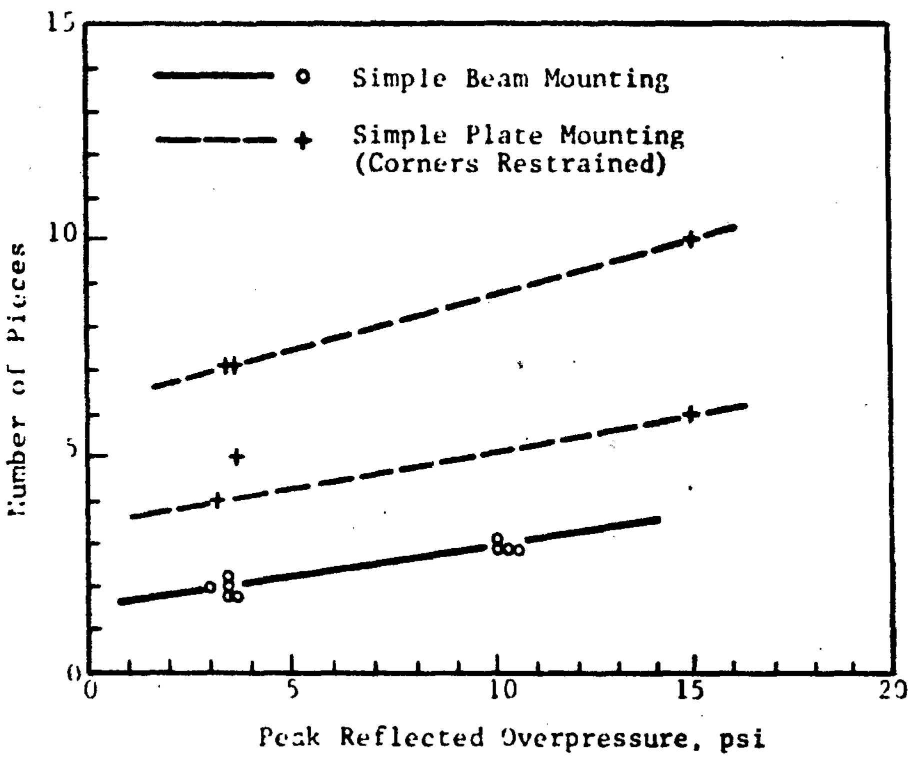


Figure 2.6 Variation of the Number of Wall Pieces with Overpressure and Support Conditions

The simple beam support data is the most consistent. At low reflected overpressures (3.0 to 3.5 psi) the walls fail, producing two large (approximately equal) pieces of debris. At higher reflected overpressures (10.0 to 10.3 psi) three pieces are produced with the third piece located at about the center and being smaller than the other two pieces.

Results of walls with simple plate mounting are less consistent. The data have more spread and form an envelope. Initial crack patterns (Figures 2.7 and 2.8) resemble classic yield lines characteristics of reinforced concrete plates.

In general, initial debris pieces are large. The number of pieces produced increases with increased overpressure. Crack patterns generally follow classic yield lines.

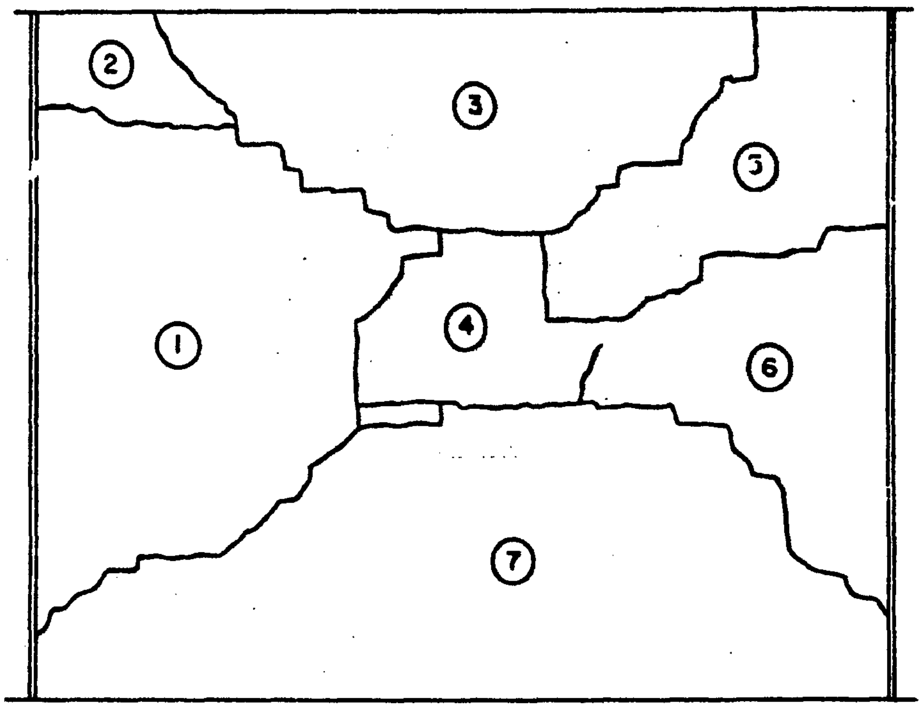


Figure 2.7 Initial Crack Pattern for Wall 25

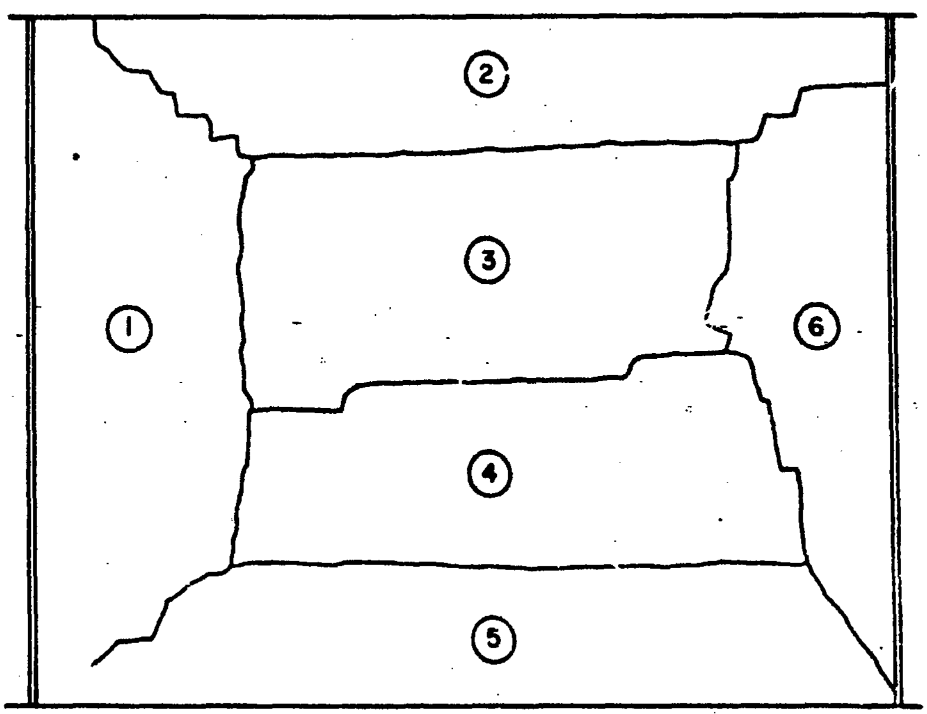


Figure 2.8 Initial Crack Patter for Wall 31

2.2.3.2 Debris Trajectory Data

Debris trajectories were calculated for 47 debris pieces. Each debris piece is identified by its height, width and initial location (x_g, y_g) relative to a convenient reference point. The debris selected are tabulated in Table 2.2. Their geometry and initial location are referenced as shown in Figure 2.9. The debris catalog allows for the assembly of a variety of different walls as illustrated in Figure 2.10. This wall was assembled using debris pieces 6, 31, 32, and 33. For the purpose of performing debris-people interaction analyses, once the trajectories have been computed, a wall is fully identified by the information given in Table 2.3, which includes block number, its z-coordinate (center of gravity), and debris designation.

The reason that the z-coordinate is missing from the debris catalog (Table 2.2) is that the debris trajectory is a planar (x,y) trajectory and therefore independent of the z-coordinate. In performing debris-people interaction analyses, the z-coordinate becomes important. People can be randomly distributed behind a given wall, and although the debris trajectories for a given debris piece and overpressure level are identical at each z-coordinate, people distributions are not.

This approach for determining debris trajectories produced by the breakup of a wall when subjected to blast, rests on the assumption that a given wall assembled from the various debris pieces given in Table 2.2 will fail along the surfaces (Ht and Wt, see Figure 2.9) bounding the selected debris pieces. The debris pieces cataloged allow for the assembly of walls having various incipient collapse crack patterns. Once a crack pattern has been assumed no further breakup is allowed.

2.3 ANALYSIS OF IMPACT CASUALTIES

Procedure described in the previous sections was applied to the analysis of people survivability in framed buildings when subjected to the blast effects of a single megaton range nuclear weapon. A range of free field overpressures from 2 psi to 20 psi in 2 psi increments was used.

Table 2.2

DEBRIS CATALOG

Debris Designation	Height (H) (ft)	Width (W) (ft)	Weight (lbs)	Initial Position	
				X_g	Y_g
1	1.33	1.33	68	0.33	0.67
2	1.33	1.33	68	0.33	0.67
3	1.33	1.33	68	0.33	0.67
4	1.33	1.33	68	0.33	0.67
5	1.33	1.33	68	0.33	0.67
6	1.33	2.67	136	0.33	0.67
7	1.33	2.67	136	0.33	0.67
8	1.33	2.67	136	0.33	0.67
9	1.33	2.67	136	0.33	0.67
10	1.33	2.67	136	0.33	0.67
11	7.30	3.75	1040	0.33	3.50
12	3.30	9.00	1128	0.33	2.25
13	4.00	9.00	1368	0.33	1.33
14	0.67	1.33	34	0.33	0.34
15	0.67	1.33	34	0.33	0.34
16	0.67	1.33	34	0.33	0.34
17	1.33	2.00	102	0.33	0.67
18	1.33	2.00	102	0.33	0.67
19	1.33	2.00	102	0.33	0.67
20	0.67	1.33	34	0.33	0.34
21	0.67	1.33	34	0.33	0.34
22	0.67	1.33	34	0.33	0.34
23	1.33	2.00	102	0.33	0.67
24	1.33	2.00	102	0.33	0.67
25	1.33	2.00	102	0.33	0.67
26	0.67	1.33	34	0.33	0.34
27	0.67	1.33	34	0.33	0.34
28	1.33	2.00	102	0.33	0.67
29	1.33	2.00	102	0.33	0.67
30	1.33	2.00	102	0.33	0.67
31	1.33	2.67	136	0.33	2.00
32	1.33	2.67	136	0.33	3.33
33	1.33	2.67	136	0.33	4.67
34	1.33	2.67	136	0.33	6.00
35	1.32	2.67	136	0.33	7.33

Table 2.2 (Concl)

Debris Designation	Height (ft)	Width (W) (ft)	Weight (lbs)	Initial Position	
				X_g	Y_g
36	1.33	2.67	136	0.33	8.67
37	1.33	2.67	136	0.33	10.00
38	1.33	2.00	102	0.33	3.33
39	1.33	2.00	102	0.33	4.67
40	1.33	2.00	102	0.33	6.00
41	1.33	2.00	102	0.33	7.33
42	1.33	2.00	102	0.33	8.67
43	1.33	1.33	68	0.33	3.33
44	1.33	1.33	68	0.33	4.67
45	1.33	1.33	68	0.33	6.00
46	1.33	1.33	68	0.33	7.33
47	1.33	1.33	68	0.33	8.67

Note: The thickness of each debris piece tabulated above is 8 in.

Table 2.3

WALL DATA
(Sample Wall, Figure 2.10)

Block	Z-Coordinate (ft)	Debris Designation
1	1.33	6
2	4.00	6
3	6.67	6
4	9.33	6
5	1.33	31
6	4.00	31
7	6.67	31
8	9.33	31
9	1.33	32
10	4.00	32
11	6.67	32
12	9.33	32
13	1.33	33
14	4.00	33
15	6.67	33
16	9.33	33

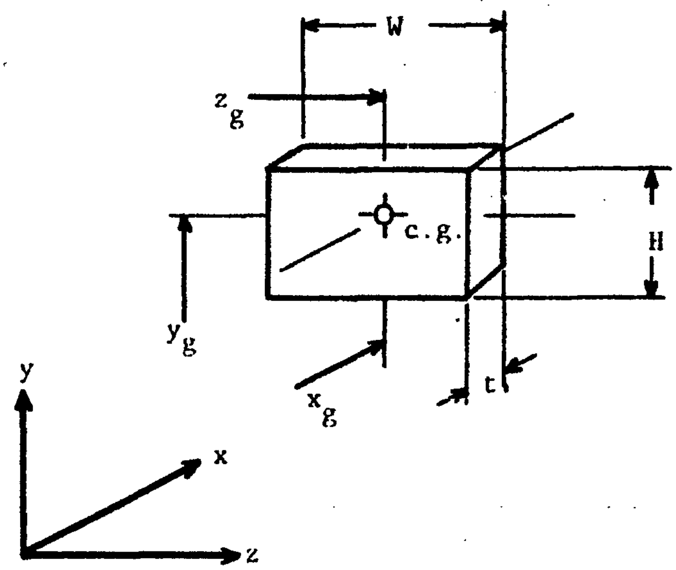


Figure 2.9 Designation for the Initial Location of a Debris Piece

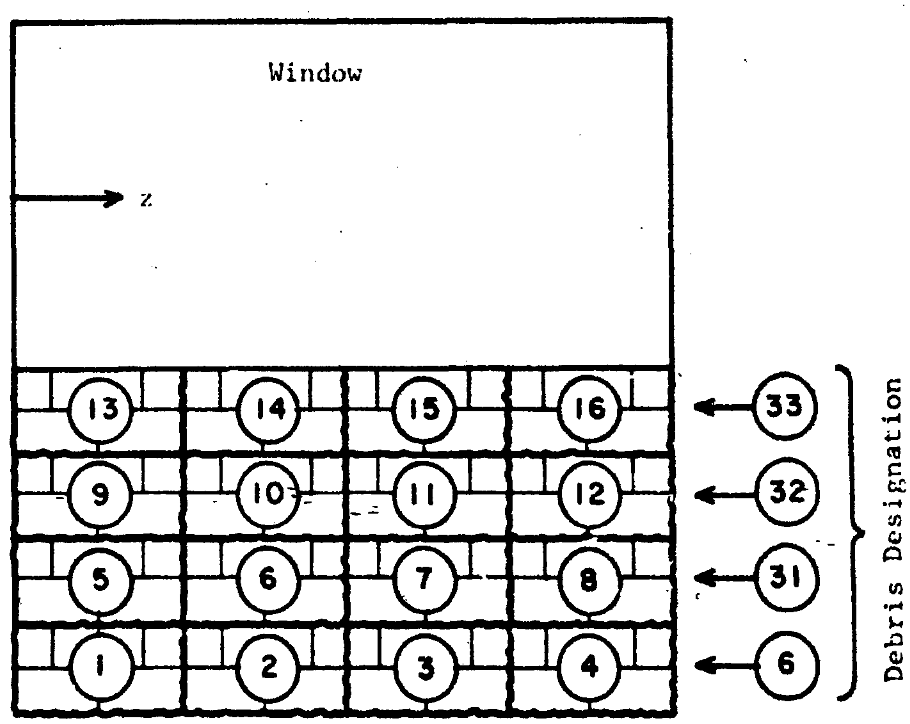
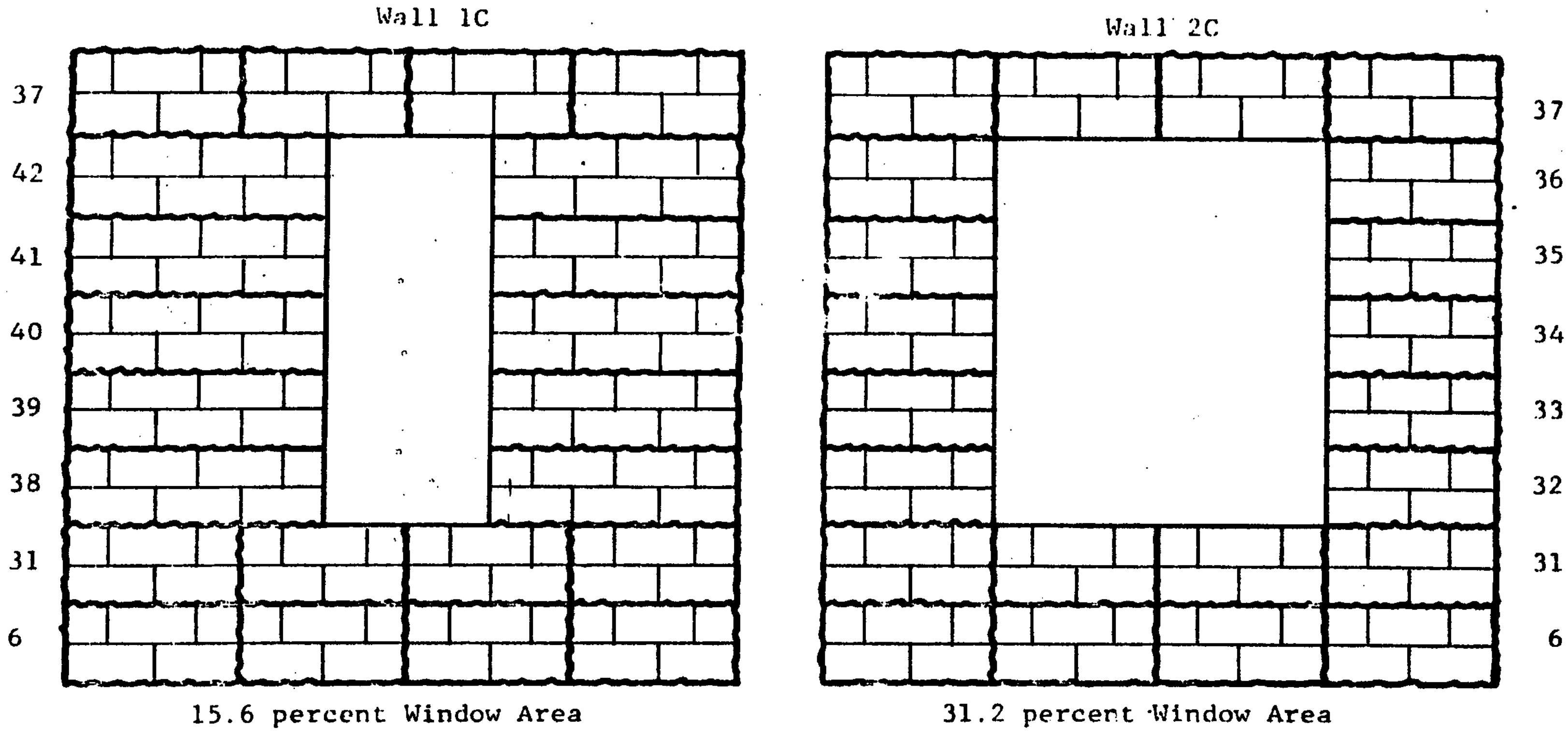


Figure 2.10 Sample Wall

The problem considers 12, four-story buildings having identical framing systems and frame geometries. Framing systems are assumed not to fail for this range of overpressures. Peripheral walls consist of masonry and in each case have an incipient collapse overpressure of 2 psi. The difference between these 12 buildings is in the size of window openings and in the number and weight of debris pieces produced when the walls collapse.

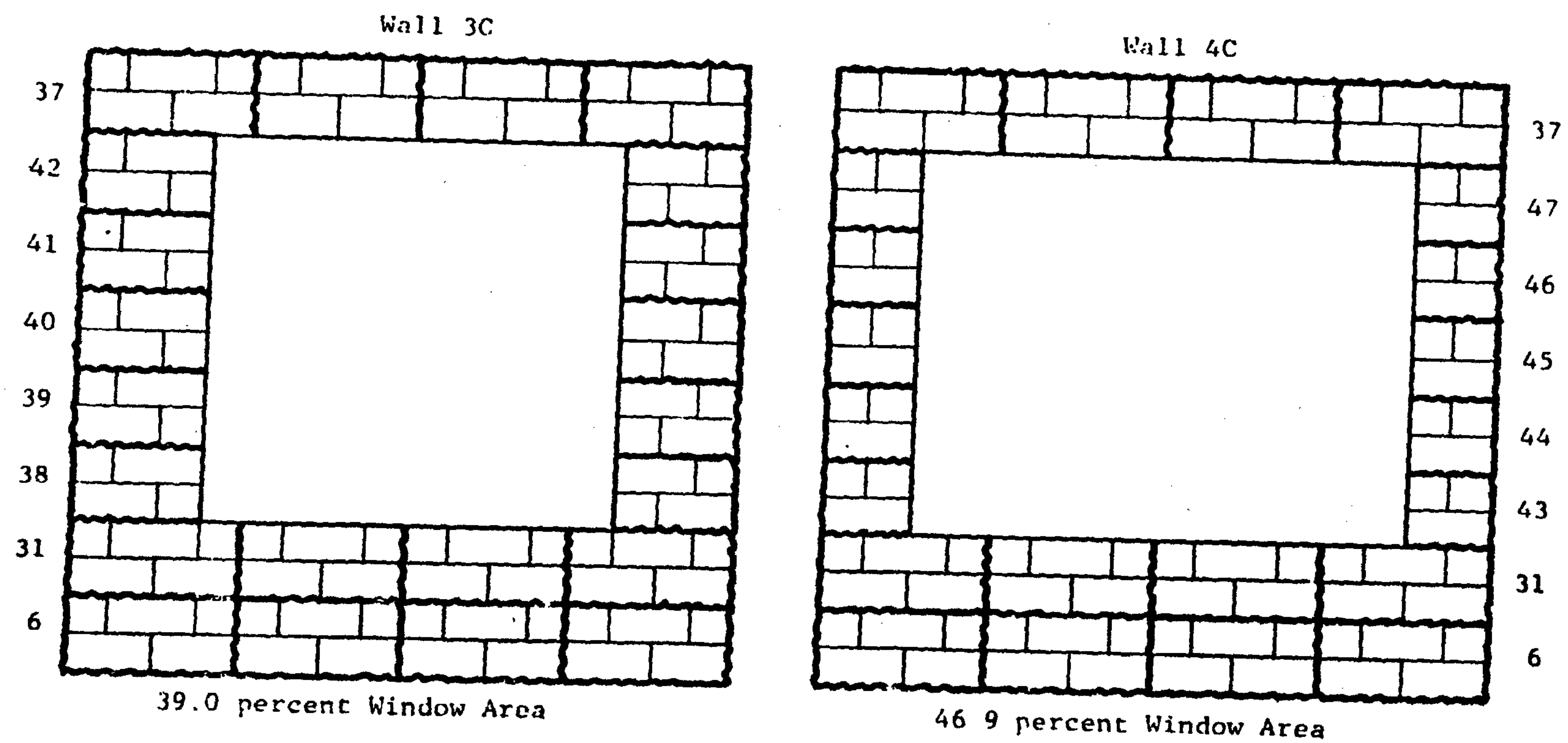
In each case the building arrangement is as shown in Figure 2.2. Story height (h) is 10 ft, bay width (w) is 11 ft and building length (ℓ) is 100 ft. Windward and leeward walls are identical. The 12 walls are illustrated in Figure 2.11 through 2.17. They are divided into two categories by the type of windows. Walls in the "C" category have centrally located windows, those in the "W" category have wide windows which span the entire width of the wall (bay). The heavy, irregular lines shown on this set of figures indicate fracture lines and thus delineate individual debris pieces. Numbers along one side of each wall are debris designations (see debris catalog, Table 2.2).

It will be recalled (see Section 2.2.3) that initial debris pieces produced by the failure of masonry walls with simple plate supports are usually large and crack patterns generally follow classic yield lines (see Figures 2.7 and 2.8). These large pieces break up when impacting the ground plane. Some of them may also separate along weak planes while in flight if the load duration is sufficiently long. Thus, although people located close to a wall may interact with the large, i.e., primary pieces, those further away are more likely to interact with secondary debris, i.e., debris broken after separation from the wall. Since the computational process used does not consider debris breakup after initial separation, the following approach was used. The number of debris pieces in each of the walls (Figures 2.11 through 2.17) represents approximately an average between the number of initial and the number of final debris pieces.



3/8 in. = 1 ft-0 in.

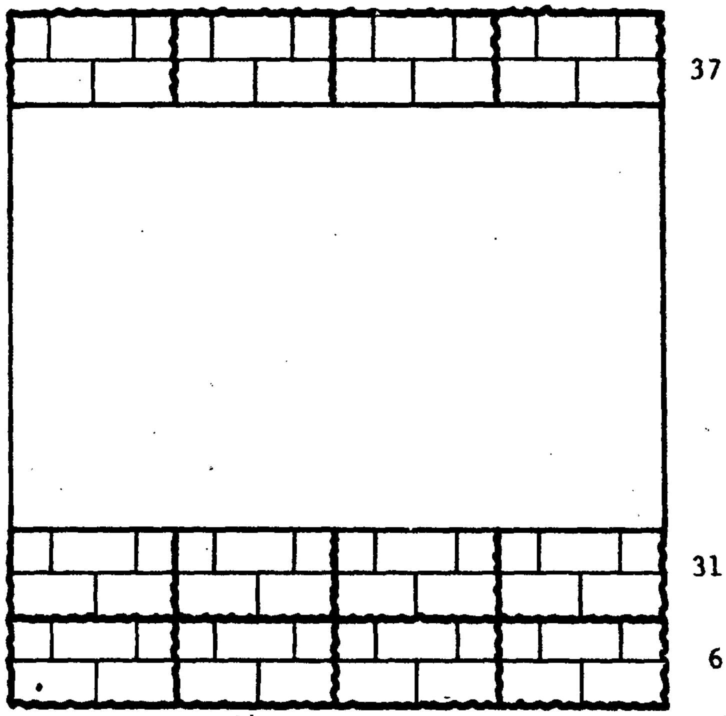
Figure 2.11 Assumed Crack Patterns for Wall Breakup (Walls 1C and 2C)



3/8 in. = 1 ft-0 in.

Figure 2.12 Assumed Crack Patterns for Wall Breakup (Walls 3C and 4C)

Wall 5C



62.5 percent Window Area

Figure 2.13 Assumed Crack Pattern for Wall Breakup (Wall 5C)

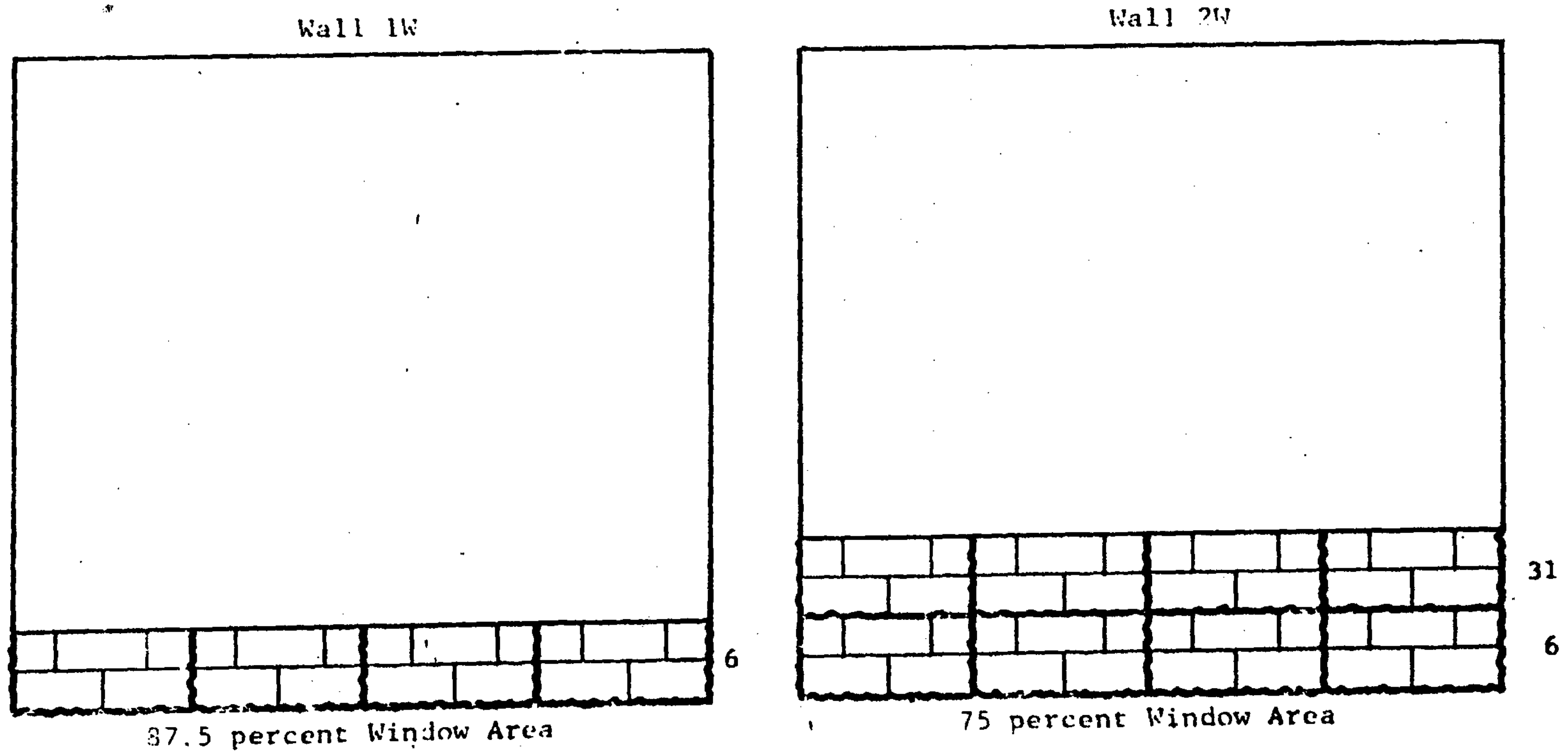


Figure 2.14 Assumed Crack Patterns for Wall Breakup (Walls 1W and 2W)

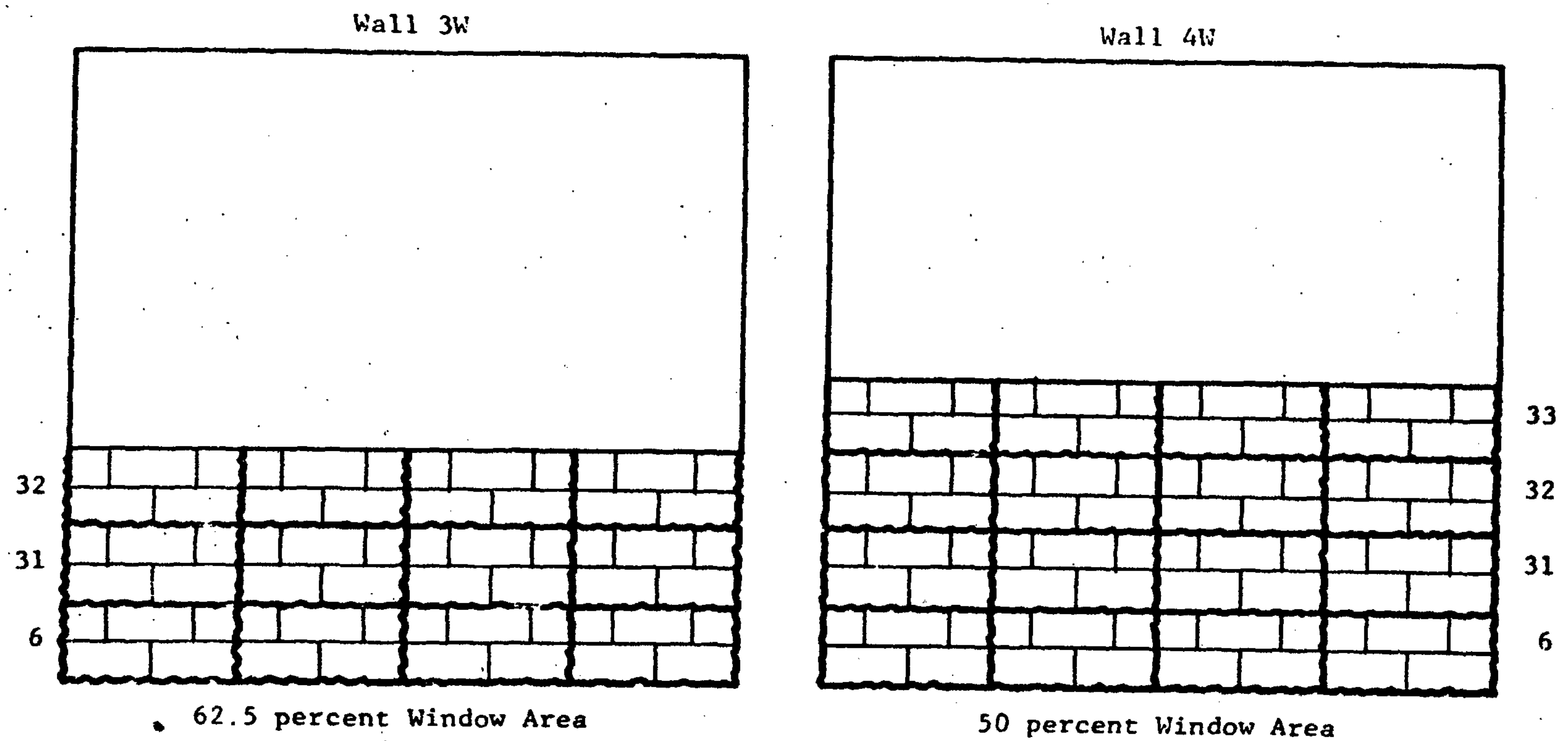


Figure 2.15 Assumed Crack Patterns for Wall Breakup (Walls 3W and 4W)

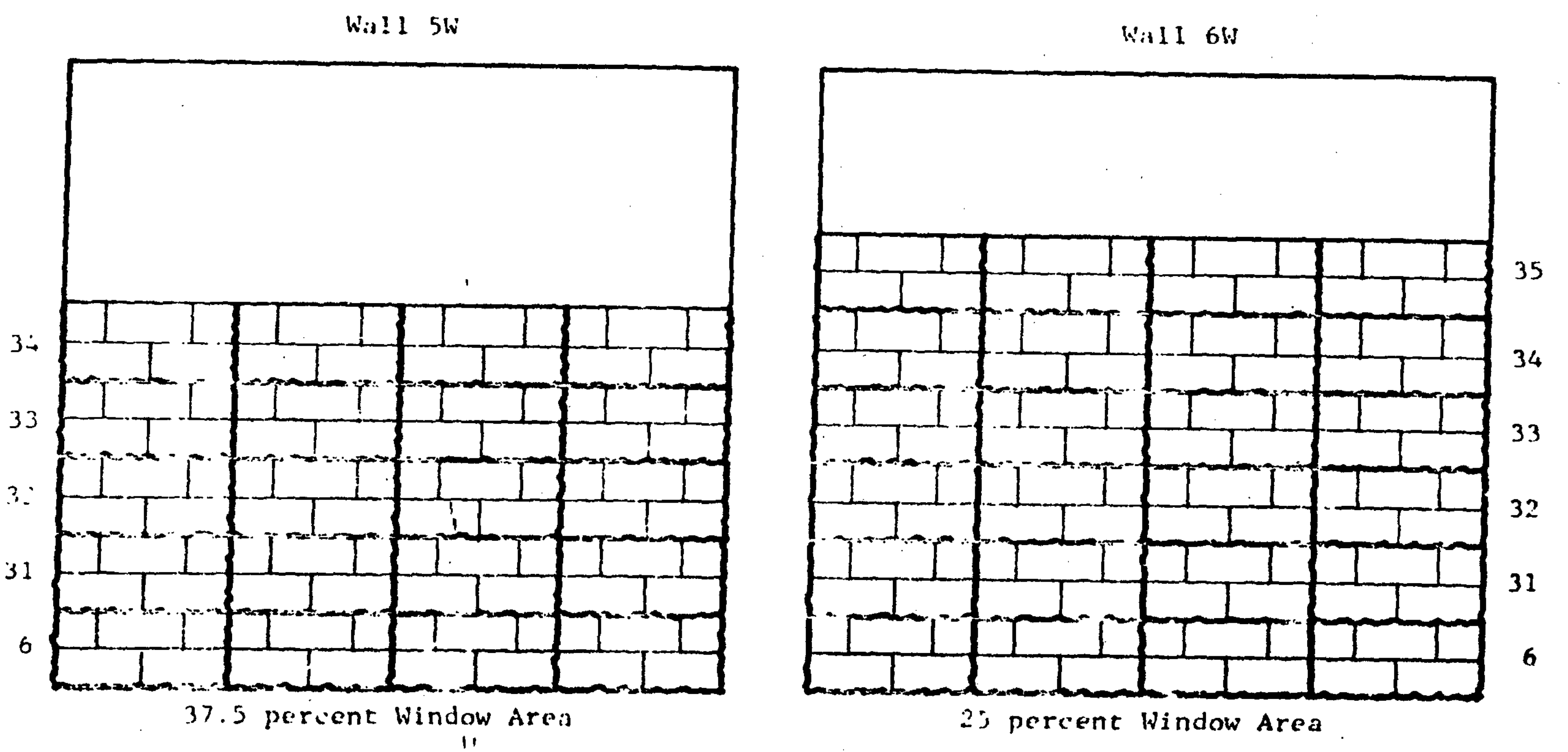


Figure 2.16 Assumed Crack Patterns for Wall Breakup (Walls 5W and 6W)

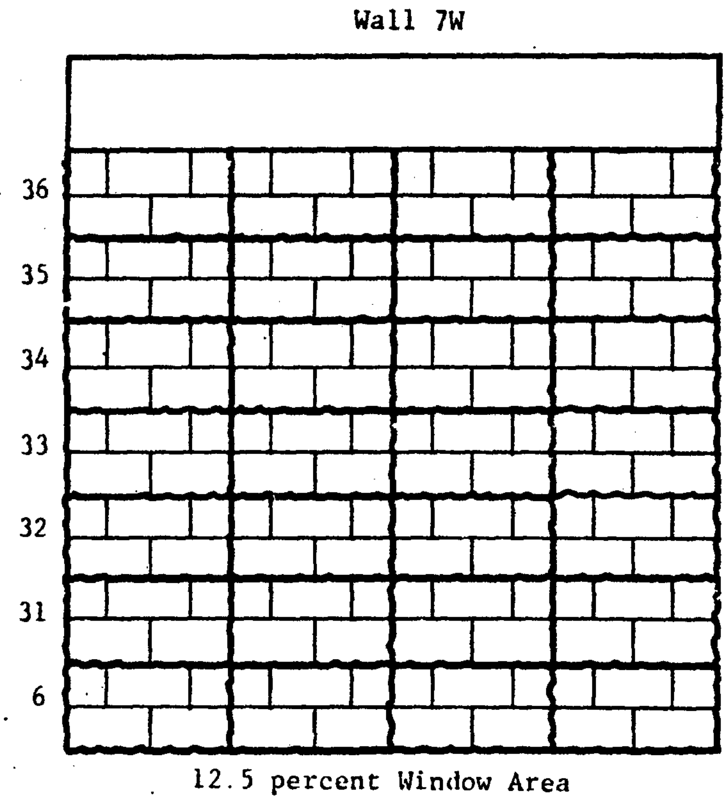


Figure 2.17 Assumed Crack Pattern for Wall Breakup (Wall 7W)

The use of regular (rectangular) debris pieces instead of irregular ones ordinarily seen when walls fail, is another approximation. It is made necessary by the two-dimensional debris transport analysis (Chapter 3, Ref. 2.1) used in this study.

For this set of walls a delay time (time to separation) of 100 msec was assumed at 2 psi free field overpressure. This was allowed to decrease linearly such that at 20 psi the delay time was 55 msec. It was also assumed that 0.8 sec after separation the plane area occupied by the wall is clear. For each of the 12 buildings three separate initial body positions are considered for building occupants. These are

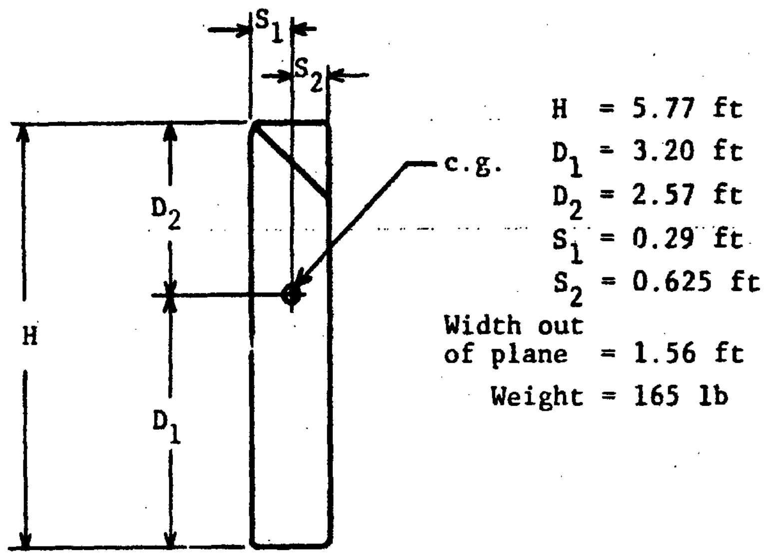
- Standing
- Prone, perpendicular to the windward wall
- Prone, parallel to the windward wall

These body positions are illustrated in Figure 2.18. This figure also illustrates the manner in which individuals are simulated in the analysis process. With these arrangements of individuals, each floor of a given building holds 100 standing individuals, 64 prone-perpendicular individuals and 50 prone-parallel individuals. With 12 buildings, four story heights and three initial body positions, 144 sets of results (curves), relating survivability to free field overpressures are possible. Thirty-six sets of such curves (first story) are given in Figures 2.19 through 2.54. In these curves, survival percentage is related to three categories of impact, i.e., debris, floor and ground plane impact. Total survival percentage, combining the three impact categories is also included.

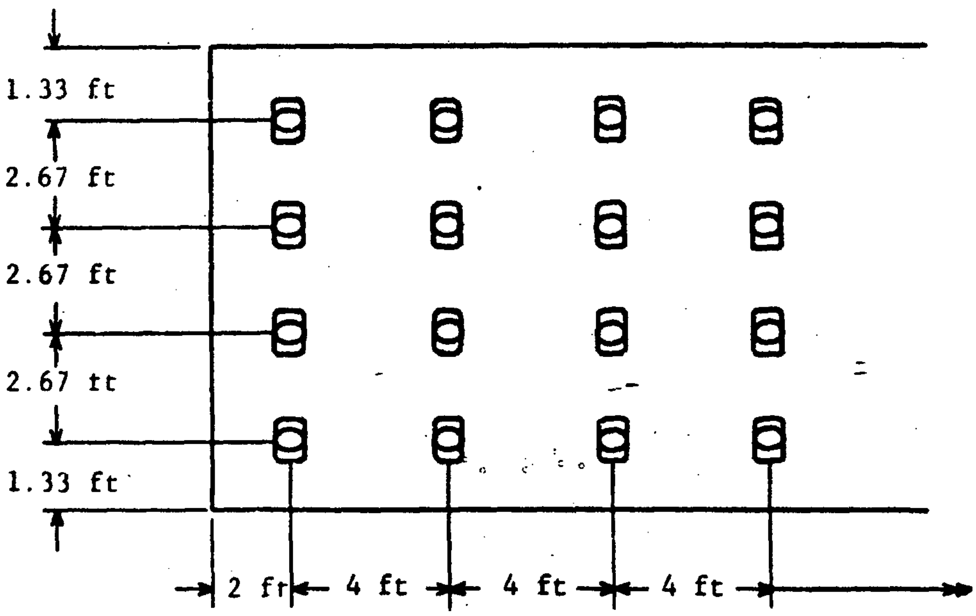
In examining these figures it will be noted that survival percentage is not necessarily a decreasing function of overpressure as far as the individual impact categories are concerned. For total survivors it is a decreasing function except for minor fluctuations as shown in Figure 2.20. Reasons for this are discussed next.

Referring to Figure 2.19 it will be noted that debris produces few casualties up to 5 psi, significant percent casualties between 5 and 10 psi and moderate thereafter. The floor impact curve follows a similar pattern. Debris casualties are produced by debris impacting people who at the same time may be subject to blast winds. In the range of 5 to 10 psi the dynamic pressures are such that simulated people rotate and impact the floor and are in turn impacted by debris thus resulting in more debris casualties. At higher overpressures floor impact is less significant since most people are simply swept out resulting in less interaction with debris.

The total survivors curve is a function of the other three curves and for the most part decreases with increasing overpressure. Variations such as those in Figure 2.20 are due in part to the assumptions inherent in the people simulation model used, casualtv criteria and numerical roundoff.

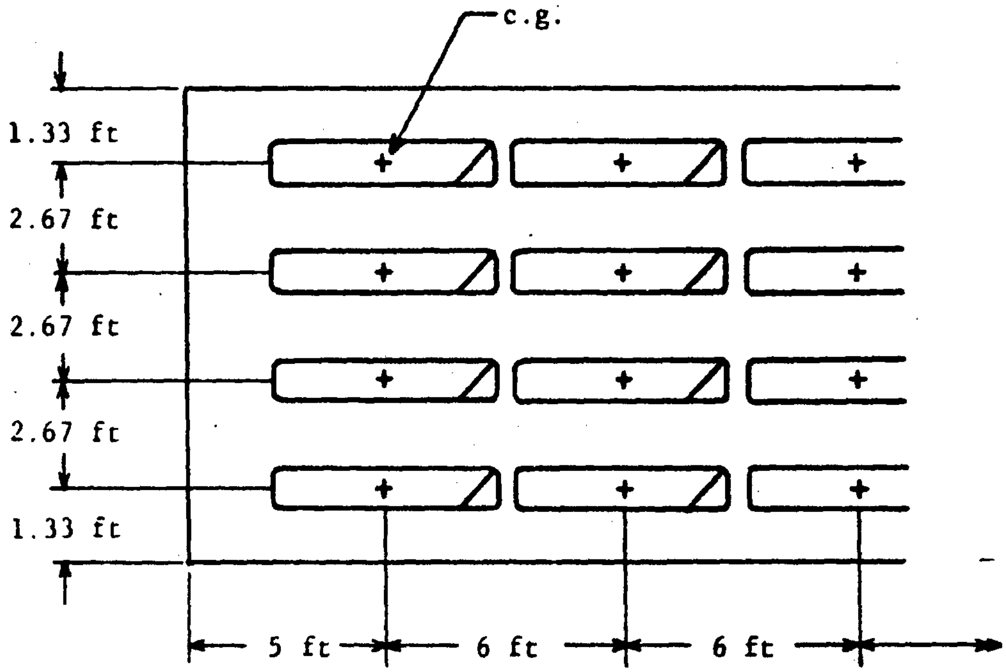


a. Individual Person Simulation Model

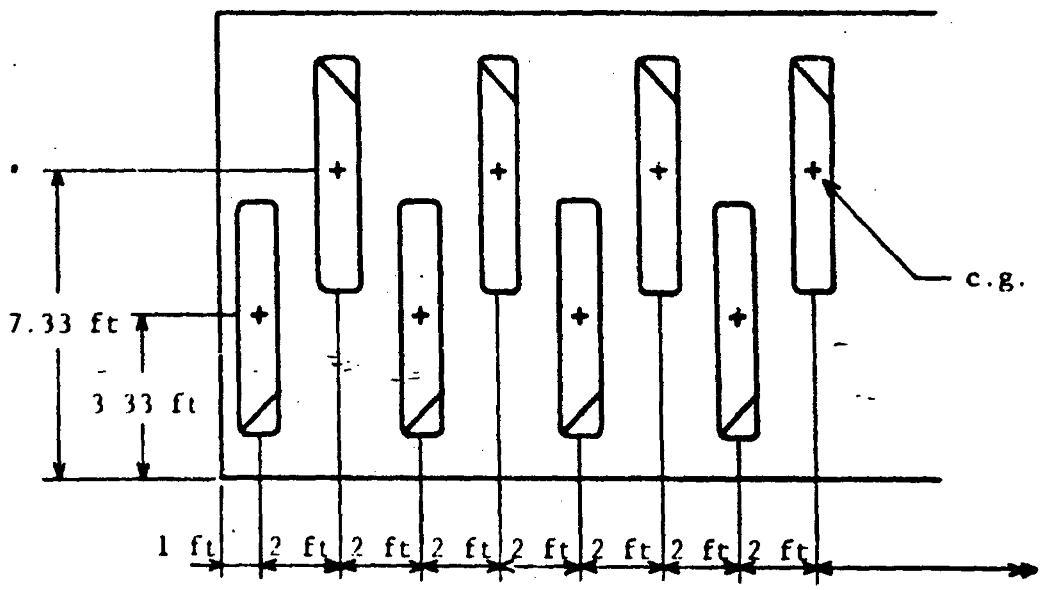


b. Arrangement for Initially Standing People

Figure 2.18 People Simulation Model and People Distributions

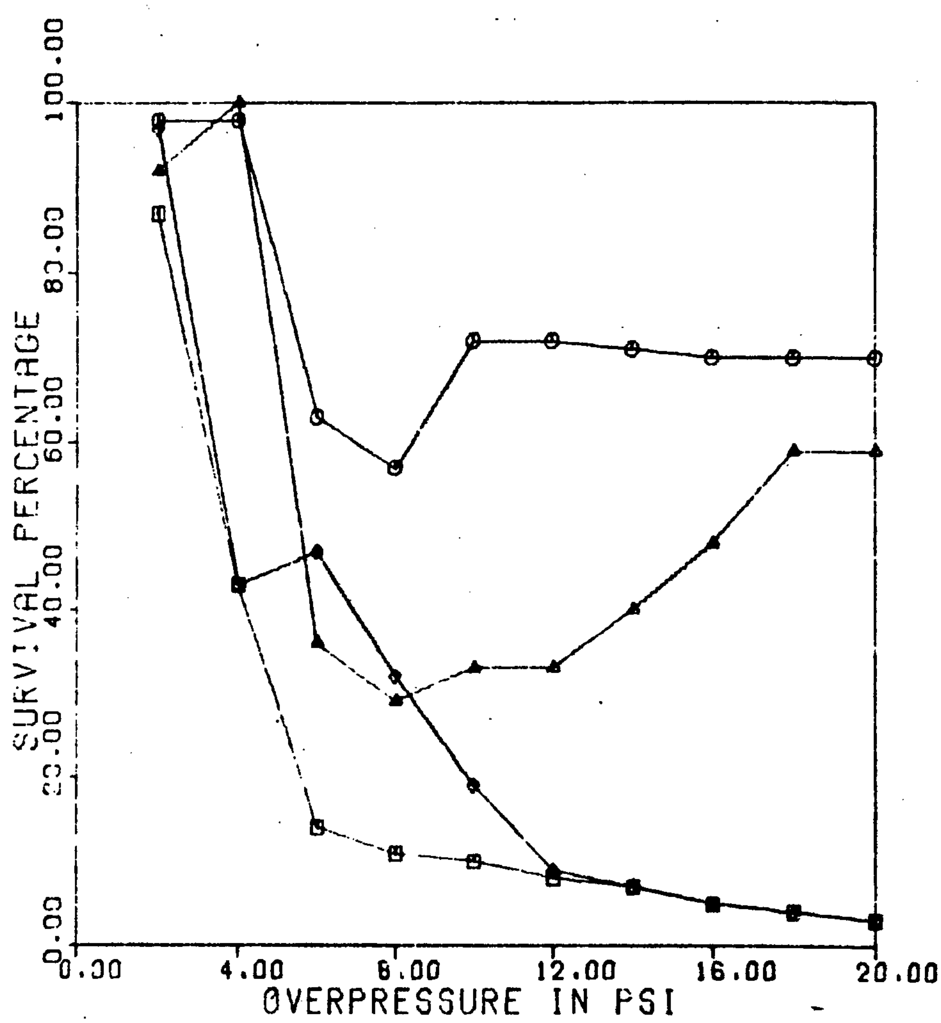


c. Arrangement for People Initially Prone, Perpendicular to the Windward Wall



d. Arrangement for People Initially Prone, Parallel to the Windward Wall

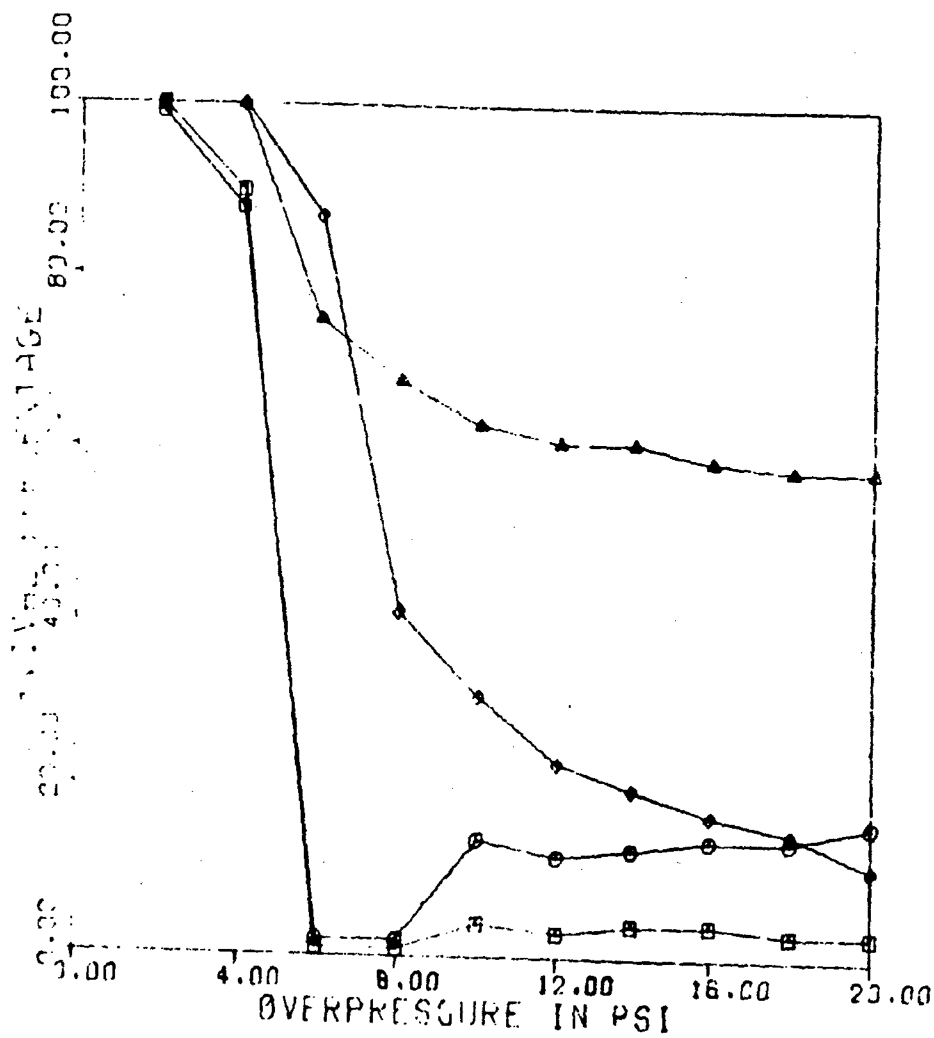
Figure 2.18 (Concl)



□ – Total Survivors
⊖ – Debris Impact Survivors
△ – Floor Impact Survivors
◇ – Ground Plane Impact Survivors

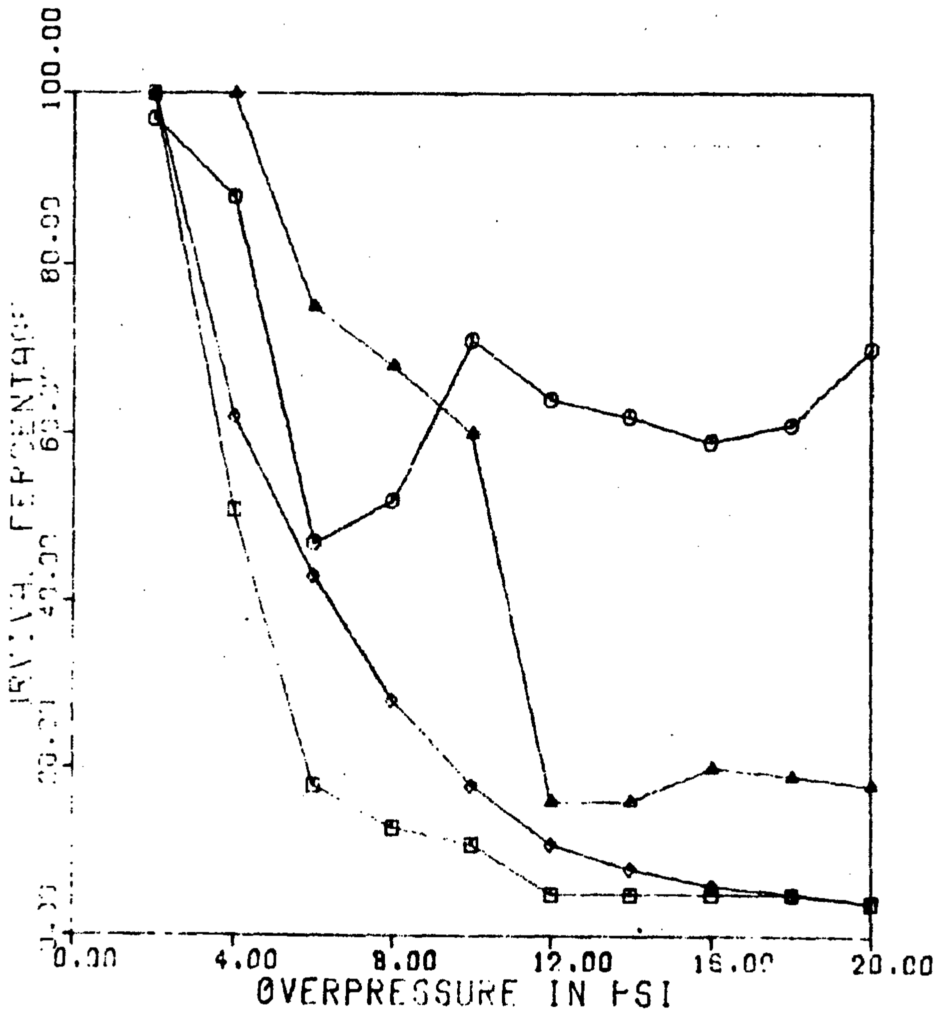
Figure 2.19 Impact Survivors Estimate (Wall 1c, People Initially Standing)

TABLES



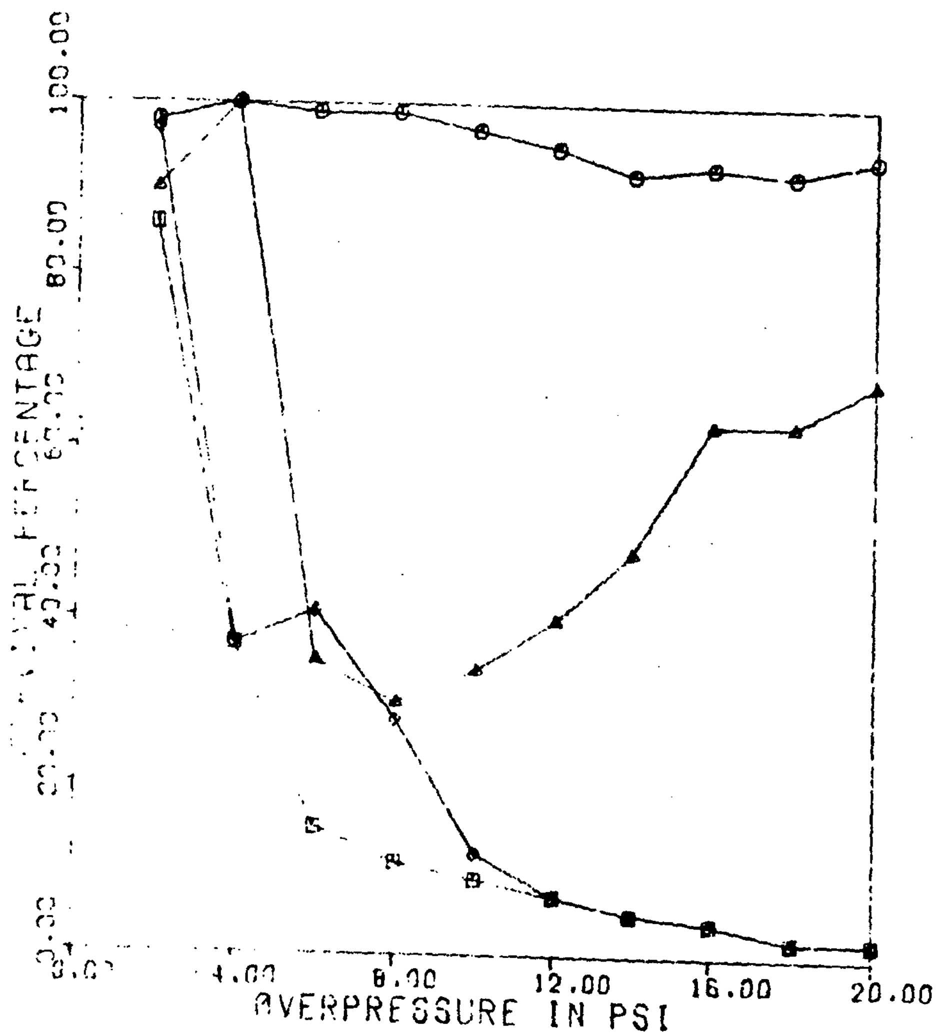
Total Survivors
Debris Impact Survivors
Floor Impact Survivors
Ground Plane Impact Survivors

Figure 2.20 Impact Survivors Estimate (Wall 1C, People Initially Prone, Perpendicular to Windward Wall)



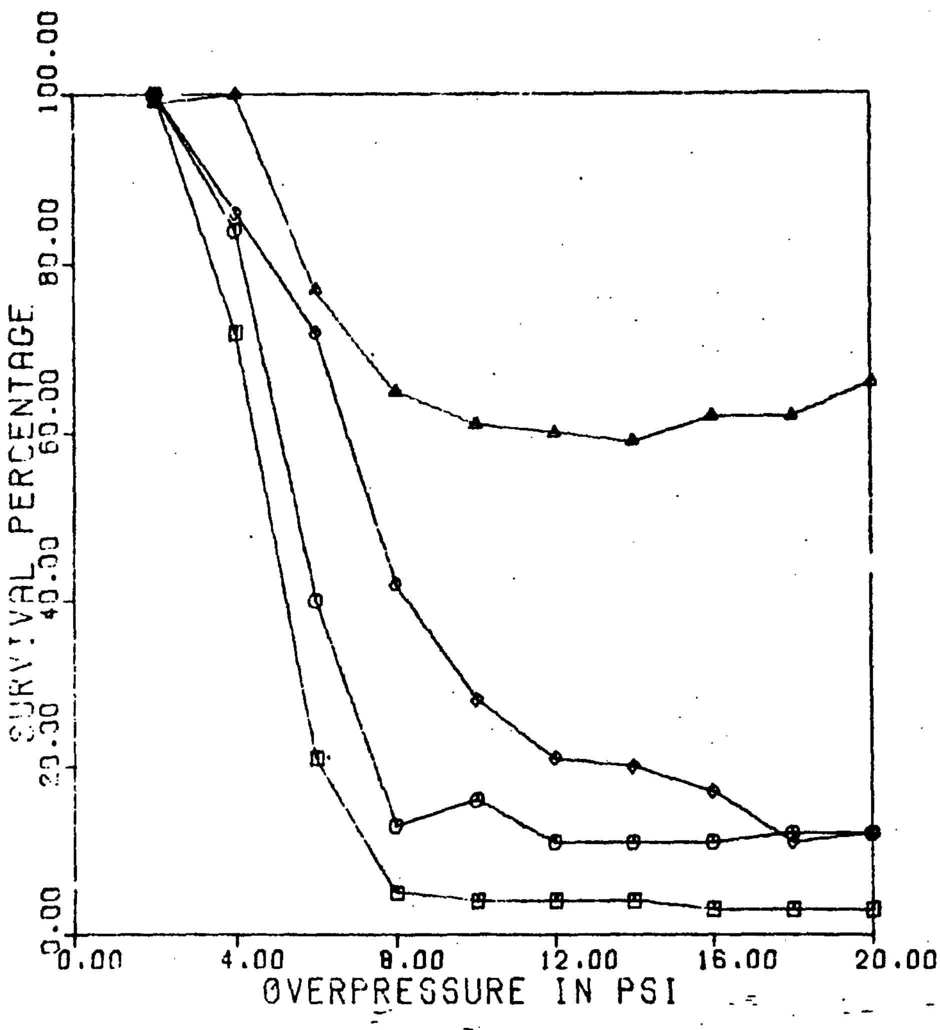
T – Total Survivors
D – Debris Impact Survivors
A – Floor Impact Survivors
G – Ground Plane Impact Survivors

Figure 2.21 Impact Survivors Estimate (Wall 1C, People Initially Prone, Parallel to Windward Wall)



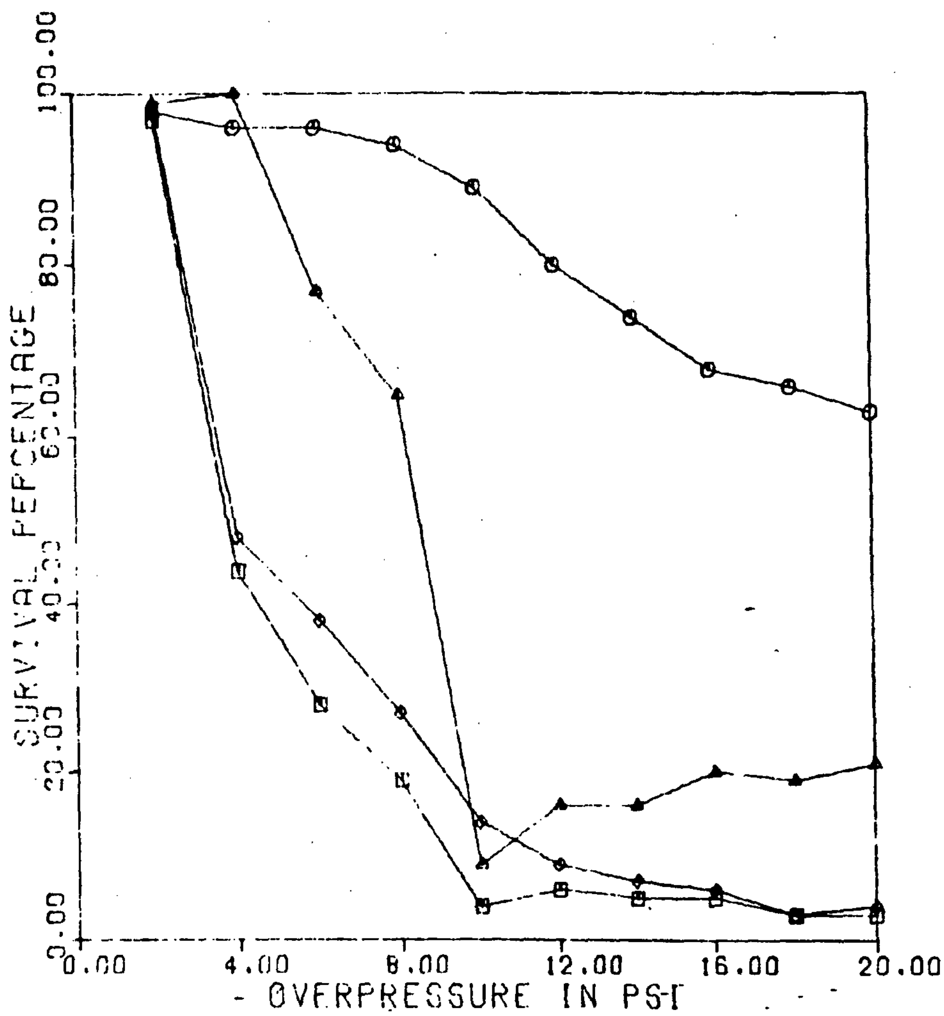
Total Survivors
Debris Impact Survivors
Floor Impact Survivors
Ground Plane Impact Survivors

Figure 2 22 Impact Survivors Estimate
(Wall 2C, People Initially Standing)



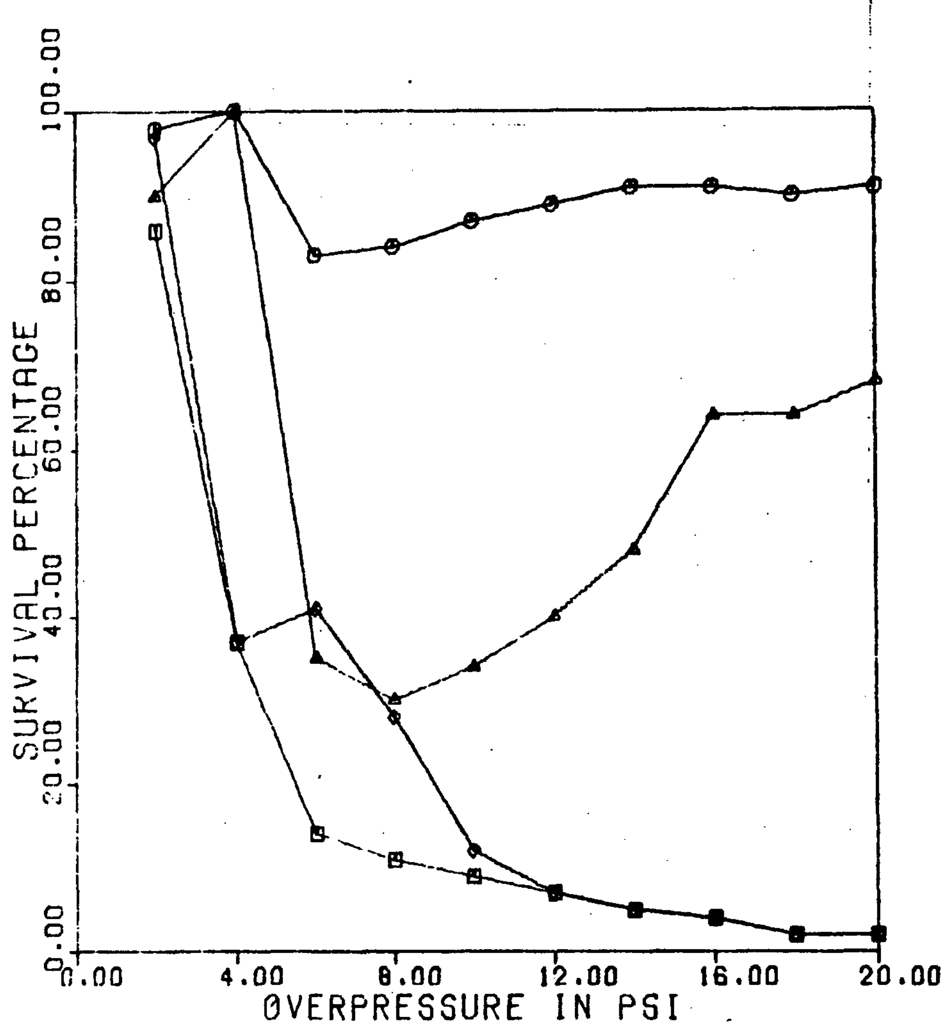
□ – Total Survivors
○ – Debris Impact Survivors
△ – Floor Impact Survivors
◇ – Ground Plane Impact Survivors

Figure 2.23 Impact Survivors Estimate (Wall 2C, People Initially Prone, Perpendicular to the Windward Wall)



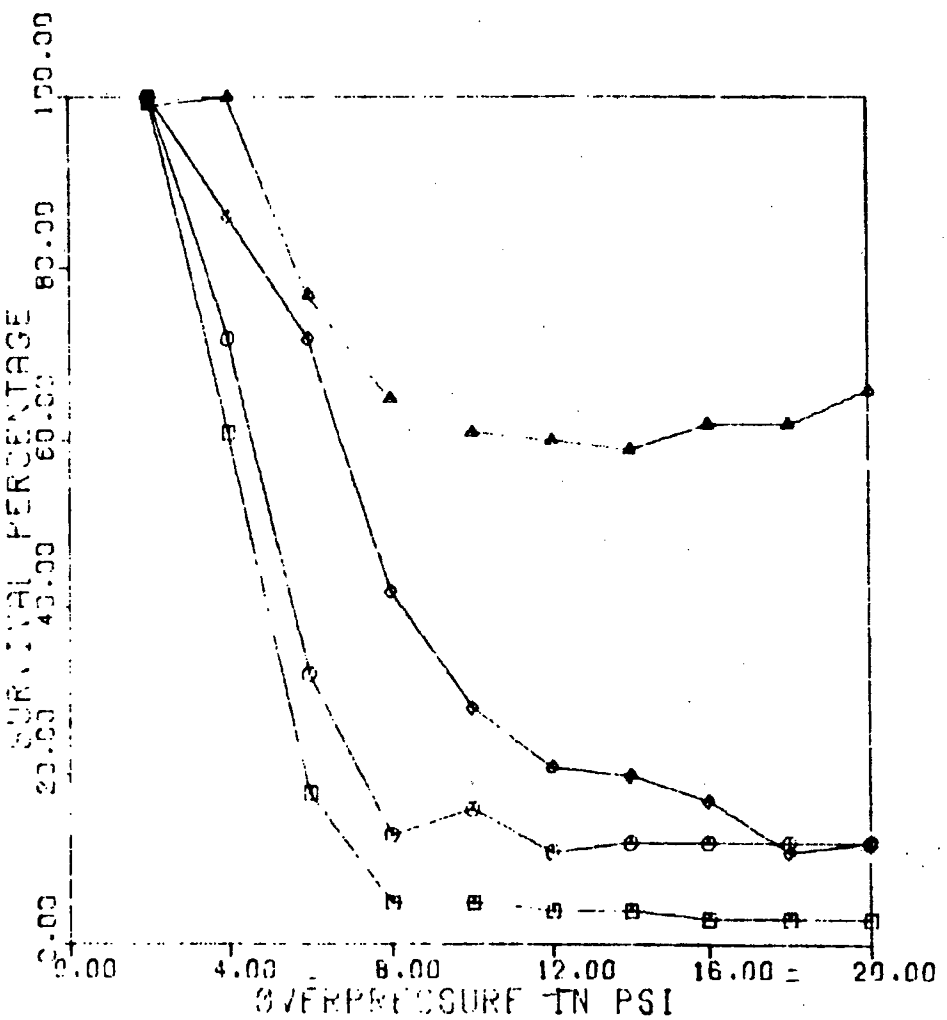
□ - Total Survivors
○ - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.24 Impact Survivors Estimate (Wall 2C, People Initially Prone, Parallel to the Windward Wall)



- Total Survivors
- Debris Impact Survivors
- Floor Impact Survivors
- Ground Plane Impact Survivors

Figure 2.25 Impact Survivors Estimate (Wall 3C, People Initially Standing)



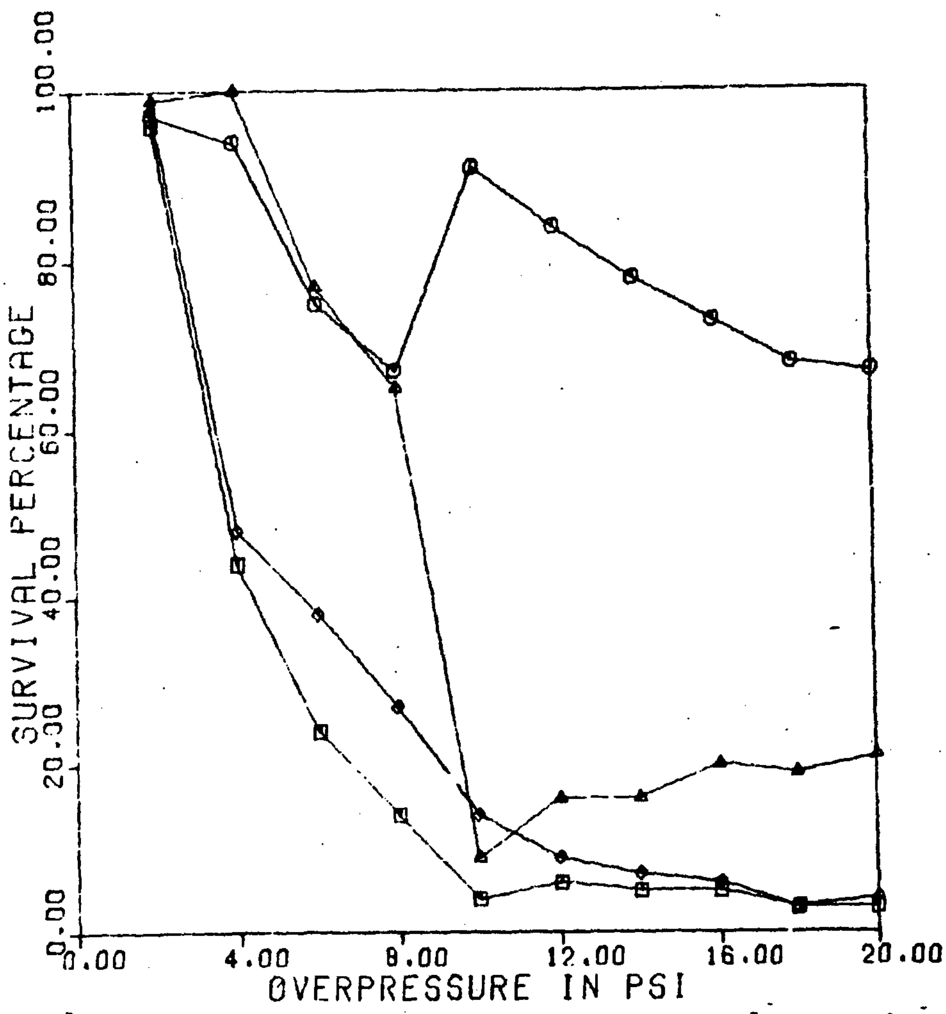
[T] - Total Survivors

[1] - Debris Impact Survivors

A - Floor Impact Survivors

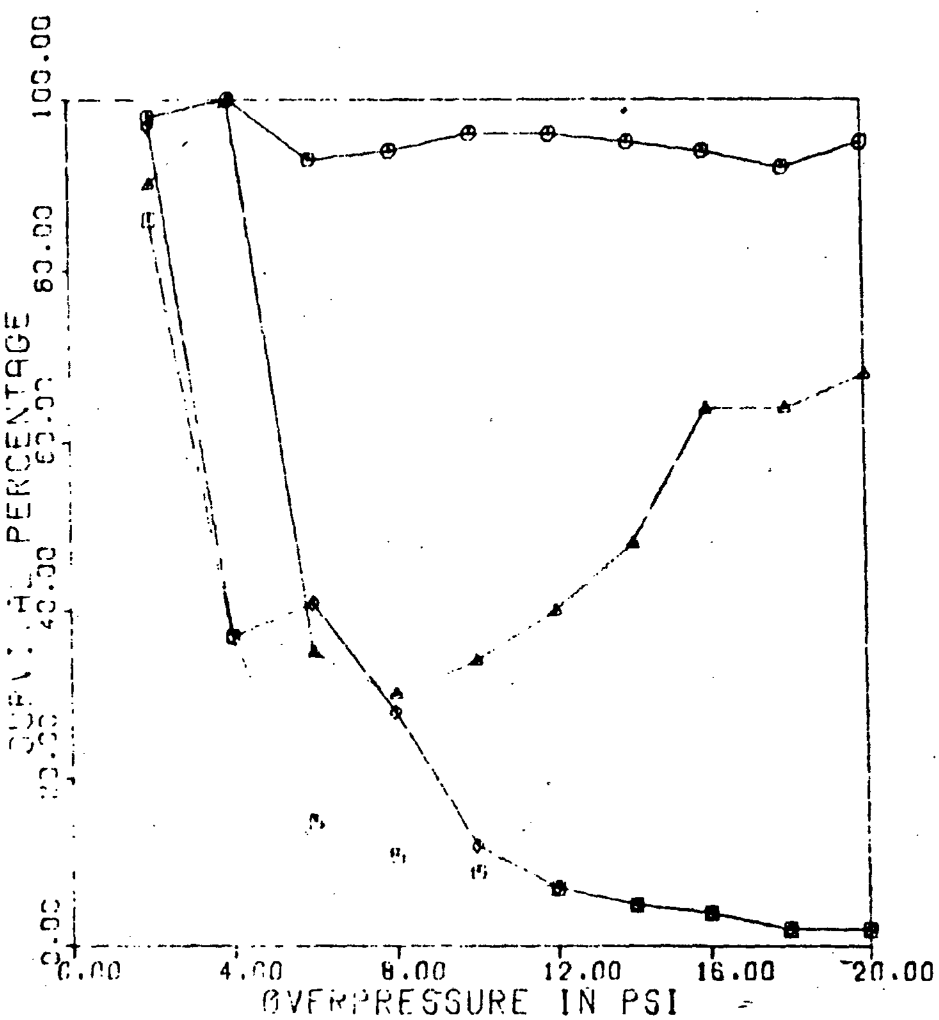
+ Ground Plane Impact Survivors

Figure 2.26 Impact Survivors Estimate (Wall 3C, People Initially Prone, Perpendicular to the Windward Wall)



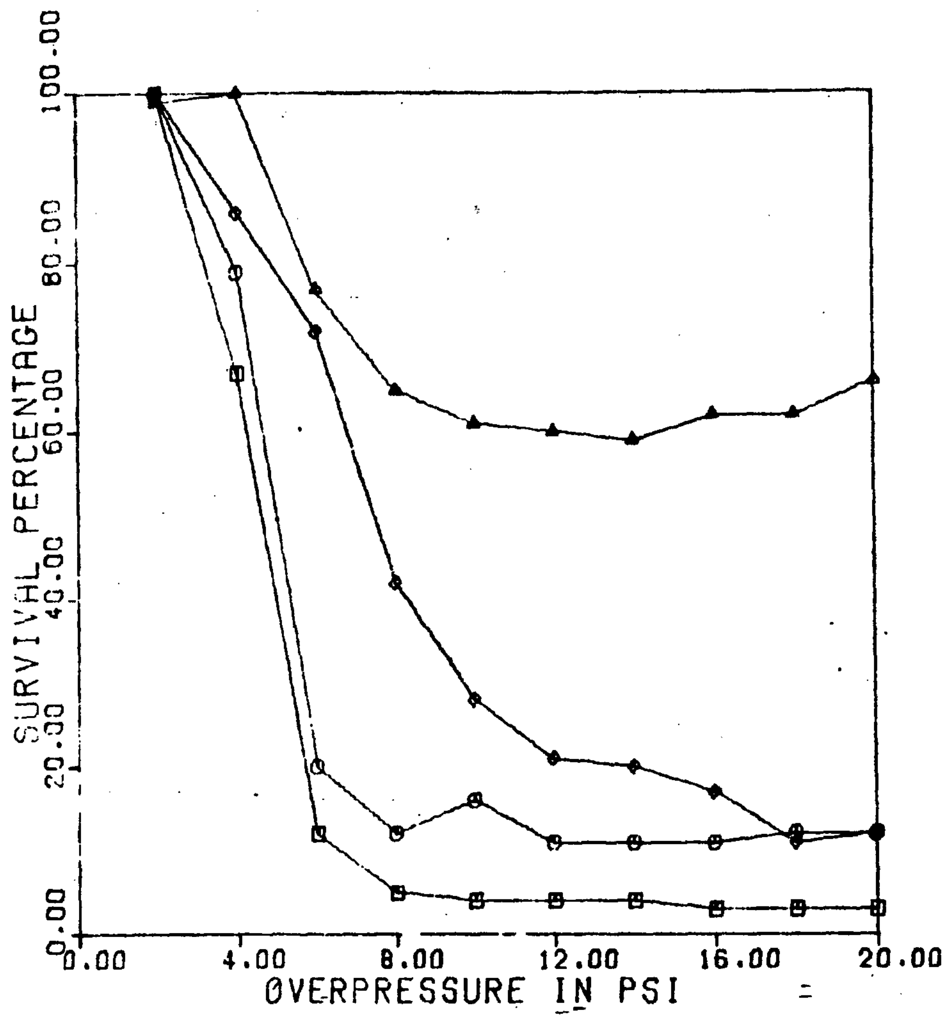
□ - Total Survivors
○ - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.27 Impact Survivors Estimate (Wall 3C, People Initially Prone, Parallel to the Windward Wall)



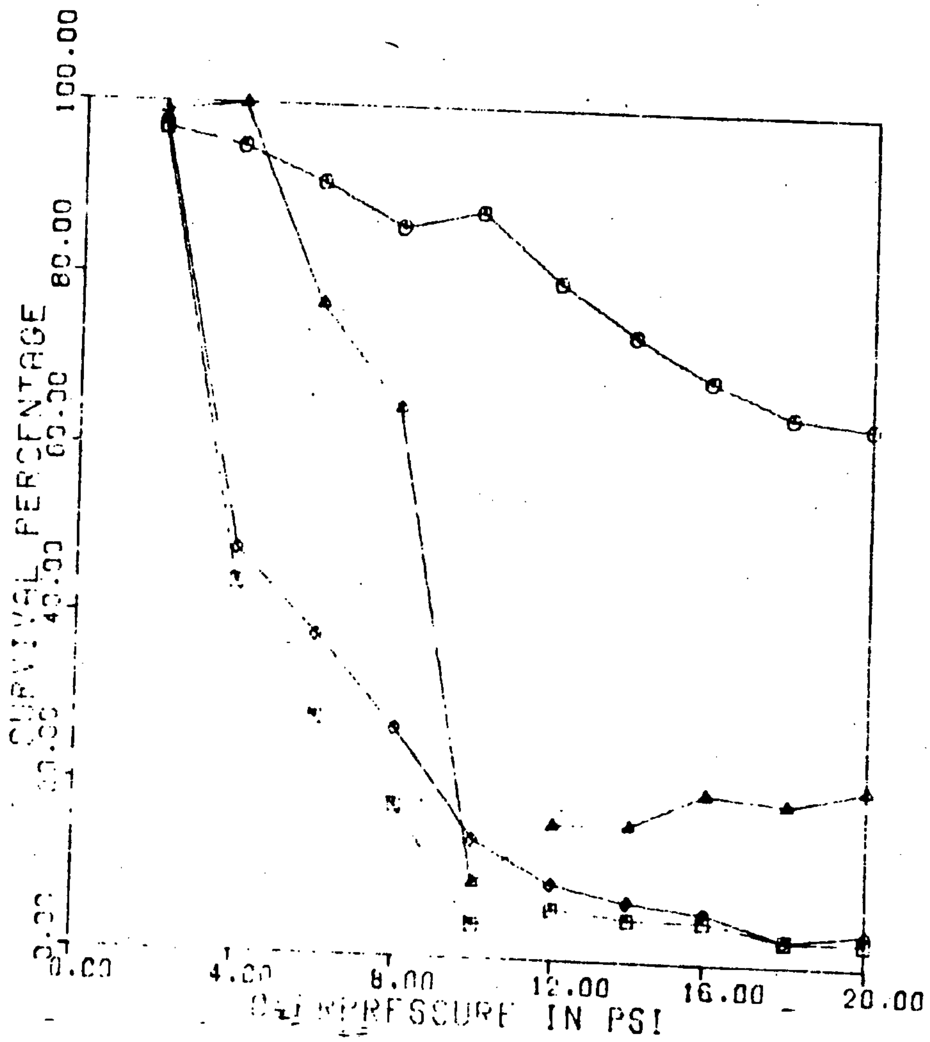
[] - Total Survivors
() - Debris Impact Survivors
△ Floor Impact Survivors
↑ - Ground Plane Impact Survivors

Figure 2.28 Impact Survivors Estimate (Wall 4C, People Initially Standing)



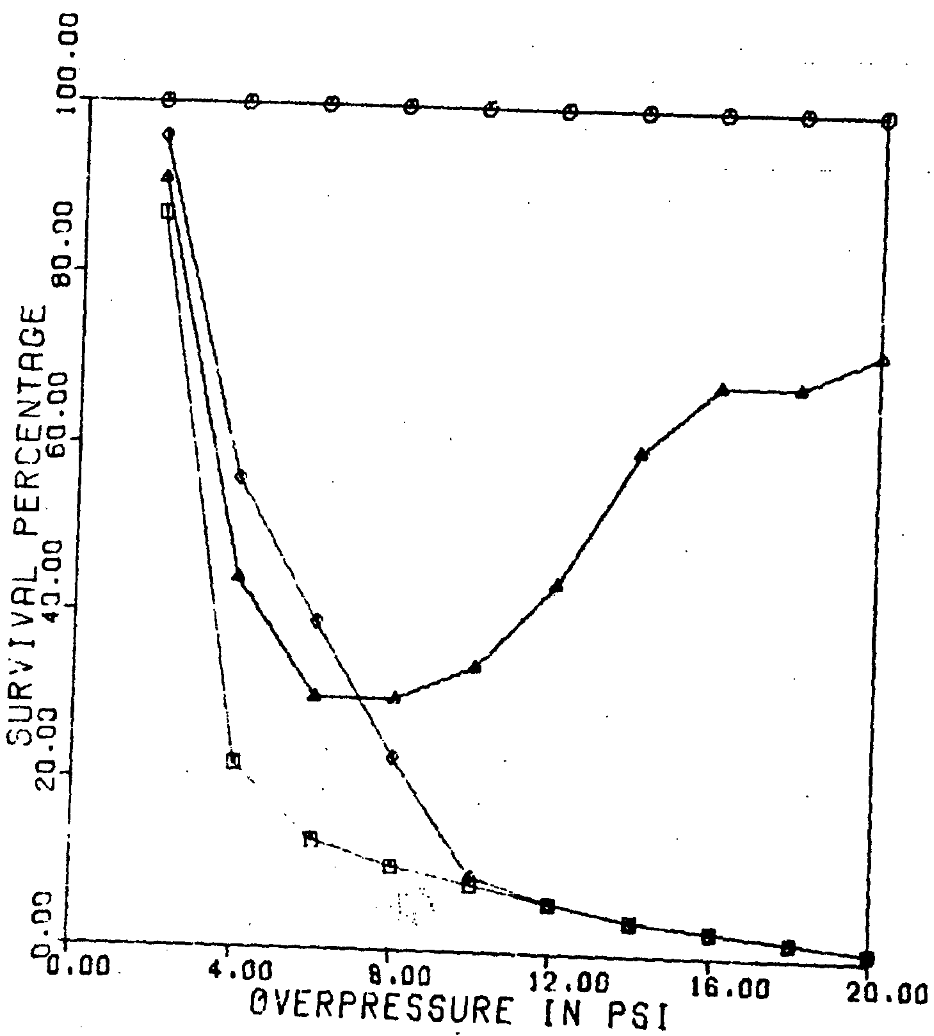
□ - Total Survivors
○ - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.29 Impact Survivors Estimate (Wall 4C, People Initially Prone, Perpendicular to the Windward Wall)



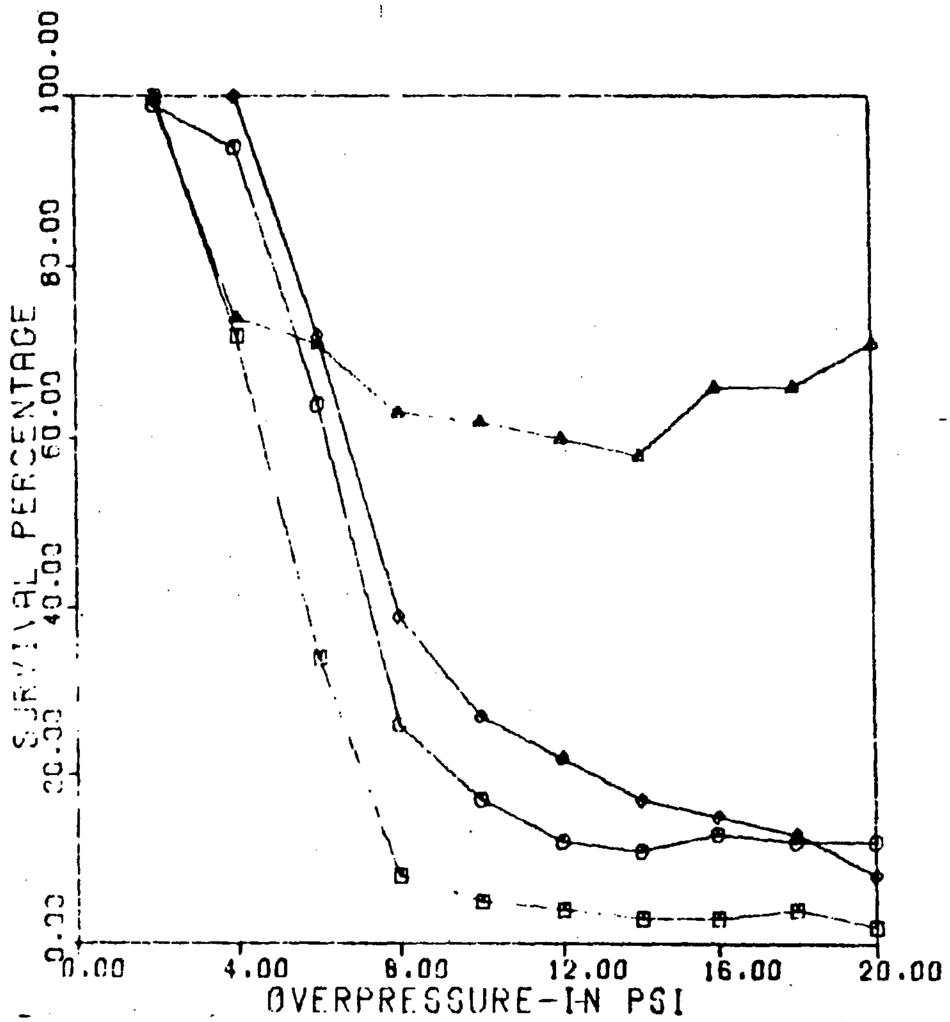
Total Survivors
Debris Impact Survivors
Floor Impact Survivors
Ground Plane Impact Survivors

Figure 2.30 Impact Survivors Estimate (Wall 4C, People Initially Prone, Parallel to the Windward Wall)



□ – Total Survivors
○ – Debris Impact Survivors
△ – Floor Impact Survivors
◇ – Ground Plane Impact Survivors

Figure 2.31 Impact Survivors Estimate (Wall 5C, People Initially Standing)



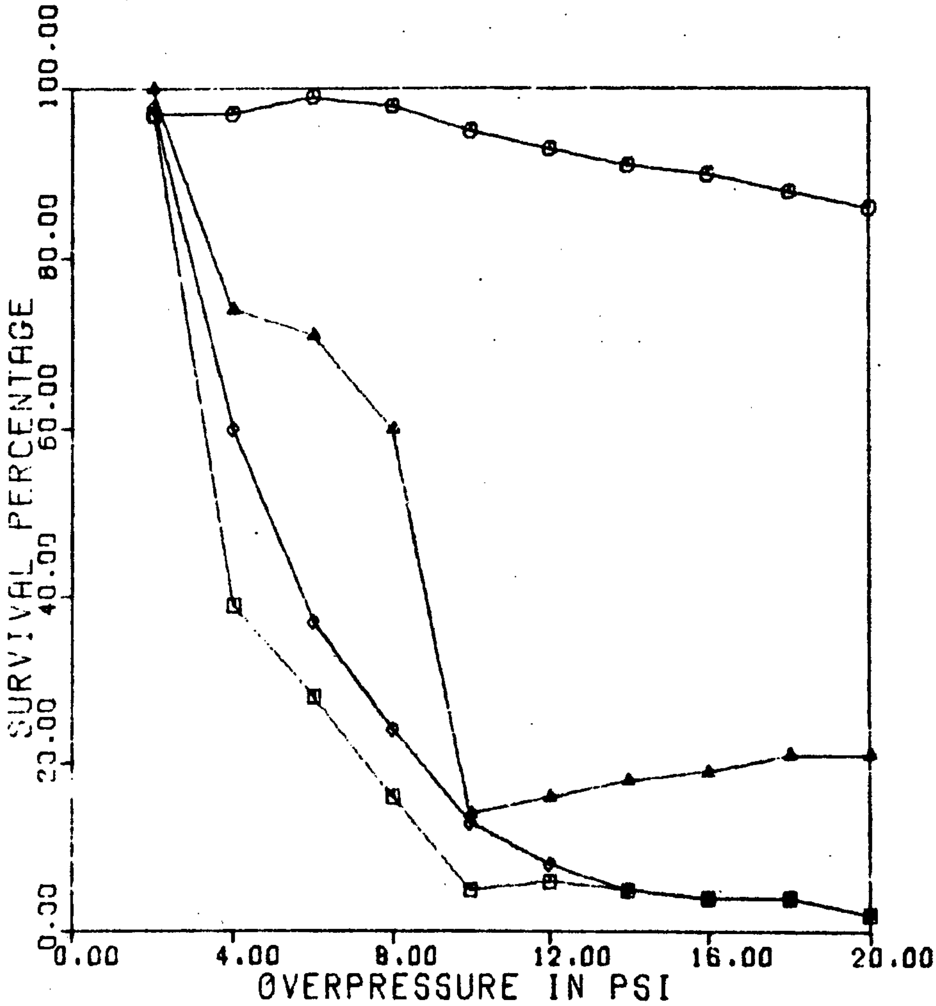
□ - **Total Survivors**

○ - **Debris Impact Survivors**

△ - **Floor Impact Survivors**

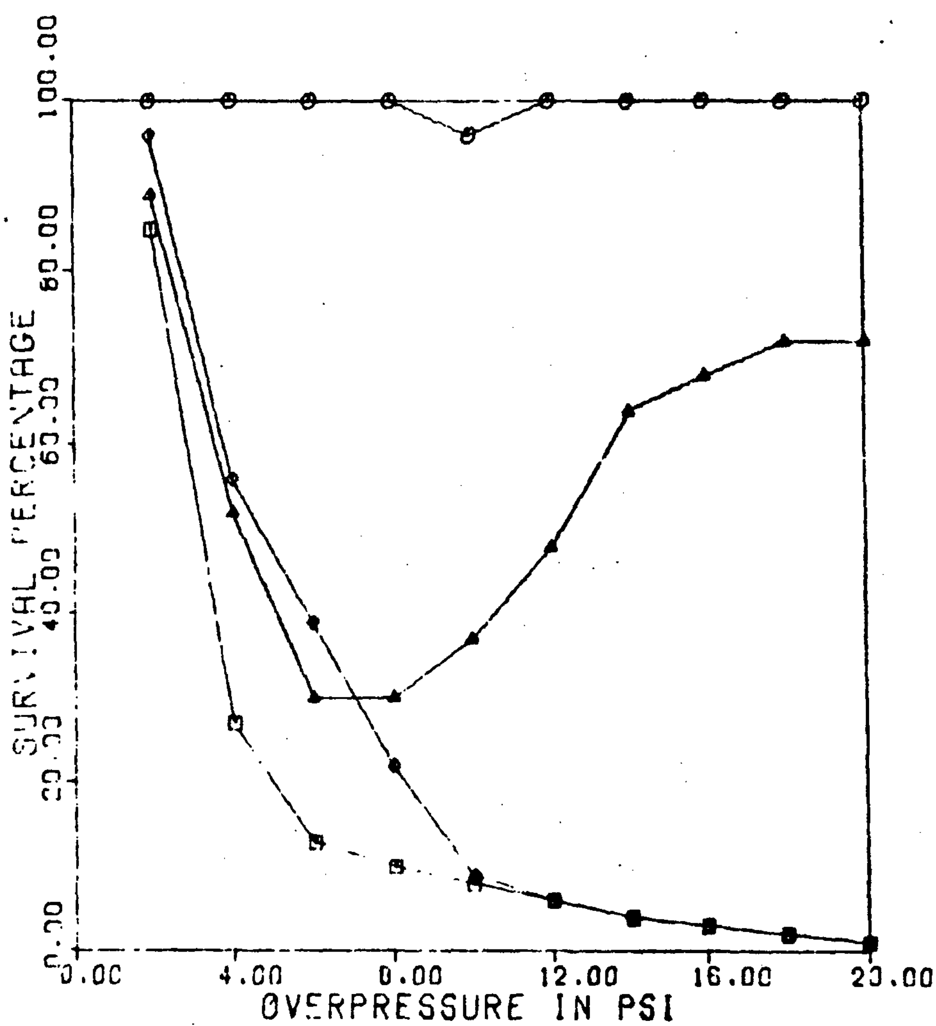
◇ - **Ground Plane Impact Survivors**

Figure 2.32 Impact Survivors Estimate (Wall 5C, People Initially Prone, Perpendicular to the Windward Wall)



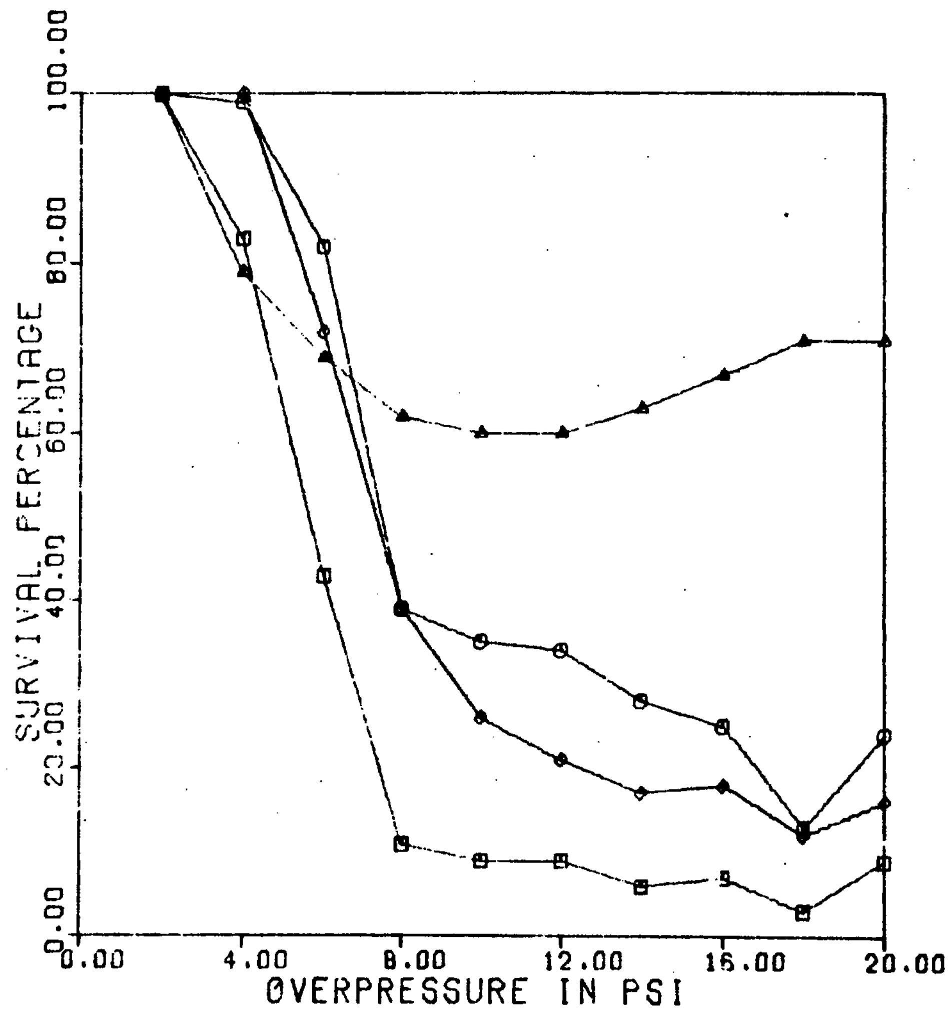
[T] - Total Survivors
(D) - Debris Impact Survivors
△ - ·or Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.33 Impact Survivors Estimate (Wall 5C, People Initially Prone, Parallel to the Windward Wall)



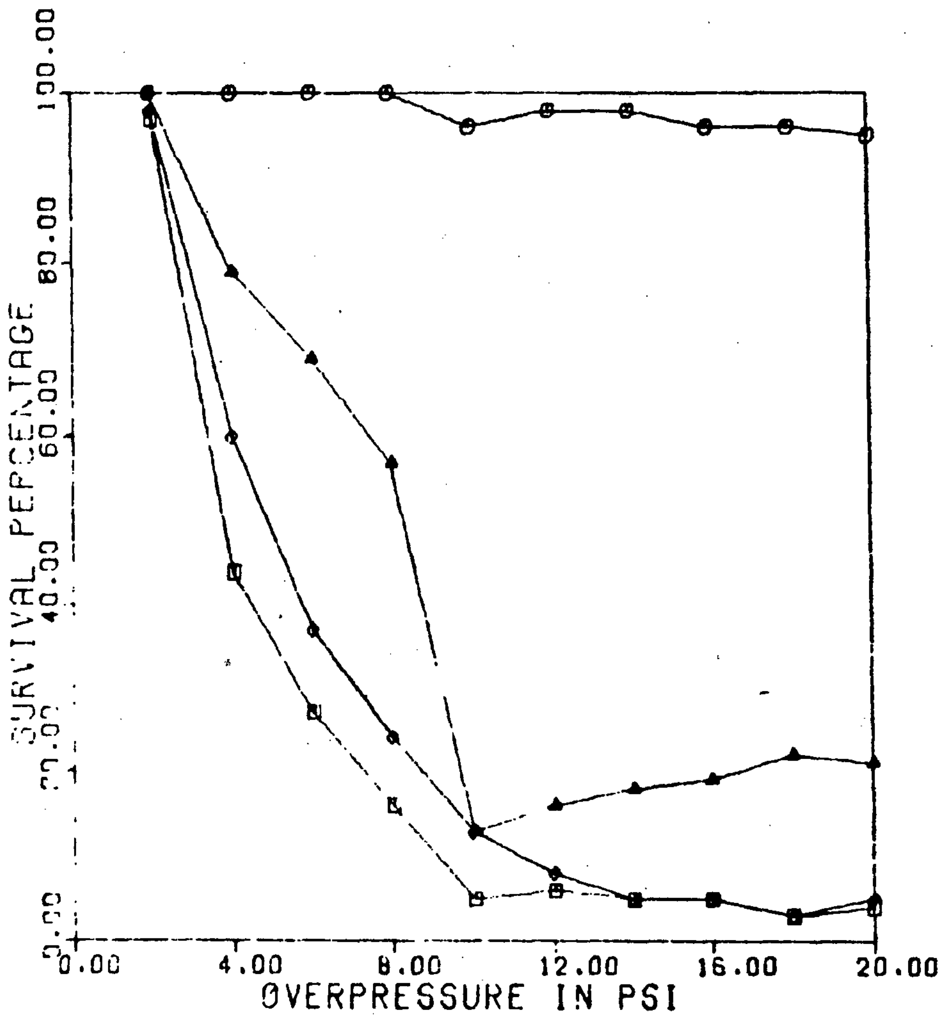
□ - Total Survivors
○ -- Debris Impact Survivors
△ · Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.34 Impact Survivors Estimate (Wall 1W, People Initially Standing)



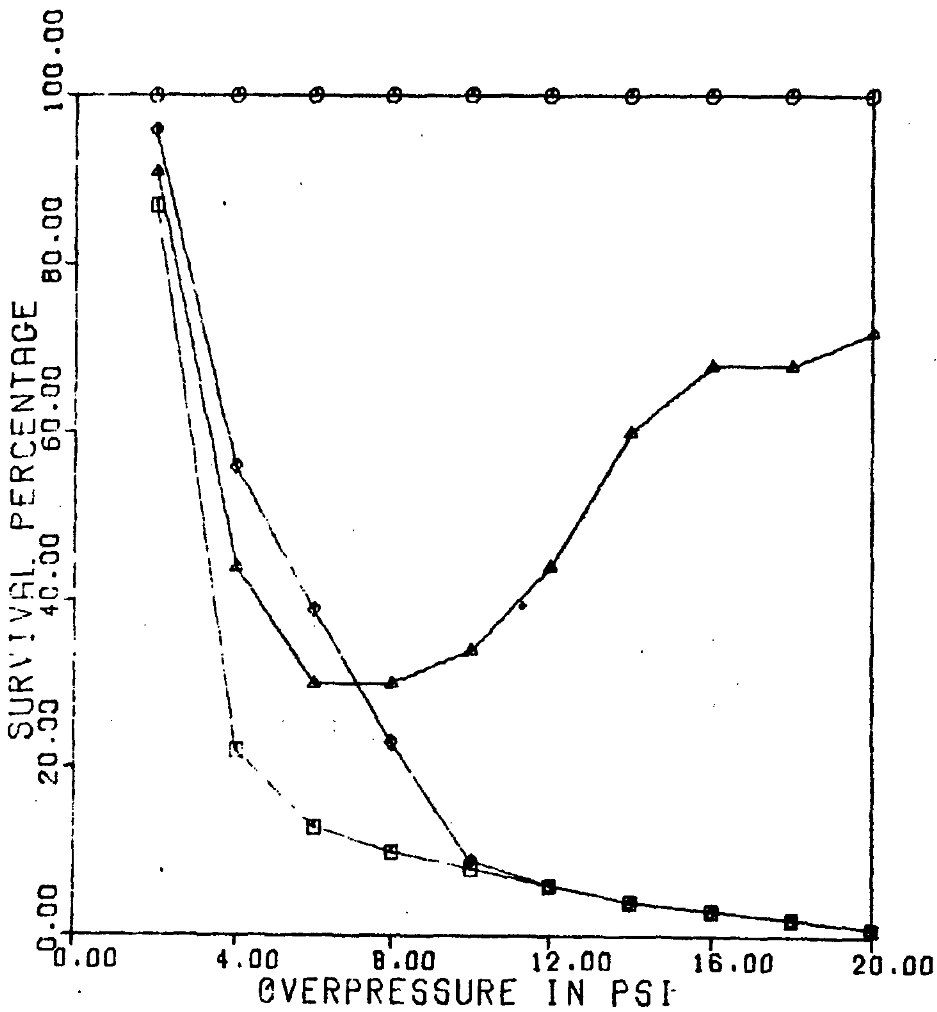
□ -- Total Survivors
○ -- Debris Impact Survivors
△ -- Floor Impact Survivors
◇ -- Ground Plane Impact Survivors

Figure 2.35 Impact Survivors Estimate (Wall 1W, People Initially Prone, Perpendicular to the Windward Wall)



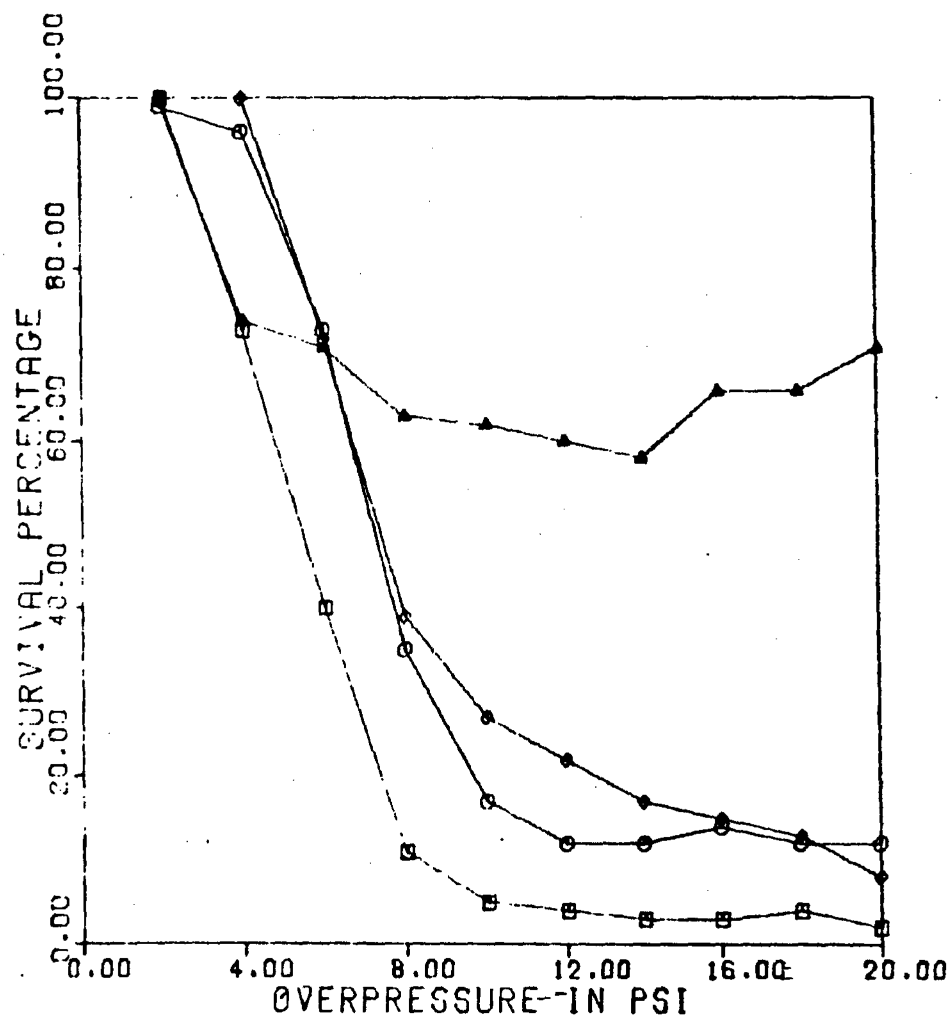
□ - Total Survivors
○ - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.36 Impact Survivors Estimate (Wall 1W, People Initially Prone, Parallel to the Windward Wall)



□ – Total Survivors
⊖ – Debris Impact Survivors
△ – Floor Impact Survivors
◇ – Ground Plane Impact Survivors

Figure 2.37 Impact Survivors Estimate (Wall 2W, People Initially Standing)



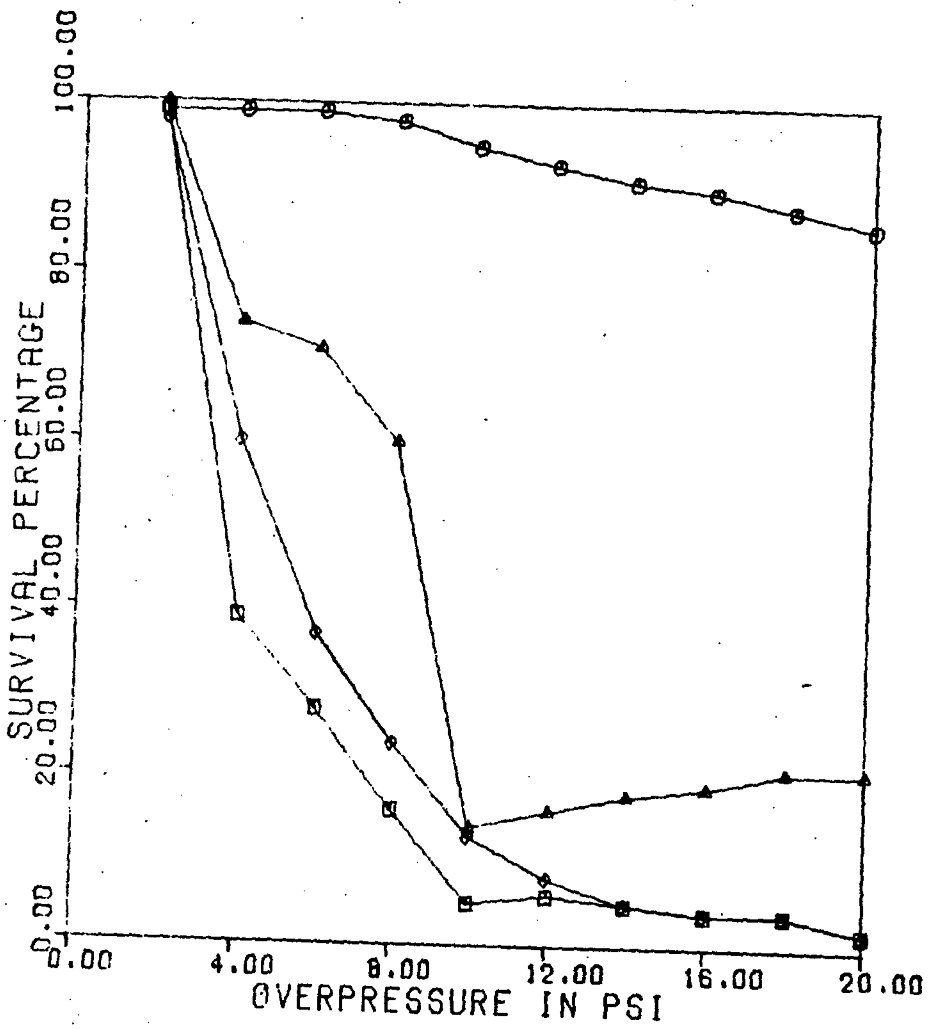
T -- Total Survivors

O - Debris Impact Survivors

Δ - Floor Impact Survivors

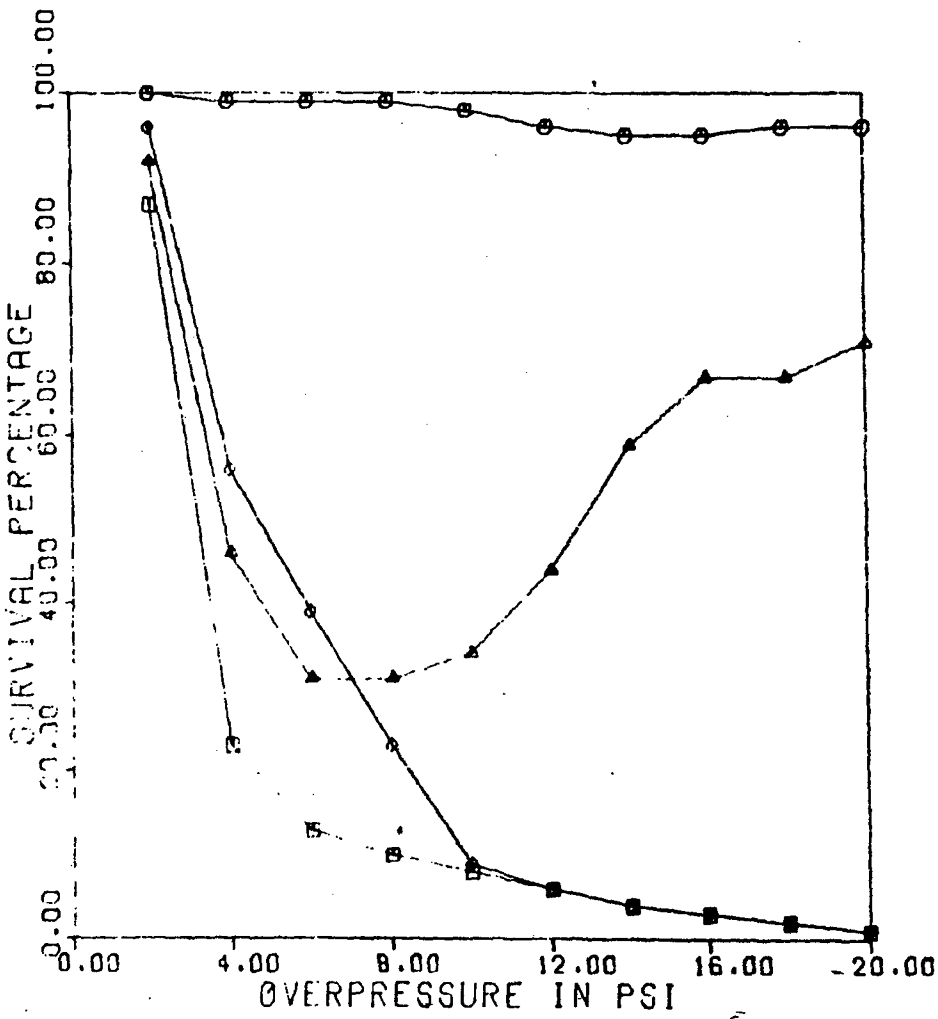
◇ - Ground Plane Impact Survivors

Figure 2.38 Impact Survivors Estimate (Wall 2W, People Initially Prone, Perpendicular to the Windward Wall)



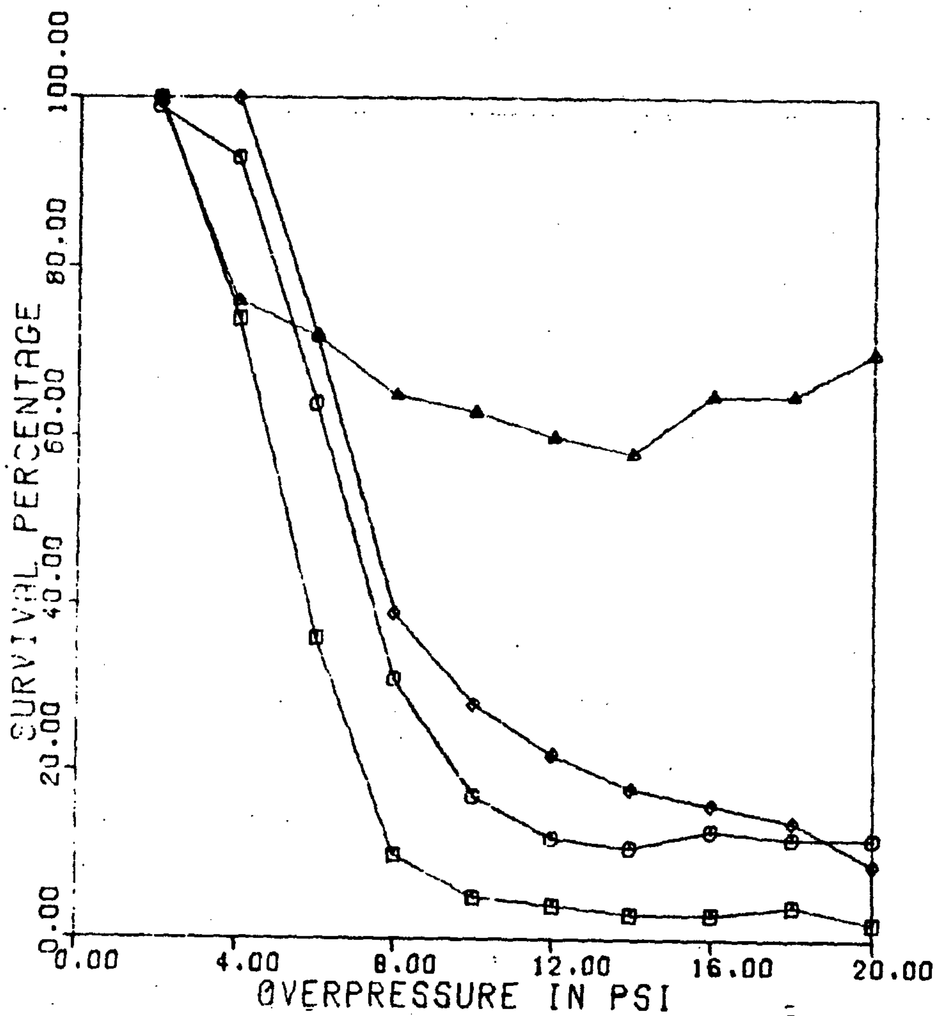
T - Total Survivors
D - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.39 Impact Survivors Estimate (Wall 2W, People Initially Prone, Parallel to the Windward Wall)



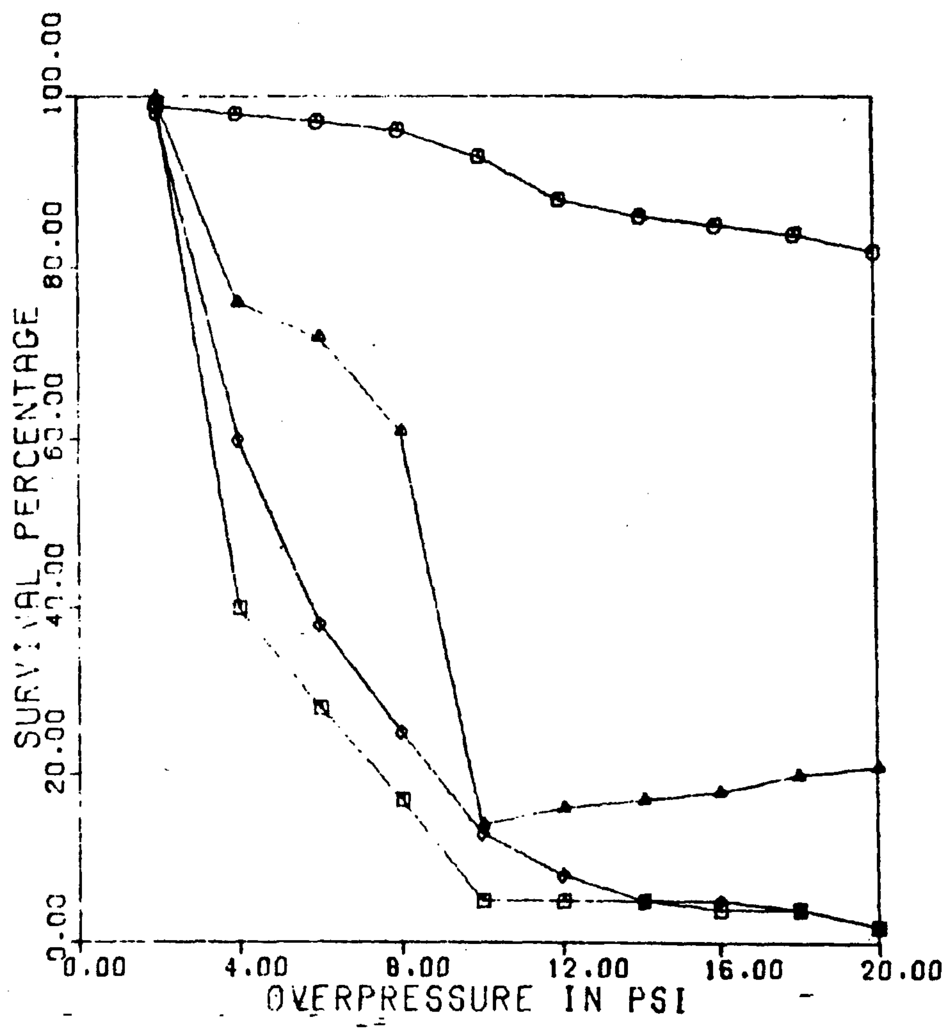
□ - Total Survivors
⊕ - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.40 Impact Survivors Estimate (Wall 3W, People Initially Standing)



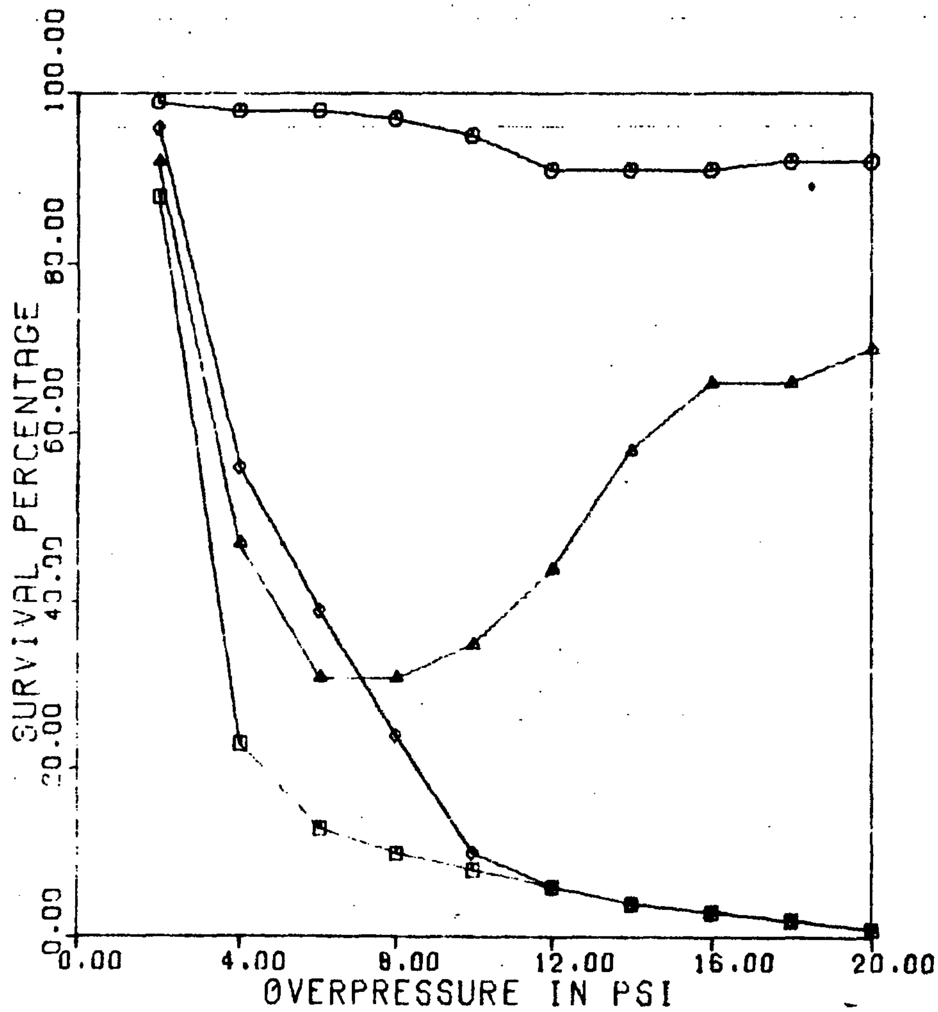
□ – Total Survivors
○ – Debris Impact Survivors
△ – Floor Impact Survivors
◇ – Ground Plane Impact Survivors

Figure 2.41 Impact Survivors Estimate (Wall 3W, People Initially Prone, Perpendicular to the Windward Wall)



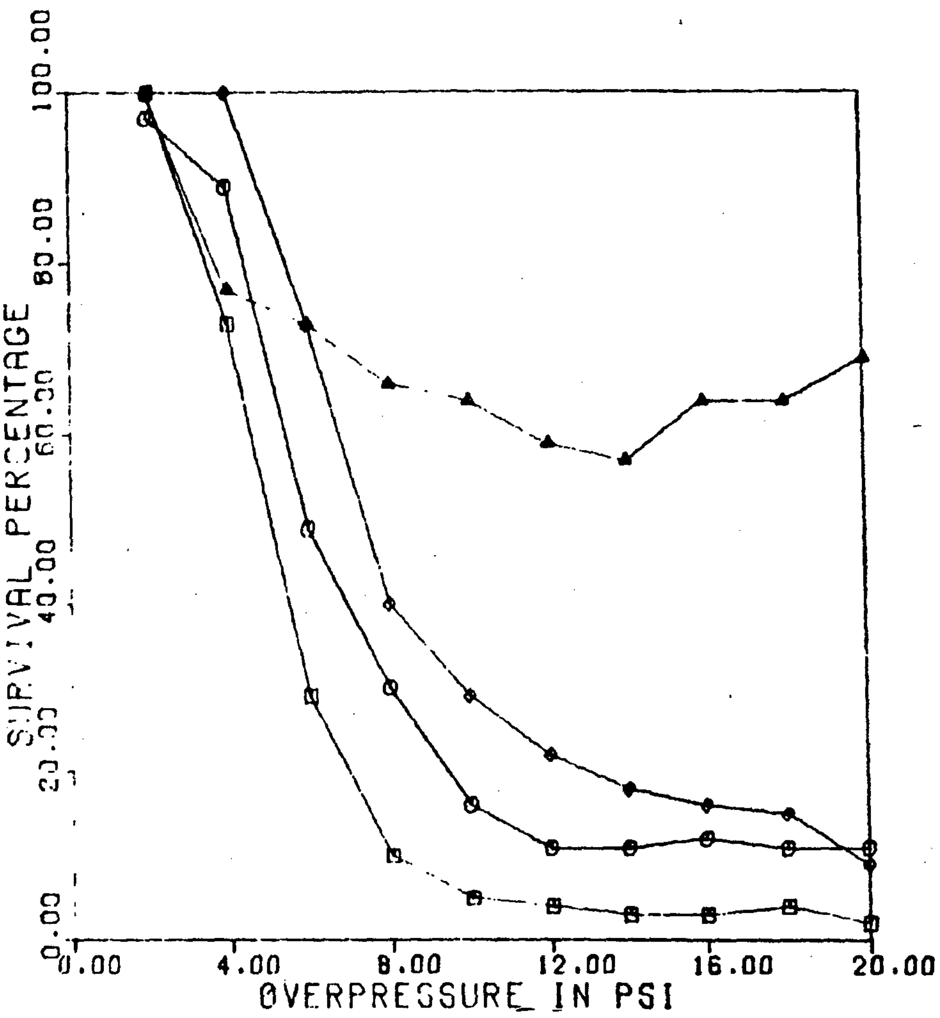
□ - Total Survivors
○ - Debris Impact Survivors
△ - Floor Impact Survivors
◇ - Ground Plane Impact Survivors

Figure 2.42 Impact Survivors Estimate (Wall 3W, People Initially Prone, Parallel to the Windward Wall)



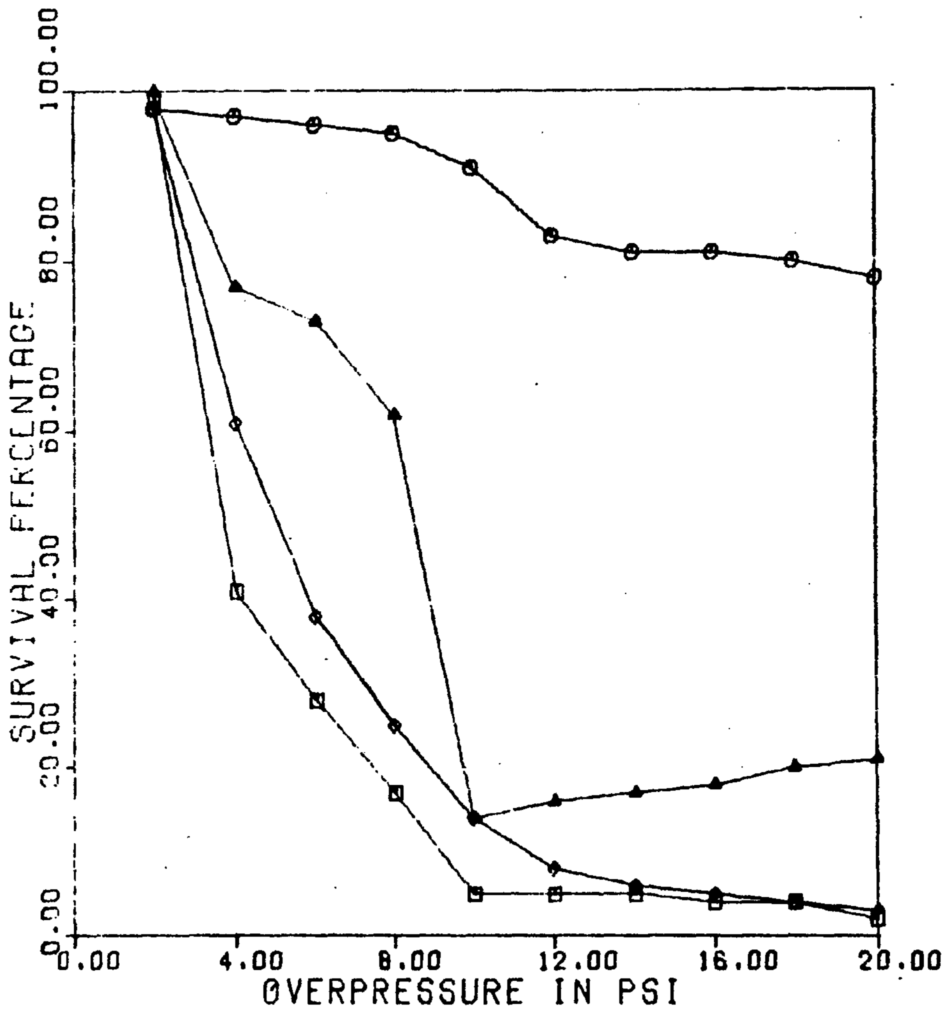
T -- Total Survivors
D -- Debris Impact Survivors
F – Floor Impact Survivors
G – Ground Plane Impact Survivors

Figure 2.43 Impact Survivors Estimate (Wall 4W, People Initially Standing)



□ -- Total Survivors
○ -- Debris Impact Survivors
△ - Floor Impact Survivors
◇ -- Ground Plane Impact Survivors

Figure 2.44 Impact Survivors Estimate (Wall 4W, People Initially Prone, Perpendicular to the Windward Wall)



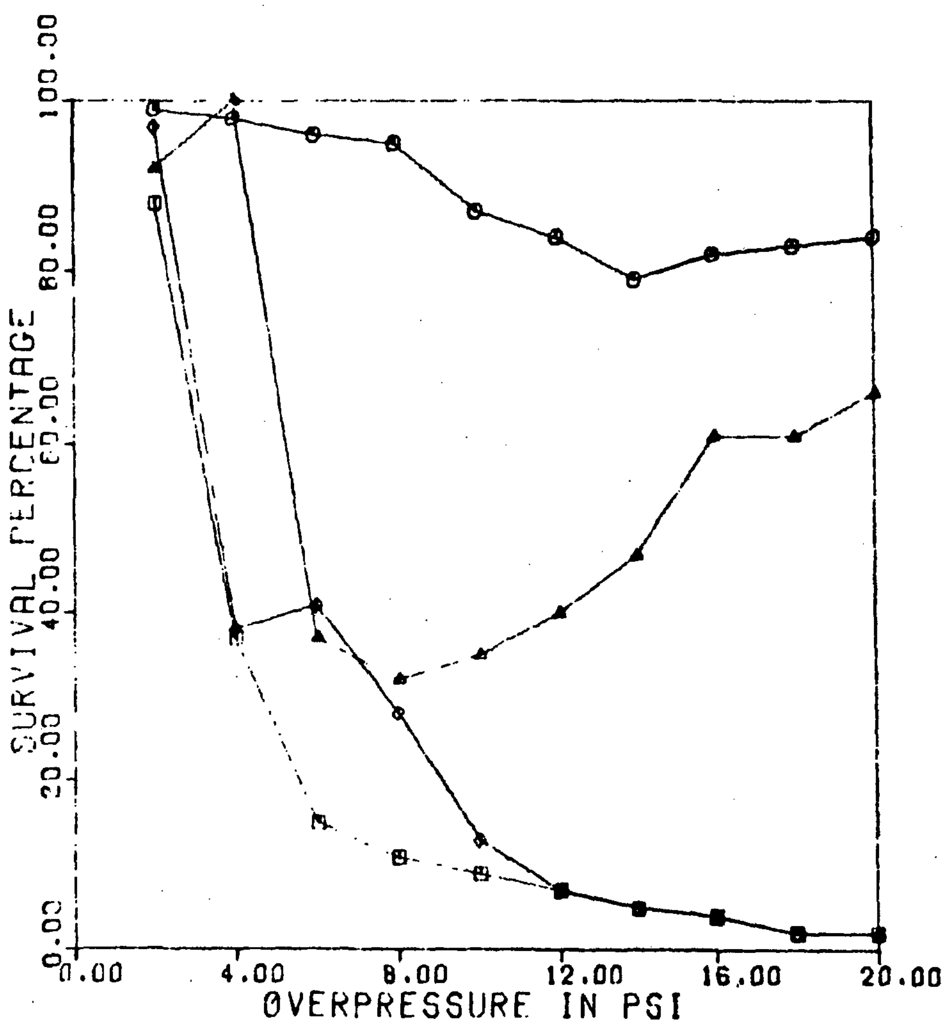
□ – Total Survivors

⊕ – Debris Impact Survivors

△ – Floor Impact Survivors

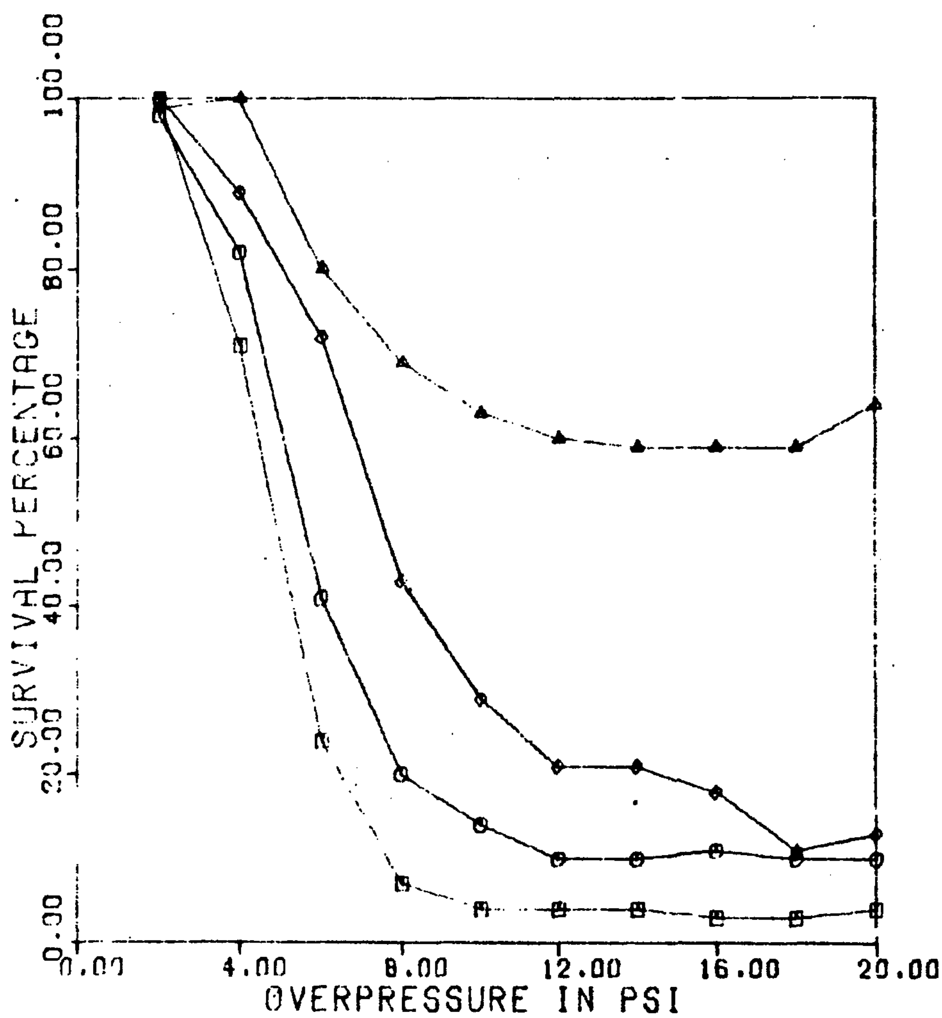
◇ – Ground Plane Impact Survivors

Figure 2.45 Impact Survivors Estimate (Wall 4W, People Initially Prone, Parallel to the Windward Wall)



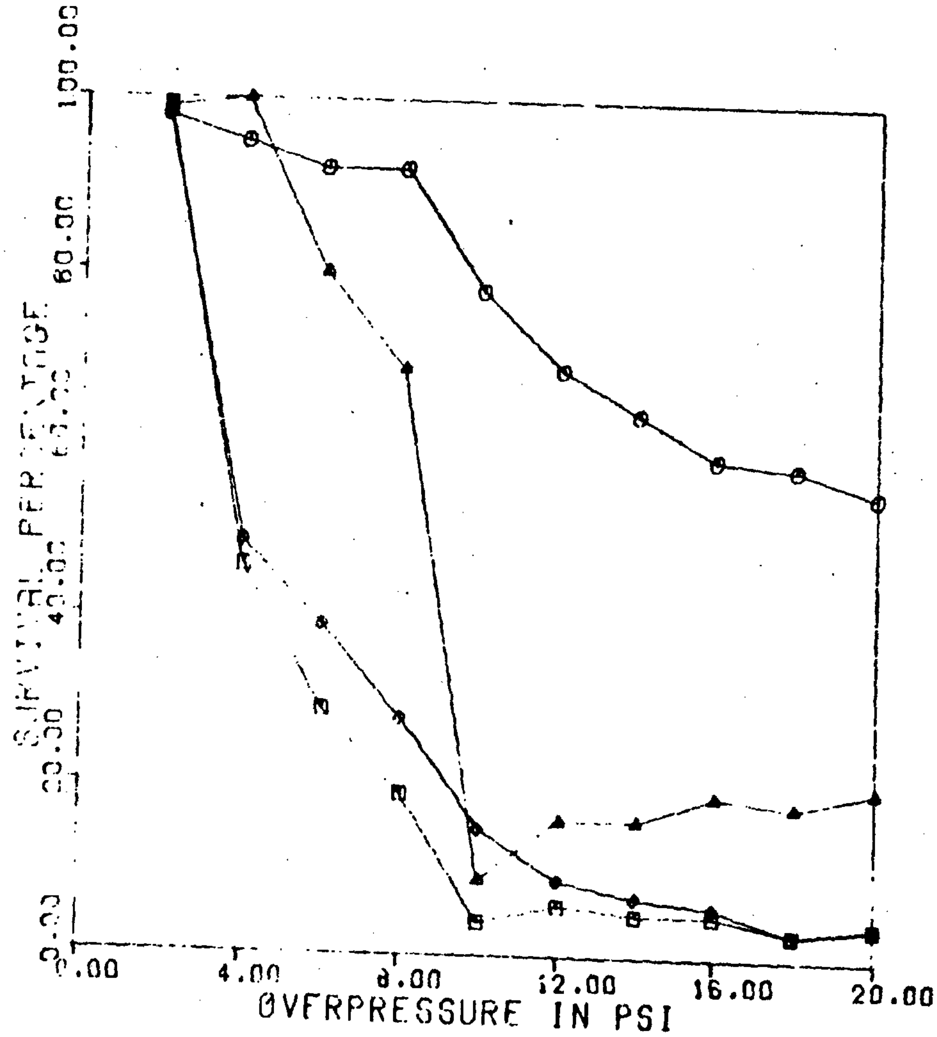
- Total Survivors
- Debris Impact Survivors
- Floor Impact Survivors
- Ground Plane Impact Survivors

Figure 2.46 Impact Survivors Estimate (Wall 5W, People Initially Standing)



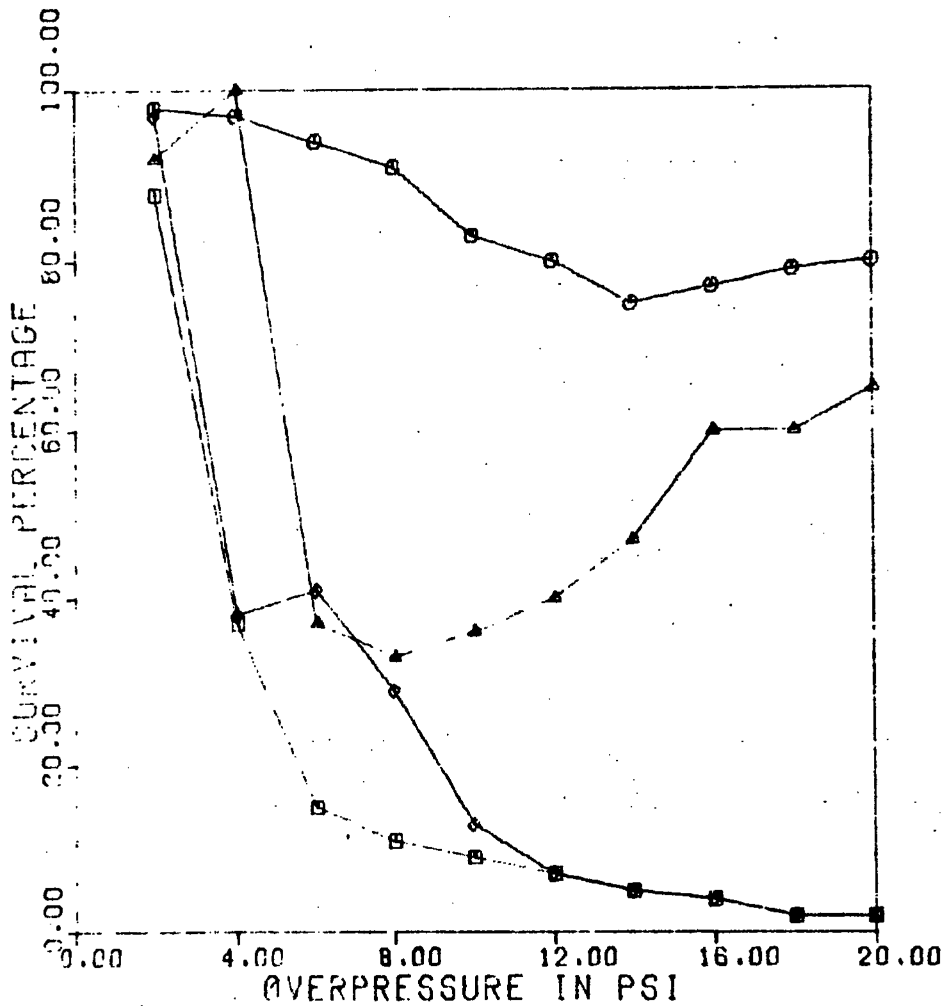
□ – Total Survivors
○ – Debris Impact Survivors
△ – Floor Impact Survivors
◇ – Ground Plane Impact Survivors

Figure 2.47 Impact Survivors Estimate (Wall 5W, People Initially Prone, Perpendicular to the Windward Wall)



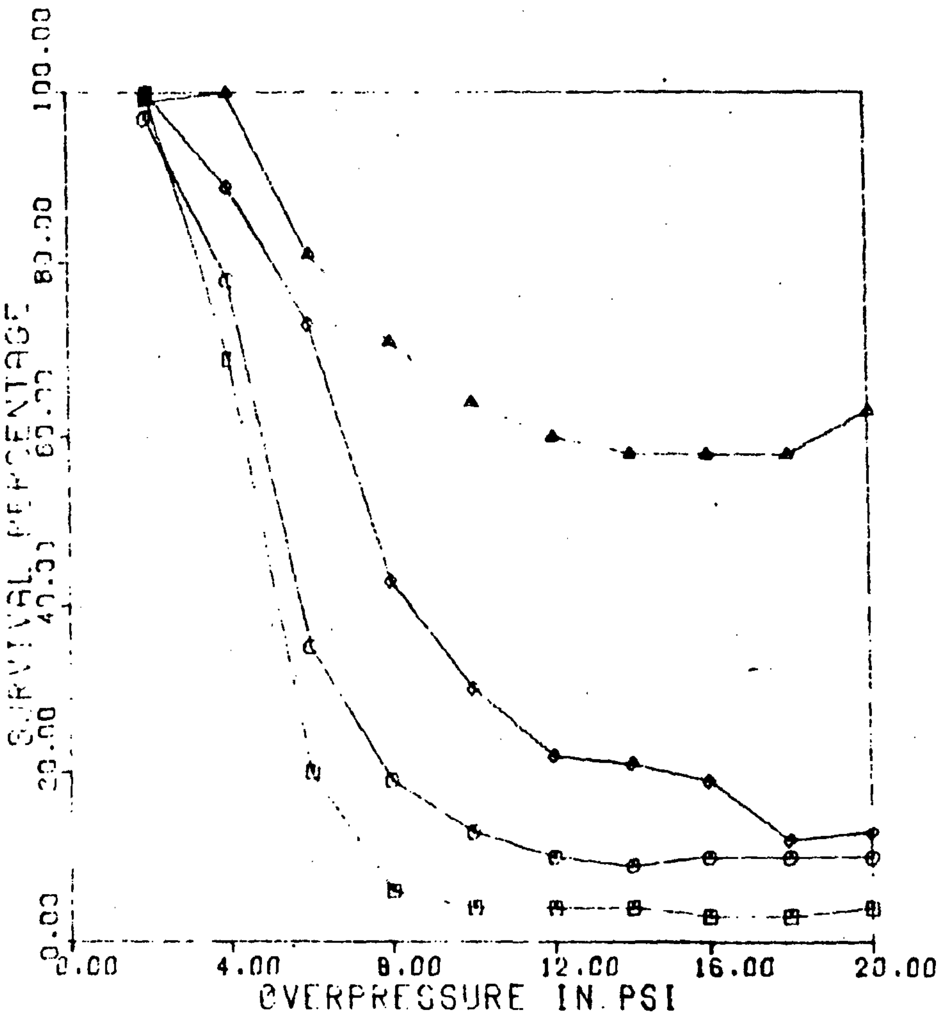
□ .. Total Survivors
○ .. Debris Impact Survivors
△ .. Floor Impact Survivors
◇ .. Ground Plane Impact Survivors

Figure 2.48 Impact Survivors Estimate (Wall 5W, People Initially Prone, Parallel to the Windward Wall)



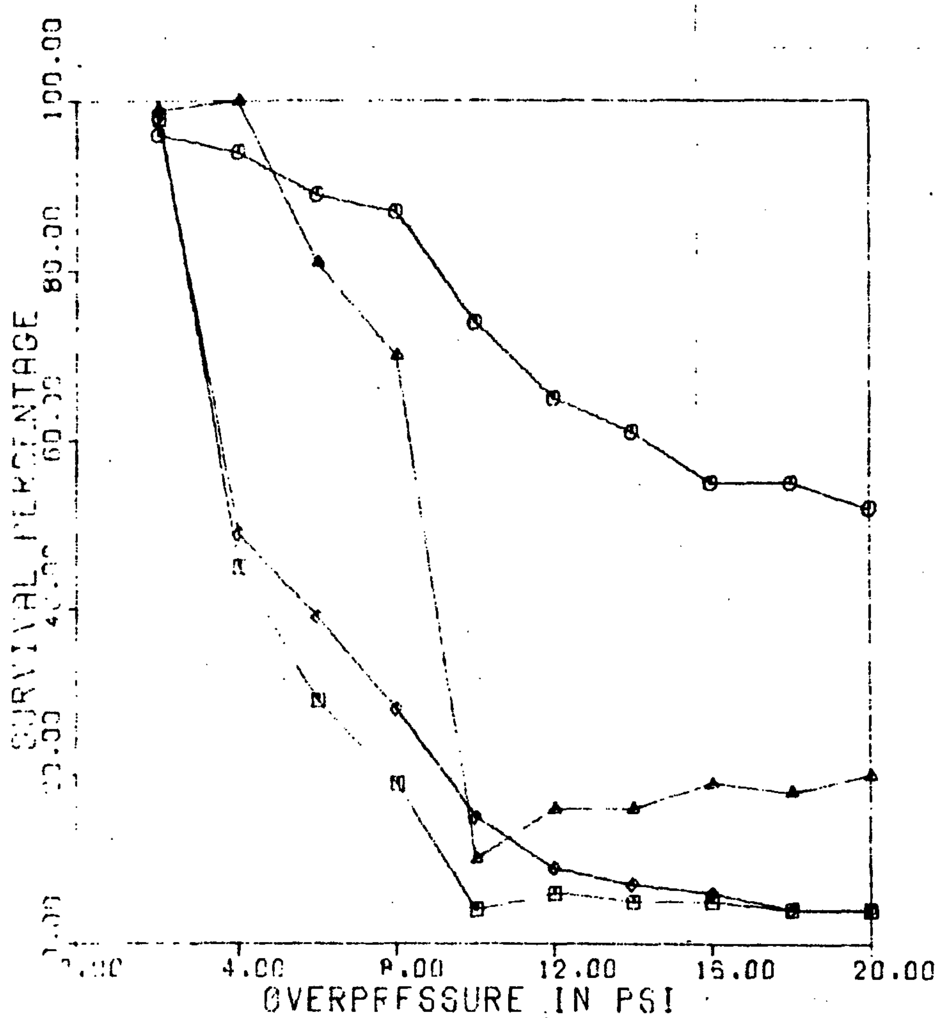
[T] · Total Survivors
(T) – Debris Impact Survivors
Δ – Floor Impact Survivors
↑ ·· Ground Plane Impact Survivors

Figure 2.49 Impact Survivors Estimate (Wall 6W, People Initially Standing)



- Total Survivors
- Debris Impact Survivors
- Floor Impact Survivors
- Ground Plane Impact Survivors

Figure 2.50 Impact Survivors Estimate (Wall 6W, People Initially Prone, Perpendicular to the Windward Wall)



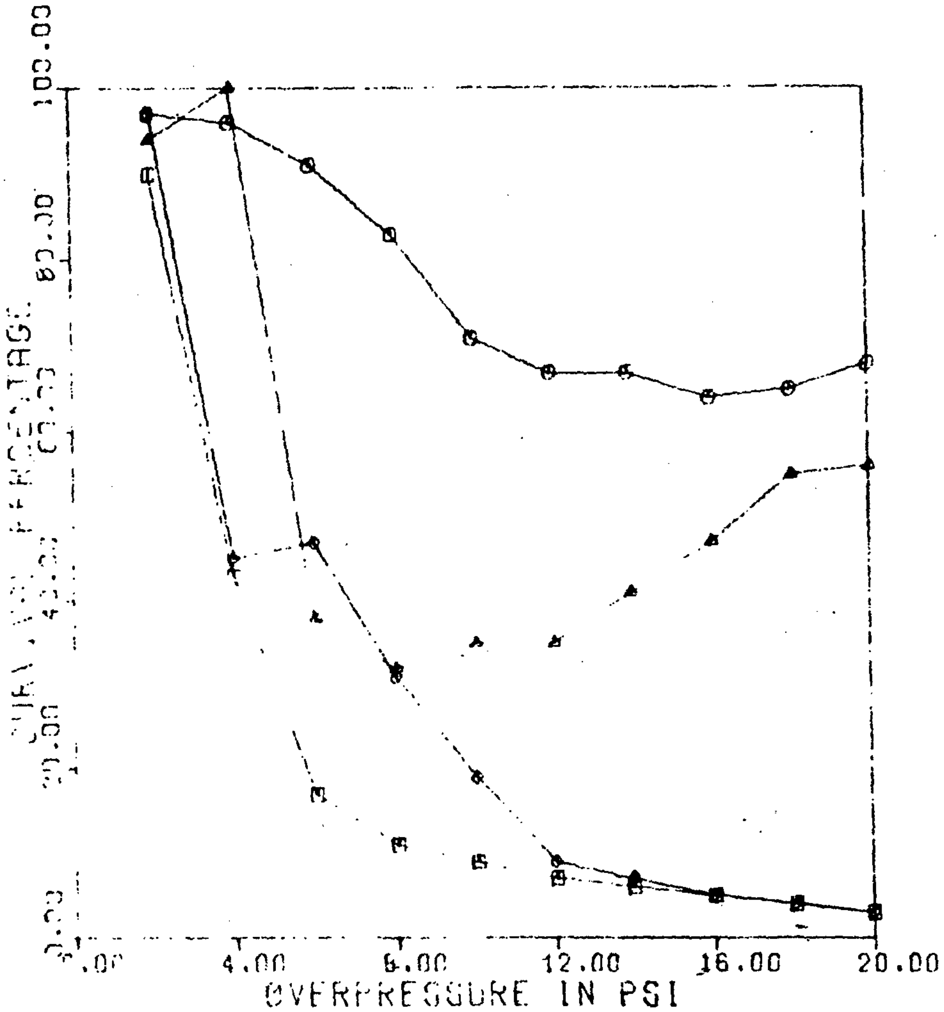
T -- Total Survivors

D -- Debris Impact Survivors

F -- Floor Impact Survivors

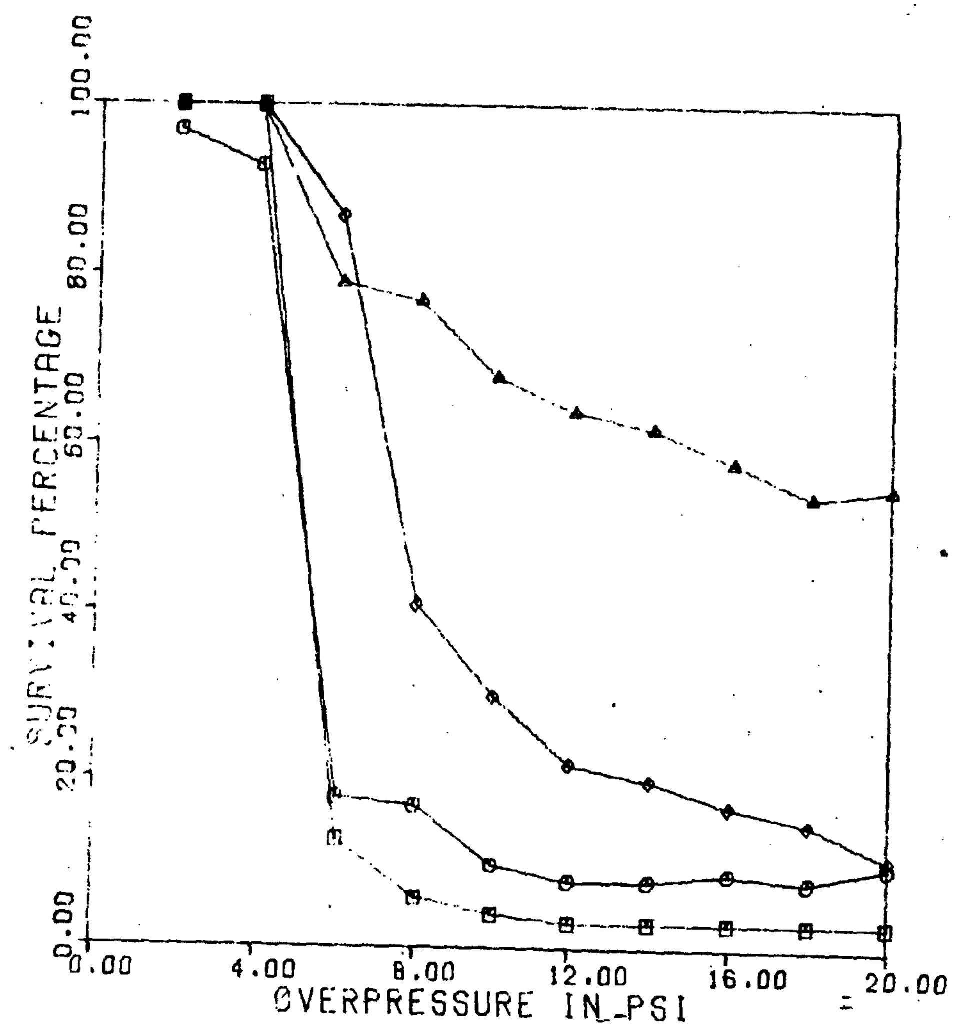
G -- Ground Plane Impact Survivors

Figure 2.51 Impact Survivors Estimate (Wall 6W, People Initially Prone, Parallel to the Windward Wall)



□ Total Survivors
○ Debris Impact Survivors
△ Floor Impact Survivors
◇ Ground Plane Impact Survivors

Figure 2.52 Impact Survivors Estimate (Wall 7W, People Initially Standing)



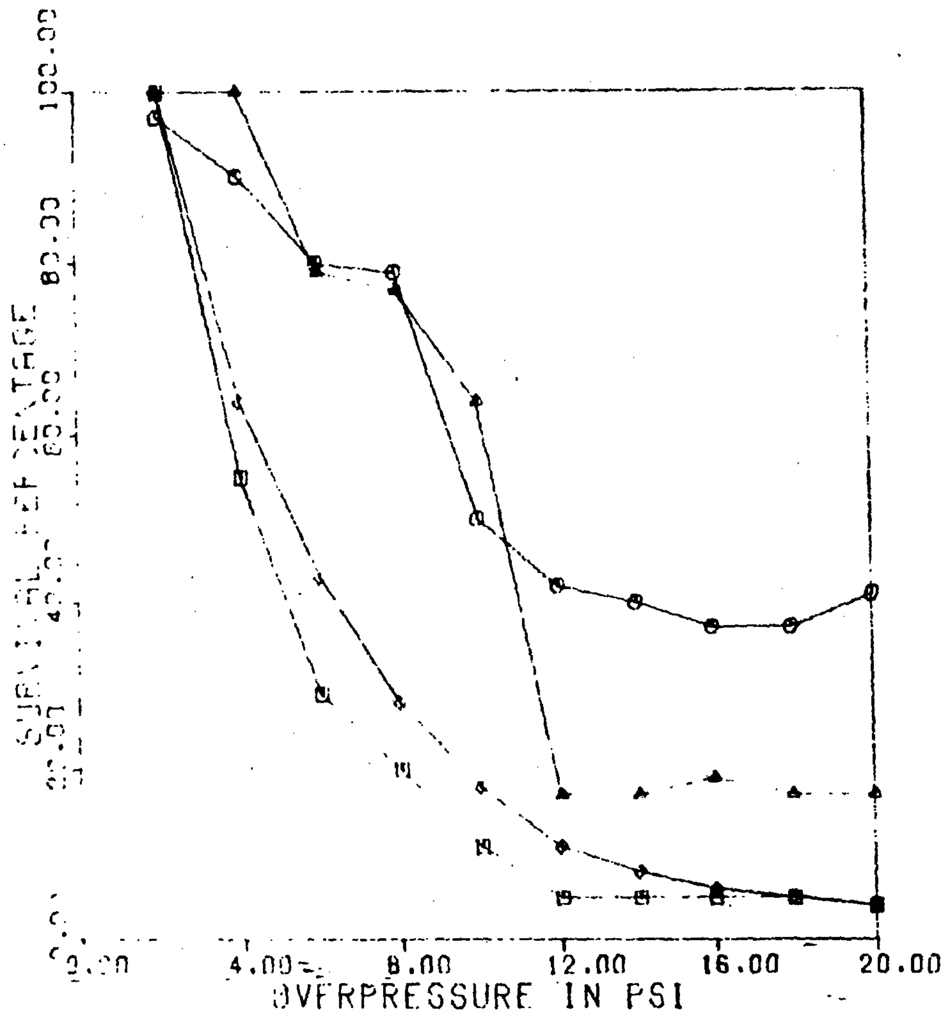
[T] – Total Survivors

(T) – Debris Impact Survivors

Δ – Floor Impact Survivors

◊ – Ground Plane Impact Survivors

Figure 2.53 Impact Survivors Estimate (Wall 7W, People Initially Prone, Perpendicular to the Windward Wall)



T Total Survivors
D Debris Impact Survivors
F Floor Impact Survivors
G Ground Plane Impact Survivors

Figure 2.54 Impact Survivors Estimate (Wall 7W, People Initially Prone, Parallel to the Windward Wall)

Due to the large quantity of data generated, it is difficult to draw conclusions from these results without recourse to systematic, statistical analysis techniques. This is done in the following section in which 144 sets of results are analyzed.

2.4 ANALYSIS OF RESULTS

Analyses were performed on people survivability results described in the previous section to determine the relationships between survivors and the three categories of impact to which building occupants would be subjected when exposed to the blast effects of nuclear weapons. The first set of analyses seeks to determine the importance of each of the three categories of impact in producing fatality. The second seeks to establish relationships between survivors and each impact category expressed in terms of wall and building parameters. These analyses and corresponding results are described in the following paragraphs.

2.4.1 Analysis of Impact Fatalities

This section describes probabilistic analyses whose purpose was to rank impact categories in the order of importance in producing fatalities. The following impact categories which include the three main categories and their combinations were considered.

- D - Debris impact
- F - Floor impact
- G - Ground plane impact
- DG - Debris plus ground plane impact
- DF - Debris plus floor impact
- GF - Ground plane plus floor impact
- DFG - Debris plus floor plus ground plane impact

Other parameters considered in the analysis include three initial body positions, four floor levels (first through fourth) and the following set of discrete, free field overpressure levels, i.e., 4, 8, 12, 16, and 20 psi.

For convenience, the following notation is used.

- S - Survival
- $\bar{S}$ - Fatality
- D - Debris impact is a cause of fatality
- $\bar{D}$ - Debris impact is not a cause of fatality
- G - Ground plane impact is a cause of fatality
- $\bar{G}$ - Ground plane impact is not a cause of fatality
- F - Floor impact is a cause of fatality
- $\bar{F}$ - Floor impact is not a cause of fatality

In the light of these definitions and results described in the previous section, the following probabilities are obtained.

- $P(\bar{D})$ - Probability that debris impact is not a cause of fatality
- $P(\bar{F})$ - Probability that floor impact is not a cause of fatality
- $P(\bar{G})$ - Probability that ground plane impact is not a cause of fatality

Assuming that these events are independent, then the probability of survival becomes

$$P(S) = P(\bar{D})\ P(\bar{F})\ P(\bar{G}) \qquad (12)$$

Probabilities corresponding to complementary events are:

$$\begin{aligned} P(D) &= 1 - P(\bar{D}) \\ P(F) &= 1 - P(\bar{F}) \\ P(G) &= 1 - P(\bar{G}) \\ P(\bar{S}) &= 1 - P(S) \end{aligned} \qquad (13)$$

With this information it is now possible to measure the probabilities associated with various fatality causes. Seven such combinations are possible (see Figure 2.55) and are defined as follows.

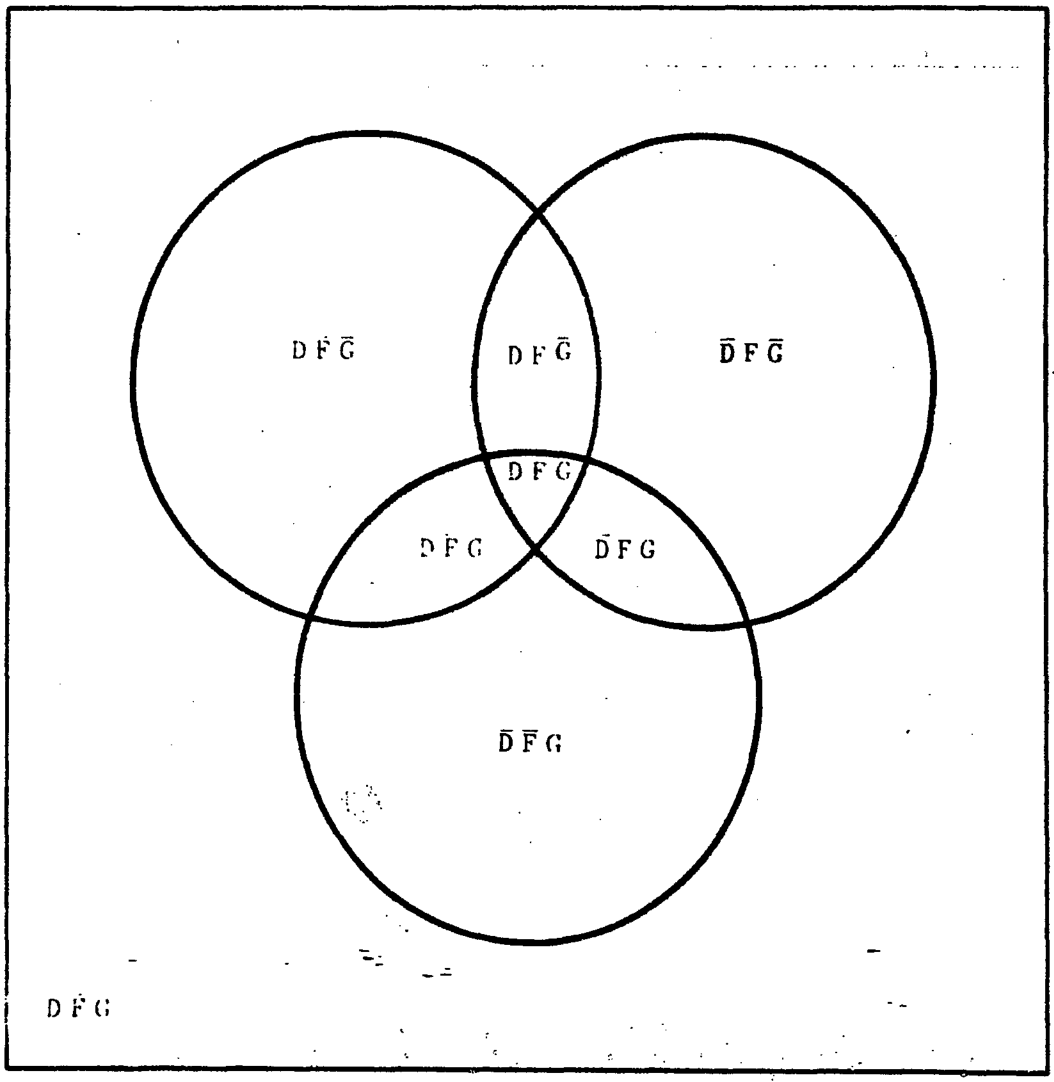


Figure 2.55 Venn Diagram (Combinations of Impact Fatality Causes)

$$P(D\,\bar{F}\,\bar{G}\mid\bar{S}) = \frac{P(D)\;P(\bar{F})\;P(\bar{G})}{P(\bar{S})}$$

$$P(\bar{D}\,F\,\bar{G}\mid\bar{S}) = \frac{P(\bar{D})\;P(F)\;P(\bar{G})}{P(\bar{S})}$$

$$P(\bar{D}\,\bar{F}\,G\mid\bar{S}) = \frac{P(\bar{D})\;P(\bar{F})\;P(G)}{P(\bar{S})}$$

$$P(D\,F\,\bar{G}\mid\bar{S}) = \frac{P(D)\;P(F)\;P(\bar{G})}{P(\bar{S})} \tag{14}$$

$$P(D\,\bar{F}\,G\mid\bar{S}) = \frac{P(D)\;P(\bar{F})\;P(G)}{P(\bar{S})}$$

$$P(\bar{D}\,F\,G\mid\bar{S}) = \frac{P(\bar{D})\;P(F)\;P(G)}{P(\bar{S})}$$

$$P(D\,F\,G\mid\bar{S}) = \frac{P(D)\;P(F)\;P(G)}{P(\bar{S})}$$

where

$P(D\,\bar{F}\,\bar{G}\mid\bar{S})$ = Probability that only debris impact is the cause of fatality given that fatality occurs

$P(\bar{D}\,F\,\bar{G}\mid\bar{S})$ = Probability that only floor impact is the cause of fatality given that fatality occurs

$P(\bar{D}\,\bar{F}\,G\mid\bar{S})$ = Probability that only ground plane impact is the cause of fatality given that fatality occurs

$P(D\,F\,\bar{G}\mid\bar{S})$ = Probability that debris and floor impact are causes of fatality given that fatality occurs

$P(D\,\bar{F}\,G\mid\bar{S})$ = Probability that debris and ground plane impact are causes of fatality given that fatality occurs

$P(\bar{D}\,F\,G\mid\bar{S})$ = Probability that floor and ground plane impact are causes of fatality given that fatality occurs

$P(D\,F\,G\mid\bar{S})$ = Probability that all three impact categories are causes of fatality given that fatality occurs

It will be noted that the above seven probabilities sum to the value of one. Hence, given the condition that fatality occurs then it will occur as a result of one of the seven combinations of events.

Results are presented in Table 2.4. For convenience, probabilities were converted to percentages. The resulting percent probabilities are tabulated fo. each of four story heights, and for five discrete free field overpressure levels. These results apply to the 12 wall types analyzed in the previous section and represent average (percent) probabilities of fatality for an arbitrary individual from populations as indicated in the table. They may be interpreted as follows. Referring to the first line in Table 2.4; given a group of 12 buildings with walls as described previously, then for initially standing people on the first story at the 4 psi range, the average probabilities of fatality for an arbitrary individual against each of the seven possible impact combinations taken separately are the following.

1	Debris impact	0.012
2	Ground plane impact	0.535
3	Floor impact	0.289
4	Debris plus ground plane impact	0.006
5	Debris plus floor impact	0.003
6	Ground plane plus floor impact	0.153
7	Debris plus ground plane plus floor impact	0.002
	Total	1.000

In this case the low debris impact probability is due to the fact that initially standing occupants are swept out of the way before wall failure in unshaded regions and also faster than debris pieces after wall failure in initially shaded regions.

2.4.2 <u>Discussion</u>

The purpose of the analysis performed in the previous section was to examine people survivability results and determine relationships between survivors and the three impact categories, i.e., debris, floor and ground plane impact.

Table 2.4

PERCENT PROBABILITY FOR VARIOUS IMPACT FATALITY CAUSES
People Initially Standing (Population 400 Persons)

FLOOR LEVEL	OVER-PRESSURE PSI	DEBRIS IMPACT	GROUND PLANE IMPACT	FLOOR IMPACT	DEBRIS + GROUND PLANE IMPACT	DEBRIS + FLOOR IMPACT	GROUND PLANE + FLOOR IMPACT	DEBRIS + GROUND + FLOOR IMPACT
1	4	1.2	53.5	26.9	.6	.3	15.3	.2
1	8	1.0	21.5	23.0	1.0	2.2	46.3	4.3
1	12	.4	34.4	4.0	4.2	.6	49.5	6.0
1	16	.4	53.3	1.8	7.2	.2	32.7	4.4
1	20	.2	59.0	.7	7.2	.1	28.0	3.5
2	4	.9	59.3	21.7	.7	.3	17.0	.2
2	8	.9	21.2	21.7	1.9	2.0	47.0	4.4
2	12	.4	34.6	4.4	4.2	.5	49.8	6.1
2	16	.4	53.4	1.6	7.2	.2	32.7	4.4
2	20	.1	59.6	.6	7.2	.1	29.0	3.5
3	4	.6	61.0	16.4	.7	.2	17.7	.2
3	8	.6	21.7	20.1	2.0	1.8	49.0	4.5
3	12	.4	34.7	4.2	4.2	.5	49.9	6.1
3	16	.3	53.6	1.5	7.2	.2	32.8	4.4
3	20	.1	59.5	.5	7.2	.1	29.0	3.5
4	4	.7	64.1	14.8	.8	.2	18.3	.2
4	8	.7	22.3	18.2	2.0	1.7	50.4	4.6
4	12	.3	34.9	3.7	4.2	.5	50.2	6.1
4	16	.3	53.7	1.3	7.3	.2	32.9	4.4
4	20	.1	59.5	.5	7.2	.1	29.0	3.5

Table 2.4 (Contd)

People Initially Prone, Perpendicular to the Windward Wall (Population 256 Persons)

FLOOR LEVEL	PEAK PRESSURE PSI	DEBRIS IMPACT	GROUND PLANE IMPACT	FLOOR IMPACT	DEBRIS + GROUND PLANE IMPACT	DEBRIS + FLOOR IMPACT	GROUND PLANE + FLOOR IMPACT	DEBRIS + GROUND + FLOOR IMPACT
1	4	53.[illegible]	.[illegible]	40.6	.0	5.9	.0	.0
1	8	29.5	7.[illegible]	4.[illegible]	27.2	14.7	3.7	13.6
1	12	15.1	5.7	1.5	38.7	9.9	3.7	25.4
1	16	12.3	6.4	1.1	43.0	7.4	3.9	26.0
1	20	6.6	7.3	.6	44.8	4.3	3.8	25.8
2	4	53.4	.0	40.6	.0	5.9	.0	.0
2	8	26.8	4.0	3.7	29.3	13.5	4.0	14.7
2	12	13.6	5.4	1.3	39.9	9.1	3.9	26.2
2	16	11.1	6.5	1.0	44.1	6.7	3.9	26.6
2	20	7.5	7.[illegible]	.5	50.6	3.9	3.8	26.2
3	4	46.1	7.9	36.6	1.1	6.3	.9	.1
3	8	26.7	6.5	3.4	31.1	12.4	4.3	15.6
3	12	12.7	6.0	1.2	40.9	8.4	4.0	24.9
3	16	10.3	6.6	.9	44.6	6.2	4.0	27.1
3	20	7.2	7.4	.5	50.8	3.7	3.9	26.4
4	4	42.3	16.3	32.2	2.4	4.7	1.8	.3
4	8	22.7	9.0	1.1	32.9	11.4	4.5	16.5
4	12	11.6	6.2	1.1	41.9	7.6	4.1	27.5
4	16	9.3	6.8	.6	45.6	5.6	4.1	27.7
4	20	6.5	7.5	.5	51.5	3.4	3.9	26.7

Table 2.4 (Concl)

People Initially Prone, Parallel to the Windward Wall (Population 200 Persons)

FLOOR LEVEL	OVERPRESSURE PSI	DEBRIS IMPACT	GROUND PLANE IMPACT	FLOOR IMPACT	DEBRIS + GROUND PLANE IMPACT	DEBRIS + FLOOR IMPACT	GROUND PLANE + FLOOR IMPACT	DEBRIS + GROUND + FLOOR IMPACT
1	4	10.2	56.4	22.6	2.6	1.1	6.3	.3
1	8	3.5	46.3	12.6	6.4	1.2	25.0	3.7
1	12	.4	11.3	7.6	3.1	2.1	59.0	16.4
1	16	.4	12.0	4.2	5.1	1.6	54.5	21.4
1	20	.3	13.6	2.5	5.9	1.1	53.6	23.1
2	4	6.6	66.2	15.2	3.3	.8	7.4	.4
2	8	3.2	47.2	11.5	7.1	1.7	25.5	3.8
2	12	.4	11.4	7.0	3.2	2.0	59.5	16.5
2	16	.3	13.0	3.6	5.1	1.5	54.8	21.5
2	20	.2	13.7	2.2	5.9	1.0	53.8	23.2
3	4	4.5	70.1	12.2	3.6	.6	7.8	.4
3	8	2.9	48.0	10.5	7.2	1.6	26.0	3.9
3	12	.4	11.5	6.7	3.2	1.8	59.9	16.6
3	16	.3	13.1	3.5	5.1	1.4	55.1	21.6
3	20	.2	13.7	2.1	5.9	.9	53.9	23.2
4	4	4.6	72.7	10.2	3.6	.5	8.1	.4
4	8	2.6	48.0	9.4	7.3	1.4	26.4	3.9
4	12	.3	11.6	5.9	3.2	1.6	60.5	16.8
4	16	.3	13.1	3.2	5.1	1.2	55.3	21.7
4	20	.2	13.7	2.0	5.9	.8	54.1	23.3

On curves included in Section 2.3, the ordinates are labeled as "Survivability Percentage". This label can be interpreted in two different ways, i.e., total, average percent survivors or percent probability of survival for an arbitrary individual from indicated populations. Either definition is correct. Analysis described in the previous section assumes the second definition.

This analysis identifies seven possible impact combinations from the basic set of three and determines the probability of fatality for each. Results are given in Table 2.4. These are individual sets of percent probabilities (probability times one hundred) which in each case assumes one, two or three combinations of impacts as being fatal given that fatality occurs. However, in each case fatality is produced by one of them. For example, in column labeled debris impact, debris is the only fatality cause considered and the probability of fatality is 0.012 for an arbitrary standing individual on the first story at the 4 psi range. In the case of debris plus floor impact the corresponding probability of fatality is 0.003. In this case debris plus floor impact are the only fatality causes considered. Fatality is produced by debris or floor impact but not in combination. Based on these results, the following observations are made.

For an arbitrary, initially standing individual in the set of 12 buildings with 2 psi walls, debris poses the least threat. The maximum probability of fatality (0.012) is for the first story at the 4 psi range. The largest threat is due to being swept out of the building (ground plane impact). The probability of fatality is 0.535 for the first story at 4 psi and increases only slightly for higher stories. There is also a drop in the probability values at 8 psi followed by an increase such that at 20 psi the probability is very nearly the same as at 4 psi. The reason for the slight increase in probability of fatality for people on higher stories is that most people who are swept out leave the building at high velocities. The difference is primarily due to those individuals who are located close to the leeward edge and are thus swept out at lower velocities. This accounts for a small number of people and thus the reason for the small differences in the probabilities of fatality.

It will be noted that at higher overpressures the probability of fatality due to floor impact is low and decreases substantially. Individuals are simply swept out at high velocities and thus have a low probability of interacting with debris or the floor. This is evident by examining the results in the column under the heading of debris plus floor impact.

The reason for the decrease at 8 psi is that the mode of translation is different at different overpressure levels. At 8 psi the mode is such that initially standing individuals have essentially an even probability of fatality due to striking the floor and being swept out.

People initially prone and parallel to the windward wall are only a little more susceptible to debris impact than initially standing people. With respect to fatality these two initial body positions produce similar results. Reasons for this are as follows. Although an individual who is prone and parallel to the wall initially presents an area (5.3 sq ft) to the blast which is approximately 60 percent of that presented by a standing individual (9.0 sq ft). This varies between the two extremes as he is being tumbled. His mode of translation is also different, and although he has more resistance to sliding, this advantage is quickly lost since in this body position he is more susceptible to being tumbled, i.e., rolled by the blast winds. Like in the case of the initially standing position, people located in unshaded areas are quickly displaced from the path of oncoming debris with ground plane impact becoming the major fatality cause. Although debris affects people located in shaded areas this casualty mechanism is minor and decreases with higher overpressures.

The situation is significantly different for people who are initially prone and parallel to the direction of blast. In this position the body area presented directly to the blast winds is significantly smaller and greater resistance to sliding is provided. Consequently the probability of fatality due to being swept out is substantially reduced. However since individuals are not being translated quickly enough they interact with debris from the failing wall. Debris impact is the major fatality cause in this case. Thus depending on the initial body position and relative location to the debris source, debris can be the most important fatality cause for people in upper stories.

Individuals located on the first story have an advantage over those on higher stories. This advantage however appears to be quite small Although this conclusion is based on results for framed buildings with weak walls, it should hold for stronger walls also. In buildings with strong walls, individuals and especially those located in shaded areas will survive longer. However once the walls fail they will be swept out at higher velocities and thus differences in survival between story heights should be small.

Further, in strong walled buildings debris is expected to be a minor fatality cause for initially standing and prone individuals located parallel to the windward walls. Individuals in unshaded areas will be displaced prior to wall failure. When walls fail, those in shaded areas will be displaced at high velocities thus minimizing interaction with debris. For people prone and perpendicular to windward walls, debris is expected to be a major fatality cause though to a significantly lesser extent than in weak walled buildings. In this case people located in unshaded areas will be displaced prior to wall failure. Debris will affect primarily those who are initially located in shaded zones. The remainder will be swept out.

2.4.3 Analysis of Impact Categories in Terms of Building Parameters

This section describes analyses performed to determine relationships between survivors and the three impact categories expressed in terms of building parameters. Analyses were performed using three survivors percentages, i.e., 10, 50 and 90 percent survivors; three initial body positions, i.e., standing, prone-perpendicular to the windward wall; prone - parallel to the windward wall; and four story levels, i.e., first, second, third and fourth.

Each of the 12 windward walls considered previously was described in terms of six parameters shown in Figure 2.56. These are defined as follows:

- L - Lower sill height
- U - Height to upper sill
- W - Width of side walls
- NL - Number of debris pieces in the lower sill
- NU - Number of debris pieces in the upper sill
- NS - Number of debris pieces in the side walls

The first stepwise regression analysis performed seeks to express the free field overpressure at each survival percentage and initial body position in terms of floor heights and wall parameters described above.

Free field overpressures in each impact category are denoted as follows.

- D(P,B) - Overpressures associated with debris impact survivors, psi
- F(P,B) - Overpressures associated with floor impact survivors, psi
- G(P,B) - Overpressures associated with ground plane impact survivors, psi
- T(P,B) - Overpressures associated with total survivors.

In these functions, P refers to percent survivors and takes on values of 10, 50, and 90. B refers to initial body position and takes on values of 1, 2, and 3.

Results of the first regression analysis are given in Table 2.5 Coefficients in this table are those corresponding to the parameters which were found to be significant in the analysis. The stepwise regression procedure only includes those parameter values which are significantly related to each individual variable. In the table the symbol "C" corresponds to the constant value of each particular regression equation. FL refers to the floor level. Thus, the first regression equation in row 1, Table 2.5 can be written as follows.

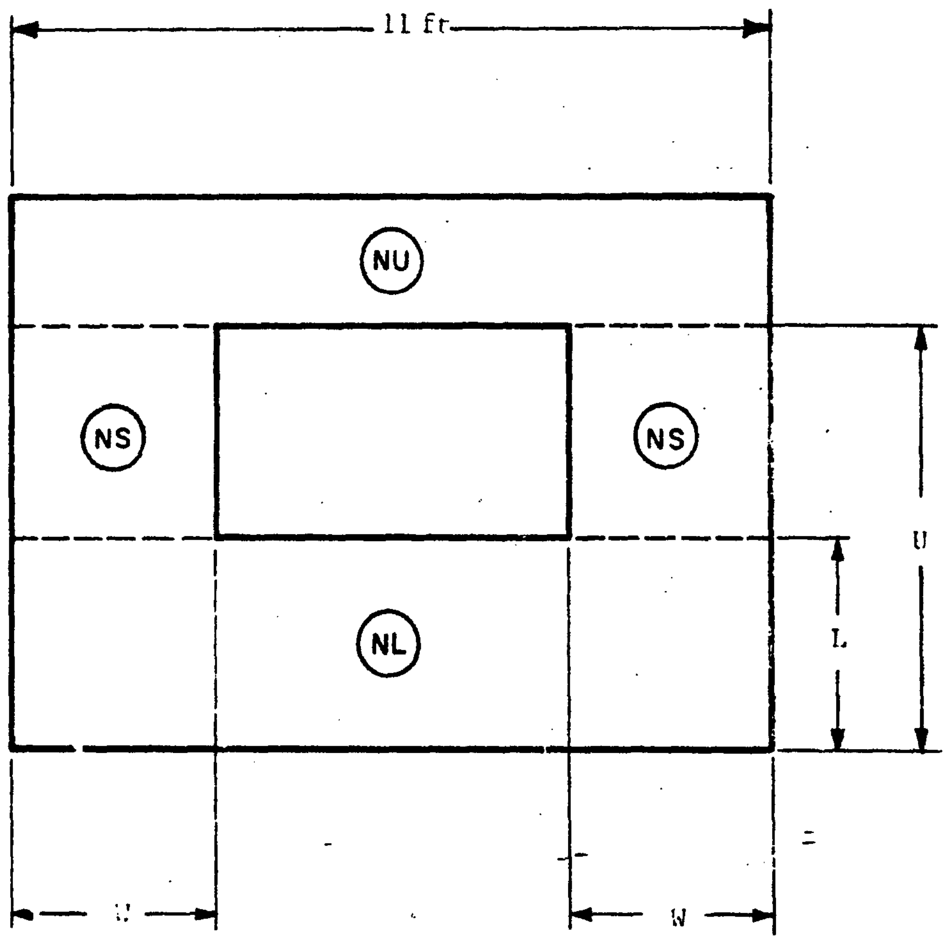


Figure 2.56 Wall Parameters

Table 2.5

STEPWISE REGRESSION ANALYSIS RESULTS

Variable	C	L	U	W	NL	NU	NS	FL	R	n
T(10,1)	10.44				0.0605		0.1785	-0.7390	0.97	48
T(50,1)	3.48				0.0315		0.0789	-0.1733	0.92	48
T(90,1)	2.19				0.0133			-0.1858	0.89	48
D(10,1)										0
D(50,1)										0
D(90,1)	-47.80	-0.0950	[illegible]7	-0.0300					0.99	20
F(10,1)										0
F(50,1)	3.43	0.0198		0.0430					0.81	48
F(90,1)	7.83	0.0319	-0.0537	0.0426					0.87	48
G(10,1)	10.53	0.0208		0.0414				-0.3481	0.95	48
G(50,1)	6.93							-0.7609	0.73	48
G(90,1)	2.97	-0.0023		-0.0058				-0.1358	0.80	48
T(10,2)	11.20				-0.1275	-0.3053	-0.2225	-0.2765	0.87	48
T(50,2)	2.98		0.0284	0.0163	-0.0411		-0.1323	-0.1936	0.93	48
T(90,2)	- 0.11		0.0372	0.0153				-0.4181	0.25	48
D(10,2)	-77.49	-0.1022	0.7729						1.00	16
D(50,2)	7.95			0.0356	-0.1081	-0.1733	-0.3580		0.96	48
D(90,2)	5.03				-0.0691	-0.1969	-0.0680		0.71	48
F(10,2)										0
F(50,2)										0
F(90,2)	7.21	0.0287	-0.0412	0.0383					0.84	48
G(10,2)	19.29	0.0121							0.85	16
G(50,2)	8.28	0.0036		0.0070					0.92	48
G(90,2)	6.83								0.81	48

Table 2.5 (Concl)

Variable	C	L	U	W	NL	NU	NS	FL	R	n
T(10,3)	9.12	0.0111					0.0966	-0.1432	0.69	48
T(50,3)	4.86				0.0286		0.0377	-0.4024	0.91	48
T(90,3)	2.01		0.0041		0.0069		0.0173	-0.0843	0.88	48
D(10,3)										0
D(50,3)									NS	8
D(90,3)	18.68			0.1975	-0.5344		-2.2243		0.94	44
F(10,3)	9.96	0.0003							0.98	20
F(50,3)	7.60	0.0181		0.0321					0.74	48
F(90,3)	7.21	0.0287	-0.0412	0.0383					0.84	48
G(10,3)	12.28	0.0197		0.0368				-0.5183	0.92	48
G(50,3)	6.65							-0.5348	0.83	48
G(90,3)	3.26							-0.2323	0.68	48

$$T(10,1) = 10.44 + 0.0605\ NL + 0.1785\ NS - 0.7390\ FL,\ psi$$

Included with each equation is the correlation coefficient "R" and the sample size "n". If ever the sample size is zero then of course no results are shown. Also, whenever no significant relationship is found the symbol "NS" is listed in the correlation column. To facilitate interpretation of results given in Table 2.5, all parameters were ranked in the order of their importance to the various regression equations. In each row of Table 2.4 these parameters (L, V, W, NL, NU, NS, FL) were ranked on the basis of their significance values. These values are obtained as part of the regression analysis but are not included in Table 2.5. The ranking is given in Table 2.6.

Based on results of this regression analysis a summary of mean overpressures for the three survival percentages is given in Table 2.7.

Table 2.8 lists the percent of observations on the basis of which a given percent survivability value is determined (measured). A zero entry indicates no observations for the particular percent survivors. This implies that the particular condition is safe with respect to survivability. Therefore the smaller the percent the safer the condition. Table 2.8 is based on sample sizes given in Table 2.5.

The second stepwise regression analysis performed seeks to relate the free field overpressure at each of the three survival percentages, initial body positions and floor levels to the set of wall parameters defined previously.

Overpressures in each impact category are defined as follows:

G(P,B,FL) - Overpressures associated with ground plane impact survivors

T(P,B,FL) - Overpressures associated with total survivors

Table 2.6

RANKING OF SIGNIFICANT PARAMETERS

Overpressure (Percent Survivors, Body Position)	Parameters						
	L	U	W	NL	NU	NS	FL
T(10,1)				3		2	1
T(50,1)				2		1	3
T(90,1)				2			1
D(10,1)							
D(50,1)							
D(90,1)	2	1	3				
F(10,1)							
F(50,1)	2		1				
F(90,1)	1	3	2				
G(10,1)	2		1				3
G(50,1)							1
G(90,1)	3		2				1
T(10,2)				1	3	2	4
T(50,2)		3	5	1		4	2
T(90,2)		2	3				
D(10,2)	2	1					
D(50,2)			4	1	3	2	
D(90,2)				1	2	3	
F(10,2)							
F(50,2)							
F(90,2)	1	3	2				
G(10,2)	1						2
G(50,2)	3		2				1
G(90,2)							1
T(10,3)	1					2	3
T(50,3)				2		3	1
T(90,3)		4		2		3	1
D(10,3)							
D(50,3)							
D(90,3)			3	1		2	
F(10,3)	1						
F(50,3)	1		2				
F(90,3)	1	3	2				
G(10,3)	3		2				1
G(50,3)							1
G(90,3)							1

Table 2.7

MEAN OVERPRESSURES (psi) FOR INDICATED PERCENT SURVIVORS

Impact Category (Percent Survivors)	Initial Body Positions		
	Standing	Prone, Perpendicular to Windward Wall	Prone, Parallel to Windward Wall
	1	2	3
T(10)	9.7	7.9	9.5
T(50)	3.6	5.3	4.3
T(90)	1.9	3.5	2.4
D(10)	-	10.2	-
D(50)	-	5.9	7.9
D(90)	6.7	3.9	8.6
F(10)	-	-	10.0
F(50)	4.9	-	8.8
F(90)	3.4	4.0	4,0
G(10)	11.1	19.6	12.3
G(50)	5.0	7.8	5.3
G(90)	2.5	5.3	2.7

Table 2.8

PERCENT OF OBSERVATIONS FOR INDICATED PERCENT SURVIVORS

Impact Category (Percent Survivors)	Initial Body Positions		
	Standing	Prone, Perpendicular to Windward Wall	Prone, Parallel to Windward Wall
	1	2	3
T(10)	100	100	100
T(50)	100	100	100
T(90)	100	100	100
D(10)	0	33	0
D(50)	0	100	16
D(90)	42	100	90
F(10)	0	0	42
F(50)	0	0	100
F(90)	100	100	100
G(10)	100	33	100
G(50)	100	100	100
G(90)	100	100	100

In these functions, P refers to percent survivors and takes on values of 10, 50, and 90. B refers to initial body position and takes on values of 1, 2, and 3. FL refers to the floor level and takes on values of 1, 2, 3, and 4. Independent parameters used with T(P,B,FL) include L, U, W, NL, NU, NS. Those used with G(P,B,FL) include L, V, W. Since debris and floor impacts are independent of floor level, they are not treated as separate categories in this regression analysis. Results are given in Table 2.9. As previously, the table includes a set of coefficients which are significantly related to various wall parameters. Together with the constant terms "C" they form a set of independent regression equations which relate free field overpressure at various percent survivors, body position and floor level to significant wall wall parameters. To facilitate interpretation of results, wall parameters were ranked in the order of their significants to each of these equations. Ranking results are given in Table 2.10. Corresponding mean overpressures for three survival percentages and four floor levels are related to the three initial body positions in Table 2.11.

2.4.4 Discussion

Analysis described in Section 2.4.1 was concerned with establishing relationships between fatality and a corresponding set of possible impact fatality causes. This was done by considering the wall parameters in an implicit manner. The analysis described in this section attempts to relate wall parameters to impact categories explicitly and on this basis establish relationships between impact and people survivability. As previously analyses performed herein are based on 144 sets of results, 36 of which are given in Section 2.3.

Table 2.6 is a ranking of significant parameters for each impact category, percent survivors and initial body position. This is based on a stepwise regression analysis (see Table 2.5) which considered wall parameters and story heights as independent variables.

Table 2.9

STEPWISE REGRESSION ANALYSIS RESULTS

(Percent Survivors, Body Position, Floor Level)	A	L	U	W	NL	NU	NS	R	n
T(10,1,1)	9.69				0.0655		0.2044	0.94	12
(50,1,1)	3.13				0.0438		0.1092	0.91	12
(90,1,1)	2.02	0.0020						0.74	12
(10,1,2)	8.89				0.0549		0.1872	0.93	12
(50,1,2)	3.05				0.0338		0.0850	0.92	12
(90,1,2)	1.93	0.6297						0.63	12
(10,1,3)	8.21				0.0586		0.1785	0.93	12
(50,1,3)	3.02				0.0267		0.0651	0.91	12
(90,1,3)	1.63	0.0044						0.64	12
(10,1,4)	7.60				0.0629		0.1438	0.94	12
(50,1,4)	3.00				0.0220		0.0553	0.92	12
(90,1,4)	1.32	0.0048						0.89	12
G(10,1,1)	10.16	0.0213		0.0426				0.90	12
(50,1,1)	5.76	0.0102		0.0200				0.91	12
(90,1,1)	3.11	-0.0057		-0.0139				0.75	12
(10,1,2)	9.74	0.0217		0.0433				0.96	12
(50,1,2)								NS	12
(90,1,2)	2.64	-0.0022		-0.0054				0.72	12
(10,1,3)	9.50	0.0205		0.0408				0.96	12
(50,1,3)	4.82			-0.0299				0.57	12
(90,1,3)								NS	12
(10,1,4)	9.24	0.0195		0.0388				0.93	12
(50,1,4)	4.94	-0.114		-0.0268				0.77	12
(90,1,4)								NS	12

Table 2.9 (Contd)

(Percent Survivors, Body Position, Floor Level)	A	L	U	W	NL	NU	NS	R	n
T(10,2,1)	10.99				-0.1389		-0.4322	0.82	12
(50,2,1)	6.50				-0.0478		-0.1378	0.93	12
(90,2,1)								NS	12
(10,2,2)	10.54				-0.1278		-0.3946	0.81	12
(50,2,2)	6.23				-0.0430	-0.1096	-0.0600	0.94	12
(90,2,2)								NS	12
(10,2,3)	9.35				-0.0813		-0.2922	0.91	12
(50,2,3)	5.74				-0.0281		-0.0869	0.79	12
(90,2,3)								NS	12
(10,2,4)	9.01				-0.0729		-0.2666	0.93	12
(50,2,4)	0.97	-0.0071	0.0364					0.79	12
(90,2,4)								NS	12
G(10,2,1)								NS	4
(50,2,1)								NS	12
(90,2,1)	6.09	0.0026		0.0045				0.94	12
(10,2,2)								NS	4
(50,2,2)								NS	12
(90,2,2)	4.87	0.0094		0.0.75				0.76	12
(10,2,3)								NS	4
(50,2,3)	7.49	0.0027		0.0054				0.81	12
(90,2,3)								NS	12
(10,2,4)								NS	4
(50,2,4)	7.24	0.0031		0.0057				0.94	12
(90,2,4)								NS	12

Table 2.9 (Concl)

(Percent Survivors, Body Position, Floor Level)	A	L	U	W	NL	NU	NS	R	n
T(10,3,1)								NS	12
(50,3,1)	4.76	0.0054						0.78	12
(90,3,1)								NS	12
(10,3,2)								NS	12
(50,3,2)	3.74	0.0094					0.0605	0.79	12
(90,3,2)	2.32	0.0019					0.0115	0.75	12
(10,3,3)	8.72	0.0104					0.0892	0.66	12
(50,3,3)	3.50	0.0077					0.0490	0.76	12
(90,3,3)	2.31	0.0013						0.62	12
(10,3,4)	8.64	0.0101					0.0828	0.68	12
(50,3,4)	3.44	0.0058					0.0373	0.77	12
(90,3,4)	2.23	0.0014						0.60	12
G(10,3,1)	11.40	0.0267		0.0485				0.93	12
(50,3,1)	5.67	0.0070		0.0130				0.86	12
(90,3,1)								NS	12
(10,3,2)	11.05	0.0207		0.0369				0.93	12
(50,3,2)								NS	12
(90,3,2)								NS	12
(10,3,3)	10.84	0.0167		0.0328				0.83	12
(50,3,3)								NS	12
(90,3,3)								NS	12
(10,3,4)	10.63	0.0146		0.0291				0.87	12
(50,3,4)								NS	12
(90,3,4)								NS	12

Table 2.10

RANKING OF SIGNIFICANT PARAMETERS

Variables	Parameters L	U	W	NL	NU	NS	Variables	Parameters L	U	W	NL	NU	NS	Variables	Parameters L	U	W	NL	NU	NS
T(10,1,1)				2		1	T(10,2,1)				2		1	T(10,3,1)						
(50,1,1)				2		1	(50,2,1)				2		1	(50,3,1)	1					
(90,1,1)	1						(90,2,1)							(90,3,1)						
(10,1,2)				2		1	(10,2,2)				2		1	(10,3,2)						
(50,1,2)				2		1	(50,2,2)				1	2	3	(50,3,2)	1					2
(90,1,2)	1						(90,2,2)							(90,3,2)	1					2
(10,1,3)				2		1	(10,2,3)				2		1	(10,3,3)	1					2
(50,1,3)				2		1	(50,2,3)				2		1	(50,3,3)	1					2
(90,1,3)	1						(90,2,3)							(90,3,3)	1					
(10,1,4)				2		1	(10,2,4)				2		1	(10,3,4)	1					2
(50,1,4)				2		1	(50,2,4)							(50,3,4)	1					2
(90,1,4)	1						(90,2,4)	2	1					(90,3,4)	1					
G(10,1,1)	2		1				G(10,2,1)							G(10,3,1)	1		2			
(50,1,1)	2		1				(50,2,1)							(50,3,1)	1*		1*			
(90,1,1)	2		1				(90,2,1)	1		2				(90,3,1)						
(10,1,2)	2		1				(10,2,2)							(10,3,2)	1					
(50,1,2)							(50,2,2)							(50,3,2)						
(90,1,2)	2		1				(90,2,2)	2		1				(90,3,2)						
(10,1,3)	2		1				(10,2,3)							(10,3,3)	2		1			
(50,1,3)			1				(50,2,3)	2		1				(50,3,3)						
(90,1,3)							(90,2,3)							(90,3,3)						
(10,1,4)	2		1				(10,2,4)							(10,3,4)	2		1			
(50,1,4)	2		1				(50,2,4)	1*		1*				(50,3,4)						
(90,1,4)							(90,2,4)							(90,3,4)						

*Equal significance

Table 2.11

MEAN OVERPRESSURES (PSI) FOR INDICATED PERCENT SURVIVORS

Impact Category (Percent Survivors, Floor Level)	Initial Body Positions		
	Standing 1	Prone, Perpendicular to Windward Wall 2	Prone, Parallel to Windward Wall 3
T(10,1)	10.9	8.3	9.8
(50,1)	3.9	5.6	5.0
(90,1)	2.1	4.2	2.6
(10,2)	10.0	8.1	9.6
(50,2)	[illegible].7	5.4	4.3
(90,2)	2.0	3.6	2.4
(10,3)	9.3	7.7	9.4
(50,3)	3.5	5.2	4.0
(90,3)	1.9	3.2	2.4
(10,4)	8.7	7.5	9.3
(50,4)	3.4	5.0	3.8
(90,4)	1.6	3.0	2.3
G(10,1)	11.7	19.7	13.2
(50,1)	6.5	8.3	6.2
(90,1)	2.7	6.3	3.1
(10,2)	11.3	19.7	12.5
(50,2)	5.0	7.9	5.6
(90,2)	2.5	5.5	2.7
(10,3)	11.0	19.4	12.0
(50,3)	4.5	7.7	5.0
(90,3)	2.4	4.9	2.5
(10,4)	10.6	19.4	11.7
(50,4)	4.1	7.4	4.6
(90,4)	2.3	4.4	2.4

It will be noted that debris is fairly insignificant for initially standing individuals and for people initially prone-parallel. In all three cases there are no observations for 10 and 50 percent survivors. For initially standing individuals the significant parameters are related to wall geometry and not to the number of debris pieces. In the case of prone-parallel individuals the most significant parameters (NL and NS) are related to debris. Since these parameters enter the equation, then people in shaded areas interact with debris/ The extent to which this interaction is significant relative to other impact categories cannot be determined from this analysis alone. This aspect of the problem was treated in the previous section and results are given in Table 2.4.

People prone and perpendicular to the windward wall are most susceptible to debris. This body position provides the least drag area and the largest resistance to sliding. Since parameters such as NL, NU AND NS are significant, then people in shaded and unshaded areas are not moved out fast enough and therefore interact with debris. Again, the extent to which this interaction contributes to fatality can ge gauged from results given in Table 2.4.

Although wall parameters are significant in cases of debris and floor impact, it will be noted that floor level (FL) is the most significant parameter for total survivors, i.e., with respect to all three impact categories.

Table 2.7 lists mean free field overpressure levels for three survivors percentages and 12 body positions. These were obtained from the regression analysis whose results are given in Table 2.5. Results given in Table 2.7 may be viewed as representing 12 four-story buildings with 2 psi walls. The walls are described in Appendix A. In these results story height is an implicit parameter.

As far as total survivors are concerned, the second body position, i.e., prone-perpendicular provides the best protection of the three. However when walls fail, this body position is the most susceptible to debris effects. Debris is least important for initially standing individuals.

The second regression analysis considers wall parameters as dependent variables. In this case floor level is treated as an explicit independent variable together with percent survivors and initial body position. While the first regression analysis treats the 12 buildings as a whole, the second separates results by floor level in addition to percent survivors and initial body position.

Results of the regression analysis are given in Table 2.9, the ranking of significant parameters in Table 2.10. Results are for total and ground plane impact survivors. Since debris and floor impact are independent of story height these results are not included.

In the case of ground plane impact, i.e., translation and sweeping out, the significant parameters are width of side walls and sill height and mostly in that order. For total survivors debris parameters (NL and NS) dominate results. At each floor level and a given initial body position the significant parameters are essentially the same.

Table 2.11 lists mean free field overpressure levels for three survival percentages and three initial body positions. These were obtained from the regression analysis results given in Table 2.9. These results are similar to those given in Table 2.7 except that in this case story heights are explicitly considered. It will be noted that as far as ground plane impact is concerned, mean overpressures don't change drastically from the first to the fourth story. As observed previously, differences that exist are due mostly to those people who are located close to the leeward side of the building and are swept out at low velocities. The remainder are swept out at sufficiently high velocities such that story height at high overpressures is no longer an important parameter.

2.5 CONCLUSIONS AND RECOMMENDATIONS

The problem of assessing and separating impact casualties in a blast environment or predicting debris-people interaction, is a complex problem. Self-contained procedures capable of analyzing this problem in all of its generality do not exist. The procedure described in this chapter is a first attempt at the problem and as such contains a number of gross approximations. These are due to lack of available information and restrictions imposed by the size and complexity of the problem. The following is noted.

In this process, debris-people interaction is treated approximately. When impact between an individual and debris occurs, the trajectories of the two impacting bodies are assumed not to change as a result of it. Also, their relative velocity is taken as a measure of induced trauma. In those instances where the relative velocity is sufficient to produce fatality, this approximation is certainly acceptable. In those, where the relative velocity is such that only minor injuries are produced it is also acceptable since trajectories are not expected to change very much. For values between these extremes unacceptable errors may occur. However, a great deal depends on how wide or how narrow this range is. Since debris sizes considered in this process are large, and translational velocities high, then the range between survival and fatality is in all probability very narrow and therefore the approximation made is considered to be acceptable in the light of other assumptions.

It will be noted that although more refined models exist, the people simulation model and the corresponding blast loading routine used are fairly crude. The major reason for using these rather than more refined models is due to the size of the resulting computer program. Both in programming and computer running times such a task was well beyond the scope of this study. Also, although the "articulated man" simulation model is operational, at the present time it lacks a workable casualty estimation routine. A fairly extensive casualty data review effort is required before such a routine can be developed. Since the current casualty criterion is based exclusively on impact velocities, the use of these crude models is considered acceptable.

This procedure for the analysis of impact casualties is an operational computer program. Although it contains a fair number of approximations, it admits of more detail and is considered to be more accurate than any other similar procedure available at this time. From the debris catalog stored in this program (Table 2.2) it is possible to assemble a fairly large variety of masonry walls having different fracture patterns and incipient collapse overpressures. Individuals can be fairly randomly distributed. In its present form this computer program can be used for the analysis of a variety of different framed buildings for the purpose of determining people survivability and assessing the effectiveness of different modes of evasive action. It is recommended that this computer program be utilized for this purpose.

REFERENCES

2.1 Longinow, A., et al, Survivability in a Direct Effects Environment and Related Topics, for DCPA Contract DAHC20-68-C-0126, Work Unit 1614D, IIT Research Institute, May 1973.

2.2 Feinstein, D. I., et al, Personnel Casualty Study for Office of Civil Defense, Contract OCD-PS-64-201, Work Unit 1125A, Subcontract B-10923 (4949A-24)-US, IIT Research Institute, July 1968.

2.3 Edmunds, J. E., Experiments to Determine Debris Formation from Corrugated Steel and Brick Walls, for OCD, Contract DAHC20-69-C-0129, Work Unit 3313C, URS Research Company, January 1970.

2.4 Wilton, C. and Gabrielson, B., Shock Tunnel Tests of Wall Panels, for DCPA, Contract DAHC20-71-C-0223, URS Research Company, January 1972.

CHAPTER 3

CLASSIFICATION OF SHELTER SPACES

3.1 <u>INTRODUCTION</u>

This chapter discusses the feasibility of developing a classification system for conventional buildings in terms of best available shelter space, relative to the prompt effects of nuclear weapons.

Results are presented of a regression analysis used to rank a number of building parameters and thus determine their significance in contributing to people survivability. Resulting regression analysis equations were then used to generate a table of results relating free field overpressure to people survivability in terms of six building parameters. This table forms a <u>basic classification system</u> for framed buildings.

It is concluded that a general classification system is feasible and can be developed. However, for it to be usable at any civil defense level, the effort should be preceded by a field data analysis study. Its purpose would be to categorize all significant building parameters and to establish the significance of their variability on the final results, i.e., people survivability.

3.2 <u>STATEMENT OF THE PROBLEM</u>

In order to provide for the safety of the population in the case of an emergency, the civil defense planner requires knowledge on best available shelter space in his community. Conventional buildings constitute the only significant, current sheltering resource. Each of them possesses some level of inherent ability in providing protection not only against the effects of nuclear weapons but also against natural disasters such as tornados, hurricanes, and earthquakes. It is therefore 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 so as to gain full advantage of these capabilities in an emergency situation.

What is needed is a simple, reliable building classification and rating system that can be quickly and effectively used at any civil defense level 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 rating procedure. Such a system should have the following attributes. It should be reliable, be easy to understand and apply, and should require the use of only the most commonly available building parameters as descriptors.

One way to develop a classification system for a given category of buildings is to perform a series of analyses in which all relevant building parameters are appropriately varied over their respective ranges. This would result in a set of people survivability estimates for various modes of evasive action. Results could then be grouped in terms of appropriate building parameter categories and cast in the form of nomographs, curves and/or tables for ready use. This approach to the problem is discussed in the following section in which a simplified classification system for framed buildings is developed.

3.3 CLASSIFICATION OF SHELTER SPACES IN FRAMED BUILDINGS

Table 3.1 is a set of free field overpressure levels for three survivors percentages (90, 50, 10) and two initial body positions, i.e., standing and prone. Results in the table include the following casualty mechanisms produced by the direct-effects of a single megaton range (1 MT) nuclear weapon, i.e., thermal radiation, prompt nuclear radiation and three categories of impact-debris, floor and ground plane impact. Results were produced using regression analysis equations. These were developed using a set of results generated by the use of the BUILDINGS computer program described in Appendix A of this report. Debris survivability data used are those for three walls (1C, 2C and 5C) described in the previous chapter. Values in this table were rounded to the nearest whole number. They apply to framed buildings and are expressed in terms of six building parameters.

Table 3.1

PEOPLE SURVIVABILITY IN UPPER STORIES OF FRAMED BUILDINGS
(Overpressures for 90 percent Survivors, Initially Standing People)

		WS	2	2	2	2	2	2	8	8	8	8	8	8	14	14	14	14	14	14
		AP	25	25	25	50	50	75	25	25	25	50	50	75	25	25	25	50	50	75
		SH	1	3	6	1	3	1	1	3	6	1	3	1	1	3	6	1	3	1
FL	BL	DW																		
1	30	10	4	4	3	4	4	4	6	6	5	5	5	4	7	7	6	6	7	5
1	30	20	4	3	3	3	3	3	5	5	5	5	5	4	7	7	7	6	6	4
1	30	30	4	3	2	3	3	3	5	5	5	4	4	3	7	7	7	5	6	4
1	50	10	4	4	3	4	4	4	6	6	5	5	5	4	7	7	6	6	7	5
1	50	20	4	3	3	3	3	3	5	5	5	5	5	4	7	7	7	6	6	4
1	50	30	4	4	2	3	3	3	5	5	5	4	4	3	7	7	7	5	6	4
1	70	10	4	4	3	4	4	4	6	5	5	5	5	4	7	7	6	6	7	5
1	70	20	4	3	3	3	3	3	5	5	5	5	5	4	7	7	7	6	6	4
1	70	30	4	3	2	3	3	3	5	5	5	4	4	3	7	7	7	5	6	4
2	30	10	4	4	3	4	4	4	6	5	5	5	5	4	7	7	7	6	6	5
2	30	20	4	3	3	3	3	3	5	5	5	4	5	4	7	7	7	6	6	4
2	30	30	3	3	2	3	3	2	5	5	4	4	4	4	7	7	7	5	6	4
2	50	10	4	4	3	4	4	3	6	5	5	5	5	4	7	7	7	6	6	5
2	50	20	4	3	3	3	3	3	5	5	5	4	5	4	7	7	7	6	6	4
2	50	30	3	3	2	3	3	2	5	5	4	4	4	3	7	7	7	5	5	4
2	70	10	4	4	3	4	4	3	6	5	5	5	5	4	7	7	7	6	6	5
2	70	20	4	3	3	3	3	3	5	5	5	4	5	4	7	7	7	6	6	4
2	70	30	3	3	2	3	3	2	5	5	4	4	4	3	7	7	7	5	6	4
3	30	10	4	4	3	4	3	3	6	5	5	5	5	4	7	7	7	6	6	5
3	30	20	4	3	2	3	3	3	5	5	5	4	5	3	7	7	7	5	6	4
3	30	30	3	3	2	3	3	2	5	5	4	4	4	3	6	6	7	5	6	4
3	50	10	4	4	3	4	3	3	6	5	5	5	5	4	7	7	7	6	5	5
3	50	20	4	3	2	3	3	3	5	5	5	4	5	3	7	7	7	5	6	4
3	50	30	3	3	2	3	3	2	5	5	4	4	4	3	6	6	7	5	5	4
3	70	10	4	4	3	4	3	3	6	5	5	5	5	4	7	7	7	6	6	5
3	70	20	4	3	2	3	3	3	5	5	5	4	5	3	7	7	7	5	6	4
3	70	30	3	3	2	3	3	2	5	5	4	4	4	3	6	6	7	5	6	4
4	30	10	4	3	3	3	3	3	5	5	5	5	5	4	7	7	7	6	6	4
4	30	20	4	3	2	3	3	3	5	5	5	4	4	3	7	7	7	5	6	4
4	30	30	3	3	2	3	3	2	5	5	4	4	4	3	6	6	6	5	5	4
4	50	10	4	3	3	3	3	3	5	5	5	5	5	4	7	7	7	6	5	4
4	50	20	4	3	2	3	3	3	5	5	5	4	4	3	7	7	7	5	6	4
4	50	30	3	3	2	3	3	2	5	5	4	4	4	3	6	6	6	5	6	4
4	70	10	4	3	1	3	3	3	5	5	5	5	5	4	7	7	7	6	6	4
4	70	20	4	3	2	3	3	3	5	5	5	4	4	3	7	7	7	5	6	4
4	70	30	3	3	2	3	3	2	5	5	4	4	4	3	6	6	6	5	6	4

WS - Wall Strength, psi
AP - Aperture, percent
SH - Sill Height, ft

FL - Floor Level
BL - Building Length, ft
DW - Distance to First Interior Wall, ft

Table 3 1 (Contd)

(Overpressures for 90 percent Survivors, Initially Prone People)

F	W	D	WS 1P 5	2 25 1	2 25 3	2 25 5	2 50 1	2 50 3	2 75 1	8 25 1	8 25 3	8 25 6	8 50 1	8 50 3	8 75 1	14 25 1	14 25 3	14 25 6	14 50 1	14 50 3	14 75 1
1	[illegible]	[illegible]		3	3	3	4	4	4	8	8	8	8	8	8	13	13	14	12	13	11
1	[illegible]	[illegible]		3	4	2	3	3	4	8	7	7	7	8	8	13	13	14	12	12	11
1	3	[illegible]		3	4	2	4	3	4	8	8	8	7	8	7	12	13	13	12	12	11
1	[illegible]	1		3	3	3	4	4	4	8	8	8	8	8	8	13	13	14	12	13	11
1	[illegible]	[illegible]		3	3	[illegible]	4	3	4	8	8	8	8	8	8	13	13	14	12	12	11
1	[illegible]	[illegible]		3	3	2	3	3	4	8	8	8	8	8	8	12	13	13	12	12	11
1	[illegible]	[illegible]		3	3	3	4	4	4	8	8	8	8	8	8	13	13	14	12	13	12
1	[illegible]	2		3	3	2	4	3	4	8	8	8	8	8	8	13	13	14	12	13	11
1	[illegible]	[illegible]		3	3	2	3	3	4	8	8	8	8	8	7	12	13	13	12	12	11
2	[illegible]	[illegible]		3	3	2	3	3	4	8	8	7	8	8	8	13	13	14	12	12	11
2	[illegible]	[illegible]		3	3	2	3	3	4	8	8	7	7	8	7	12	13	13	12	12	11
2	[illegible]	[illegible]		3	2	2	3	3	4	7	7	8	7	7	7	12	13	13	11	12	11
2	[illegible]			3	3	2	4	3	4	8	8	8	[illegible]	8	8	13	13	14	12	12	11
2	[illegible]	[illegible]		3	2	2	3	3	4	7	7	8	7	8	7	12	13	13	12	12	11
2	[illegible]	[illegible]		3	3	2	4	3	4	8	7	7	7	7	7	12	13	13	12	12	11
2	[illegible]	[illegible]		3	3	[illegible]	3	3	4	8	8	8	8	8	8	13	13	14	12	13	11
2	[illegible]	[illegible]		[illegible]	[illegible]	2	[illegible]	3	4	7	8	8	8	8	7	12	13	13	12	12	11
2	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	7	12	13	13	12	12	[illegible]
3	[illegible]	[illegible]		3	3	2	3	3	4	8	8	8	7	8	7	12	13	13	12	12	11
3	[illegible]	2		2	2	2	3	3	4	7	7	8	7	7	7	12	13	13	11	12	11
3	[illegible]	[illegible]		2	2	2	3	3	4	7	7	7	7	7	7	12	12	13	11	12	11
4	[illegible]	1		3	3	2	3	3	4	8	8	8	8	8	7	12	13	13	12	12	11
4	[illegible]	2		3	2	3	3	3	4	7	7	8	7	7	7	12	13	13	12	12	11
4	[illegible]	3		2	2	3	3	3	3	7	7	7	7	7	7	12	12	13	11	12	11
4	[illegible]	1		3	3	2	3	3	4	8	8	8	4	8	7	12	13	13	12	12	11
4	[illegible]	2		3	2	2	3	3	4	7	8	8	7	8	7	12	13	13	12	12	11
4	[illegible]	[illegible]		2	2	2	3	3	3	7	7	7	7	7	7	12	12	13	11	12	11
4	[illegible]	1		[illegible]	2	[illegible]	3	3	4	7	7	[illegible]	7	7	7	12	13	13	11	12	11
4	[illegible]	[illegible]		2	2	2	3	3	3	7	7	7	7	7	7	12	12	13	11	12	11
4	[illegible]	[illegible]		2	2	1	3	2	3	7	7	7	7	7	7	12	12	13	11	12	10
4	[illegible]	1		3	2	2	3	3	4	7	7	[illegible]	7	7	7	12	13	13	12	12	11
4	[illegible]	2		2	2	2	3	3	3	7	7	[illegible]	7	7	7	12	12	13	11	12	11
4	[illegible]	[illegible]		2	2	2	3	2	3	7	7	[illegible]	7	7	7	12	12	13	11	12	11
4	[illegible]	[illegible]		2	2	2	3	3	4	7	8	[illegible]	7	8	7	12	13	14	12	12	11
4	[illegible]	2		2	2	2	3	3	3	7	7	7	7	7	7	12	12	14	11	12	11
4	[illegible]	[illegible]		2	2	2	3	3	3	7	7	7	7	7	7	12	12	13	11	12	10

Table 3.1 (Contd)

(Overpressures for 50 percent Survivors, Initially Standing People)

		WS	2	2	2	2	2	2	8	8	8	8	8	8	14	14	14	14	14	14
		AP	25	25	25	50	50	75	25	25	25	50	50	75	25	25	25	50	50	75
		SH	1	3	6	1	3	1	1	3	6	1	3	1	1	3	6	1	3	1
F:	3L	Da																		
1	30	10	6	5	4	5	5	5	9	9	8	8	8	7	13	12	12	10	11	8
1	30	20	5	5	4	5	5	5	9	8	8	9	8	6	12	12	12	10	10	8
1	30	30	5	4	3	5	5	4	8	8	7	7	7	6	12	12	12	10	10	7
1	50	10	6	5	4	6	5	5	9	9	8	8	8	7	13	13	12	10	11	8
1	50	20	5	5	4	5	5	5	9	8	8	8	8	6	12	12	12	10	11	8
1	50	30	5	4	3	5	5	4	8	8	7	7	7	6	12	12	12	10	10	8
1	70	10	6	5	4	6	5	5	9	9	8	8	8	7	13	13	12	11	11	9
1	70	20	5	5	4	5	5	5	9	8	8	8	8	6	12	12	12	10	11	8
1	70	30	5	4	3	5	5	4	8	8	8	7	7	6	12	12	12	10	10	8
2	30	10	6	5	4	5	5	5	9	9	8	8	8	6	12	12	12	10	11	8
2	30	20	5	4	3	5	5	4	9	8	8	7	7	6	12	12	12	10	10	8
2	30	30	5	4	3	4	4	4	8	8	7	7	7	6	12	11	11	9	10	7
2	50	10	6	5	4	5	5	5	9	9	8	8	8	6	12	12	12	10	11	8
2	50	20	5	5	4	5	5	5	9	8	8	7	8	6	12	12	12	10	10	8
2	50	30	5	4	3	4	4	4	8	8	7	7	7	6	12	11	11	9	10	7
2	70	10	6	5	4	5	5	5	9	9	8	8	8	7	12	12	12	10	11	8
2	70	20	5	5	4	5	5	5	9	8	8	7	8	6	12	12	12	10	10	8
2	70	30	5	4	4	4	4	4	8	8	7	7	7	6	12	12	11	9	10	7
3	30	10	5	5	4	5	5	5	9	8	8	7	8	6	12	12	12	10	10	8
3	30	20	5	4	3	5	4	4	8	8	7	7	7	6	12	12	11	10	10	7
3	30	30	4	4	3	4	4	4	8	7	7	7	7	5	11	11	11	9	10	7
3	50	10	5	5	4	5	5	5	9	8	8	7	8	6	12	12	12	10	10	8
3	50	20	5	4	3	5	5	4	8	8	7	7	7	6	12	12	11	10	10	7
3	50	30	5	4	3	4	4	4	8	8	7	7	7	5	11	11	11	9	10	7
3	70	10	5	5	4	5	5	5	9	8	8	8	8	6	12	12	12	10	10	8
3	70	20	5	4	3	5	5	4	8	8	7	7	7	6	12	12	11	10	10	7
3	70	30	5	4	3	4	4	4	8	8	7	7	7	5	11	11	11	9	10	7
4	30	10	5	4	3	5	5	4	8	8	7	7	7	6	12	12	11	10	10	7
4	30	20	5	4	3	4	4	4	8	8	7	7	7	6	11	11	11	9	10	7
4	30	30	4	4	3	4	4	4	8	7	7	6	7	5	11	11	11	9	9	7
4	50	10	5	4	3	5	5	4	8	8	7	7	7	6	12	12	12	10	10	8
4	50	20	5	4	3	4	4	4	8	8	7	7	7	6	11	11	11	9	10	7
4	50	30	4	4	3	4	4	4	8	7	7	6	7	5	11	11	11	9	9	7
4	70	10	5	4	3	5	5	4	8	8	7	7	7	6	12	12	12	10	10	8
4	70	20	5	4	3	4	4	4	8	8	7	7	7	6	12	11	11	9	10	7
4	70	30	4	4	3	4	4	4	8	7	7	6	7	5	11	11	11	9	9	7

Table 3.1 (Contd)
(Overpressures for 50 percent Survivors, Initially Prone People)

		WS	2	2	2	2	2	2	8	8	8	8	8	8	14	14	14	14	14	14
		AW	25	25	25	50	50	75	25	25	25	50	50	75	25	25	25	50	50	75
		SH	1	3	6	1	3	1	1	3	6	1	3	1	1	3	6	1	3	1
FT	AL	PA																		
1	30	10	5	5	5	6	6	8	9	9	9	10	10	11	14	14	14	14	14	13
1	30	20	5	5	5	6	6	8	9	9	9	10	10	11	14	14	14	14	14	13
1	30	30	5	5	5	6	6	8	9	9	9	10	10	11	14	14	14	14	14	13
1	50	10	5	5	5	7	7	8	10	10	10	10	10	11	14	14	14	14	14	14
1	50	20	5	5	5	7	7	8	10	10	10	10	10	11	14	14	14	14	14	14
1	50	30	5	5	5	7	7	8	10	10	10	10	10	11	14	14	14	14	14	14
1	70	10	5	5	5	7	7	8	10	10	10	10	10	11	14	14	14	14	14	14
1	70	20	5	5	5	7	7	8	10	10	10	10	10	11	14	14	14	14	14	14
1	70	30	5	5	5	7	7	8	10	10	10	10	10	11	14	14	14	14	14	14
2	30	10	4	4	4	6	6	7	9	9	9	9	9	10	13	13	13	13	13	13
2	30	20	4	4	4	6	6	7	9	9	9	9	9	10	13	13	13	13	13	13
2	30	30	4	4	4	6	6	7	9	9	9	9	9	10	13	13	13	13	13	13
2	50	10	4	4	4	6	6	7	9	9	9	10	10	10	13	14	14	13	13	13
2	50	20	4	4	4	6	6	7	9	9	9	10	10	10	13	14	14	13	13	13
2	50	30	4	4	4	6	6	7	9	9	9	10	10	10	13	14	14	13	13	13
2	70	10	4	4	4	6	6	8	9	9	9	10	10	10	14	14	14	13	13	13
2	70	20	4	4	4	6	6	8	9	9	9	10	10	10	14	14	14	13	13	13
2	70	30	4	4	4	6	6	8	9	9	9	10	10	10	14	14	14	13	13	13
3	30	10	4	4	4	5	5	7	8	8	8	9	9	9	13	13	13	12	12	12
3	30	20	4	4	4	5	5	7	8	8	8	9	9	9	13	13	13	12	12	12
3	30	30	4	4	4	5	5	7	8	8	8	9	9	9	13	13	13	12	12	12
3	50	10	4	4	4	5	5	7	8	8	8	9	9	10	13	13	13	13	13	12
3	50	20	4	4	4	5	5	7	8	8	8	9	9	10	13	13	13	13	13	12
3	50	30	4	4	4	5	5	7	8	8	8	9	9	10	13	13	13	13	13	12
3	70	10	4	4	4	5	5	7	8	8	8	9	9	10	13	13	13	13	13	12
3	70	20	4	4	4	5	5	7	8	8	8	9	9	10	13	13	13	13	13	12
3	70	30	4	4	4	5	5	7	8	8	8	9	9	10	13	13	13	13	13	12
4	30	10	3	3	3	5	5	5	7	8	8	8	8	9	12	12	12	12	12	12
4	30	20	3	3	3	5	5	5	7	8	8	8	8	9	12	12	12	12	12	12
4	30	30	3	3	3	5	5	5	7	8	8	8	8	9	12	12	12	12	12	12
4	50	10	3	3	3	5	5	6	8	8	8	8	8	9	12	12	12	12	12	12
4	50	20	3	3	3	5	5	6	8	8	8	8	8	9	12	12	12	12	12	12
4	50	30	3	3	3	5	5	6	8	8	8	8	8	9	12	12	12	12	12	12
4	70	10	3	3	[illegible]	5	5	6	8	8	8	8	8	9	12	12	13	12	12	12
4	70	20	3	3	3	5	5	6	8	8	8	8	8	9	12	12	13	12	12	12
4	70	30	3	3	3	5	5	6	8	8	8	8	8	9	12	12	13	12	12	12

Table 3.1 (Contd)

(Overpressures for 10 percent Survivors, Initially Standing People)

*S AP SH			2 25 1	2 25 3	2 25 6	2 50 1	2 50 3	2 75 1	8 25 1	8 25 3	8 25 6	8 50 1	8 50 3	8 75 1	14 25 1	14 25 3	14 25 6	14 50 1	14 50 3	14 75 1
FI	AL	CW																		
1	30	10	7	7	7	7	7	9	11	11	10	10	10	10	14	14	14	13	13	12
1	30	20	7	7	6	7	7	9	10	10	10	10	10	10	14	14	14	13	13	12
1	30	30	7	7	6	7	7	7	10	10	10	10	10	10	14	14	14	13	13	12
1	50	10	7	7	7	7	7	8	11	11	10	10	10	10	14	14	14	13	13	12
1	50	20	7	7	6	7	7	8	10	10	10	10	10	10	14	14	14	13	13	12
1	50	30	7	7	6	7	7	7	10	10	10	10	10	10	14	14	14	13	13	12
1	70	10	7	7	7	7	7	6	11	11	10	10	10	10	14	14	14	13	13	12
1	70	20	7	7	6	7	7	8	10	10	10	10	10	10	14	14	14	13	13	12
1	70	30	7	7	6	7	7	7	10	10	10	10	10	10	14	14	14	13	13	12
2	30	10	6	6	6	7	7	7	10	10	10	9	10	9	13	13	13	12	13	11
2	30	20	6	6	6	7	7	7	10	10	9	9	9	9	13	13	13	12	12	11
2	30	30	6	6	5	5	6	7	10	9	9	9	9	9	13	13	13	12	12	11
2	50	10	6	6	6	7	7	7	10	10	10	9	10	9	13	13	13	12	13	11
2	50	20	6	6	6	7	7	7	10	10	9	9	9	9	13	13	13	12	12	11
2	50	30	6	6	5	6	6	7	10	9	9	9	9	9	13	13	13	12	12	11
2	70	10	6	6	6	7	7	7	10	10	10	9	10	9	13	13	13	12	13	11
2	70	20	6	6	6	7	7	7	10	10	9	9	9	9	13	13	13	12	12	11
2	70	30	6	6	5	6	6	7	10	9	9	9	9	9	13	13	13	12	12	11
3	30	10	6	5	5	6	6	5	9	9	9	9	9	9	13	13	13	12	12	10
3	30	20	5	5	5	6	6	6	9	9	9	9	9	8	13	13	12	11	12	10
3	30	30	5	5	5	6	6	5	9	9	9	8	9	8	12	12	12	11	11	10
3	50	10	6	5	5	6	6	6	9	9	9	9	9	8	13	13	13	12	12	10
3	50	20	5	5	5	6	6	6	9	9	9	9	9	8	13	13	12	11	12	10
3	50	30	5	5	5	6	6	6	9	9	9	9	9	8	12	12	12	11	11	10
3	70	10	6	5	5	6	6	6	9	9	9	9	9	8	13	13	13	12	12	10
3	70	20	5	5	5	6	6	6	9	9	9	9	9	8	13	13	12	11	12	10
3	70	30	5	5	5	6	6	6	9	9	9	9	9	8	12	12	12	11	11	10
4	30	10	5	5	4	5	5	5	8	8	8	8	8	8	12	12	12	11	11	10
4	30	20	5	4	4	5	5	5	8	8	8	8	8	7	12	12	12	11	11	10
4	30	30	5	4	4	5	5	5	8	8	8	8	8	7	12	12	12	10	11	9
4	50	10	5	5	4	5	5	5	8	8	8	8	8	8	12	12	12	11	11	10
4	50	20	5	4	4	5	5	5	8	8	8	8	8	7	12	12	12	11	11	10
4	50	30	5	4	4	5	5	5	8	8	8	8	8	7	12	12	12	10	11	9
4	70	10	5	5	4	5	5	5	8	8	8	8	8	8	12	12	12	11	11	10
4	70	20	5	4	4	5	5	5	8	8	8	8	8	7	12	12	12	11	11	10
4	70	30	5	4	4	5	5	5	8	8	8	8	8	7	12	12	12	10	11	9

Table 3.1 (Concl)

(Overpressures (psi) for 10 percent Survivors, Initially Prone People

		WS	2	2	2	2	2	2	8	8	8	8	8	8	14	14	14	14	14	14
		AP	25	25	25	50	50	75	25	25	25	50	50	75	25	25	25	50	50	75
		SN	1	3	6	1	3	1	1	3	5	1	3	1	1	3	6	1	3	1
FL	HL	DA																		
1	30	10	11	11	11	13	13	15	13	13	13	14	16	16	16	16	16	16	16	16
1	30	20	11	11	11	13	13	15	13	13	13	14	14	15	16	16	16	16	16	16
1	30	30	11	11	11	13	13	15	13	13	13	14	14	16	16	16	16	16	16	16
1	50	10	11	11	11	13	13	15	13	13	13	15	15	16	16	16	16	16	15	16
1	50	20	11	11	11	13	13	15	13	13	13	15	15	16	16	15	16	16	16	16
1	50	30	11	11	11	13	13	15	13	13	13	15	15	16	15	16	16	16	16	16
1	70	10	11	11	11	13	13	15	13	13	13	15	15	15	16	15	16	16	16	15
1	70	20	11	11	11	13	13	15	13	13	13	15	15	16	15	16	16	16	16	16
1	70	30	11	11	11	13	13	15	13	13	13	15	15	16	16	16	16	16	16	16
2	30	10	10	10	10	11	11	13	12	12	12	13	13	14	14	14	14	14	14	15
2	30	20	10	10	10	11	11	13	12	12	12	13	13	14	14	14	14	14	14	15
2	30	30	10	10	10	11	11	13	12	12	12	13	13	14	14	14	14	14	14	15
2	50	10	10	10	10	11	11	13	12	12	12	13	13	14	14	14	14	14	14	15
2	50	20	10	10	10	11	11	13	12	12	12	13	13	14	14	14	14	14	14	15
2	50	40	10	10	10	11	11	13	12	12	12	13	13	14	14	14	14	14	14	15
2	70	10	10	10	10	12	12	13	12	12	12	13	13	14	14	14	14	15	15	15
2	70	20	10	10	10	12	12	13	12	12	12	13	13	14	14	14	14	15	15	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]	12	12	[illegible]	13	13	14	14	14	14	15	15	15
3	30	10	8	8	8	10	10	12	10	10	10	11	11	12	12	12	12	13	13	13
3	30	20	8	8	8	10	10	12	10	10	10	11	11	12	12	12	12	13	13	13
3	30	[illegible]	8	8	8	10	10	12	10	10	10	11	11	12	12	12	12	13	13	13
3	50	[illegible]	8	8	8	10	10	12	10	10	10	11	11	13	13	13	13	13	13	13
3	50	20	8	8	8	10	10	12	10	10	10	11	11	13	13	13	13	13	13	13
3	50	30	8	8	8	10	10	12	10	10	10	11	11	13	13	13	13	13	13	13
3	70	10	8	8	8	10	10	12	11	11	11	12	12	13	13	13	13	13	13	14
3	70	20	8	8	8	10	10	12	11	11	11	12	12	13	13	13	13	13	13	14
3	70	30	8	8	8	10	10	12	11	11	11	12	12	13	13	13	13	13	13	14
4	30	10	6	6	6	8	8	10	9	9	9	10	10	11	11	11	11	11	11	12
4	30	20	6	6	6	[illegible]	8	10	9	9	9	10	10	11	11	11	11	11	11	12
4	30	30	6	6	6	8	8	10	9	9	9	10	10	11	11	11	11	11	11	12
4	50	10	7	7	7	8	8	10	9	9	9	10	10	11	11	11	11	11	11	12
4	50	20	7	7	7	8	8	11	9	9	9	10	10	11	11	11	11	11	11	12
4	50	30	7	7	7	8	8	11	9		9	10	10	11	11	11	11	11	11	12
4	70	10	7	7	7	9	9	11	9	9	9	10	10	11	11	11	11	12	12	12
4	70	20	7	7	7	9	9	11	9	9	9	10	10	11	11	11	11	12	12	12
4	70	30	7	7	7	9	9	11	9	9	9	10	10	11	11	11	11	12	12	12

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WS - Exterior wall strength (incipient collapse overpressure), psi

AP - Aperture (window) percent

SH - Sill height, ft

FL - Floor level (story height)

BL - Building length, dimension parallel to the direction of blast, ft

DW - Distance to the first interior wall, dimension parallel to the direction of blast, ft

The strength of interior walls was taken as 1 psi for all cases considered.

Results given in Table 3.1 can be used for classifying peripheral spaces in framed buildings in terms of the six building parameters. For example, on the first story of a 70-ft long building, with a distance to the first interior wall of 30 ft, exterior wall strength of 8 psi, interior wall strength of 1 psi, 25 percent windows and a 1-ft sill; 90 percent of initially prone people are expected to survive at 8 psi. In the same building and on the same story, 90 percent of initially standing people are expected to survive at 5 psi. Corresponding values for 50 percent survivors are 10 psi and 8 psi, and for 10 percent survivors, 13 psi and 10 psi.

Regression analysis equations used in generating these results are given in Table 3.2. Numerical values (without parentheses) are coefficients which are associated with the various building parameters. Parameter "C" refers to the constant terms. For example, using these results the equation for free field overpressure at which 10 percent of initially standing individuals are expected to survive is written down as follows:

$$
\begin{aligned}
S(10) = {} & 6.40 + 0.0191\ AP - 0.7570\ FL - 0.0150\ DW \\
& + 0.1955\ SH + 0.2190\ WS + 0.0083\ (SH)(WS) \\
& + 0.0049\ (PA)(WS) - 0.0042\ (SH)(PA),\ psi
\end{aligned}
$$

In addition to the six building parameters, several combinations were used as indicated. Only those parameters which were found to be significant in the stepwise regression analysis are listed in

Table 3.2

EQUATIONS BASED ON STEPWISE REGRESSION ANALYSIS

Overpressure at Indicated Percent Survivors, psi S - Standing P - Prone	C	BL	AP	FL	DW	SH	WS	(SH)(WS)	(PA)(WS)	(SH)(PA)	R	S
S(10)	6.40		0.0181 (42)	-0.7570 (1745)	-0.0110 (55)	0.1955 (23)	0.2188 (170)	0.0083 (7)	0.0049 (384)	-0.0042 (50)	0.88	1.17
P(10)	10.05	0.0087 (37)	0.0803 (1301)	-1.7170			0.0201 (2)		0.0046 (340)		0.88	1.18
S(50)	5.05	0.0019 (4)	-0.0118 (17)	-0.2622 (232)	-0.0371 (411)	0.4988 (168)	0.0807 (26)	0.0221 (58)	0.0062 (695)	-0.0117 (421)	0.88	1.12
P(50)	1.84	0.0070 (54)	0.0748 (1295)	-0.6224 (1347)			0.2966 (502)	0.0027 (4)	0.0061 (698)		0.92	1.10
S(90)	5.19		-0.0243 (92)	-0.1212 (61)	-0.0349 (408)	0.3782 (120)	0.0368 (7)	0.0244 (88)	0.0026 (146)	-0.0092 (323)	0.76	1.00
P(90)	1.62	0.0019 (9)	0.0240 (217)	-0.2236 (381)	-0.0225 (309)		0.4804 (2372)	0.0271 (311)	0.0039 (624)	-0.0025 (94)	0.97	0.74

C - Constant term
BL - Building length, ft
AP - Aperture (window) percent
FL - Floor level
DW - Distance to first interior wall, ft
WS - Exterior wall strength, psi
PA - (100 - AP)
R - Correlation coefficient
S - Standard error of estimate

<u>Note</u>: Numbers in parentheses are statistical "F" values.

this table. For example, BL (building length) was found to be not significant for S(10) or S(90); SH (sill height) was found to be not significant for P(10), P(50), and P(90), etc. The level of significance of the various parameters listed is indicated by the numbers in parentheses. These are statistical "F"* values and their magnitudes indicate the levels of significance of associated parameters and parameter combinations. A ranking of building parameters based on the F values is given in Table 3.3. These are individual rankings for each of the six equations. It will be noted that story height (FL) is the most significant parameter in three of the equations. Wall strength (WS) is shown to be most significant in only one of them. This however is somewhat misleading since WS is also used in two combinations, i.e., (SH)(WS) and (PA)(WS). The latter parameter is fairly significant in all six equations.

In addition to parameter coefficients and F values, Table 3.2 also contains the correlation coefficients "R" and the standard errors "S", which can also be viewed as the standard deviations having units of psi. Since the size of the sample used in generating these equations was sufficiently large, magnitudes of S obtained reflect on the variability inherent in the analysis procedure as currently formulated.

3.4 DISCUSSION OF RESULTS AND CONCLUSIONS

Referring to Table 3.1, it will be noted that although this table has potential for applications, it also has a serious drawback. Out of six building parameters used, five are simple measurements which can be quickly estimated to any degree of accuracy. However, the sixth parameter, i.e., wall strength, is difficult to estimate except by highly experienced personnel. This applies to interior and exterior walls. Wall strength is not a commonly available parameter. Because of this, Table 3.1 would be difficult to use except on a research level.

*F test for equality of variances.

Table 3.3

RANKING OF BUILDING PARAMETERS

Overpressure at Indicated Percent Survivors, psi S - Standing P - Prone	BL	AP	FL	DW	SH	WS	(SH)(WS)	(PA)(WS)	(SH)(PA)
S(10)	-	6	1	4	7	3	8	2	5
P(10)	4	2	1	-	-	5	-	3	-
S(50)	9	8	4	3	5	7	6	1	2
P(50)	5	2	1	-	-	-	4	3	-
S(90)	-	5	7	1	4	8	6	3	2
P(90)	8	6	3	5	-	1	4	2	7

There are several other significant drawbacks to a classification system development approach which is not backed by a field data analysis effort. These are the following.

Table 3.1 was capable of being constructed because large framed buildings are for the most part quite uniform. Framing systems form regular grids. The strength of a framed building located in the Mach region of a nuclear weapon is for the most part dependent on the structural integrity of peripheral walls and the primary structure. For a given building these are generally quite uniform. Such uniformity is not usually found in combination framed and load-bearing buildings. Consequently a comparable table for this class of buildings and one which includes all relevant parameters is extremely difficult to construct at this time. Also, there is the previously mentioned problem of the strength of exterior and interior walls.

Basement spaces present a higher order of complexity. The class of possible overhead floor systems is large and the incipient collapse overpressure is not a commonly available parameter.

The development of a building classification system for best available shelter space should be preceded by a field data analysis effort. This should consider a sufficiently large and statistically valid sample of buildings, with each building adequately described in terms of geometry, structural system, types of structural members, connections, nonstructural components, and material properties. The sample should be broken down into subsamples in terms of all relevant descriptors. For example, steel framed buildings, arching wall buildings, wall types, etc. The field data analysis effort would seek to establish the following relationships.

- The influence of the variability of construction on strength
- The influence of the variability in material properties on strength
- The influence of observation and measurement errors in field data on strength
- The influence of all such variations on people survivability results

Such information would be used to eliminate all insignificant building parameters and provide the basis for ranking the remaining parameters in the order of significance. It would also provide the basis for constructing statistical distributions for various parameter classes. On this basis it would be possible to express survivability in terms of wall type (built-in masonry wall for example) rather than explicitly in terms of wall strength as was done in Table 3.1. The objective would be to eliminate explicit parameters such as wall strength, which are difficult to determine, and to express them implicitly in terms of parameters which are commonly available. We believe that this is possible.

At the present time DCPA has a statistically valid sample of 219 buildings described in terms of numerous relevant parameter categories (Ref. 3.2). Fifty of these buildings have been analyzed (Ref. 3.3) and a preliminary classification system has been formulated. In addition, Ref. 3.4 contains some sensitivity results on the behavior of walls. It is recommended that a study be initiated which would analyze the available field data so as to generate the information necessary for the development of a building classification and rating system. Such a study is believed to be timely, feasible and capable of producing usable results.

REFERENCES

3.1 Longinow, A., et al People Survivability in a Direct Effects Environment and Related Topics, for DCPA, Contract DAHC20-68-C-0126, Work Unit 1614D, IIT Research Institute, May 1973

3.2 Tolman, D. F., et al, Estimated Characteristics of NFSS Inventory - Final Building Classification Report, for DCPA, Contract DAHC20-72-C-0277, Research Triangle Institute, November 1972

3.3 Longinow, A., Survivability in a Direct Effects Environment (Analysis of 50 NFSS Buildings), for DCPA, Contract DAHC30-73-C-0227, IIT Research Institute, July 1974

3.4 Wiehle, C. K., All-Effects Shelter Survey, Summary of the Dynamic Analysis of 25 NFSS Buildings, for DCPA, Contract DAHC20-72-C-0315, Stanford Research Institute, March 1973

CHAPTER 4

FUNCTION LOSS ANALYSIS OF AN EMERGENCY OPERATING CENTER

This chapter describes the makeup and functions of Emergency Operating Centers (EOC's) and presents the results of an analysis which was conducted on an existing EOC to determine its "function loss" and people survivability when subjected to the direct effects of a single megaton-range nuclear weapon.

4.1 CHARACTERISTICS OF EMERGENCY OPERATING CENTERS

4.1.1 Functions of EOC's

The functions (Refs. 4.1 through 4.4) of state or local EOC's are some or all of the following.

- Receipt and dissemination of warning and warning instructions
- Direction and control of emergency operations of the political jurisdiction, including movement by people to shelter; operation of the shelter system; operation of emergency services such as police; fire, public works and health medical.
- Maintenance of contact with support EOC's for coordination of emergency activities within a political jurisdiction, with neighboring jurisdictions, and with other levels of government. Contact would also be maintained with any military units assigned to support the government concerned.
- Collection, collation, and analysis of radiation monitoring reports
- Provision of emergency information and instructions to the public and to nongovernment organizations
- Issuance of policies on the use of resources, in some instances expediting resources to the point of need, and requesting assistance of other levels of government to expedite deliveries of resources and provision of services to meet urgent needs.
- Possibly in larger communities, and at later times, the programming of resources, involving statements of resource requirements and the making of simple program determinations.

In the event of an emergency an EOC is manned by a staff consisting of support personnel and department heads of pertinent local government departments, e.g., mayor or town (village) manager, police chief, fire chief, manager of health services, etc. Local emergency measures are coordinated and put into effect by these people on the basis of existing contingency plans. The executive head of the particular government, usually with his civil defense director acting as coordinator, directs emergency operations.

4.1.2 Types of EOC's

EOC's are divided into two categories, i.e., qualified and interim. Qualified EOC's are those which met the basic functional requirements stipulated in pertinent "federal civil defense guides" (see Refs. 4.1 through 4.6). Interim EOC's are those which met some or none of these requirements.

Qualified EOC's are divided into two types, i.e., primary and support. The types and number of each type required depends on the nature and complexity of the emergency functions to be performed. This in turn depends on the size, geography, population distribution and other characteristics of the particular jurisdiction.

> Primary EOC -- A facility with fallout protection (minimum PF = 100) and the necessary staff and communications from which essentially all emergency functions are directed and controlled by the principal officials of the government. A state EOC would be in this category.
>
> Support EOC -- A facility with fallout protection (minimum PF = 100) and the necessary staff and communications to provide direction and control for one or more emergency functions. For example, police, fire or public works engineering. If properly organized, equipped and staffed, the Support EOC could serve as an alternate to the Primary EOC should it become inoperable.

4.1.3 Basic Elements and Requirements for Qualified EOC's

The basic elements of an EOC include:

(1) Fallout radiation protection

(2) Trained personnel to carry out essential functions

(3) Communications and warning capabilities
(4) Necessary equipment and supplies.

Requirements associated with each of these elements are described next.

The primary nuclear weapon induced hazard that is considered in the design of new EOC's and the refurbishing of existing buildings to serve as EOC's is fallout radiation although hardening to direct effects has been incorporated recently. Minimum acceptable protection factor (PF) is 100. This is achieved in a variety of ways, not all of them necessarily structural.

Recommended sizes of trained personnel staffs are discussed in Ref. 4.4. The staff size is used as a guide in determining gross floor area requirements. Eighty-five square feet per person is considered adequate. The minimum is 50 sq ft per person. For municipalities and counties of more than 300,000 population, special determinations of staff sizes are made.

A separate communications area is a requirement for a qualified EOC. Depending on the type of EOC, i.e., primary or support, it may contain all or some of the following communications and warning systems.

- State police radio
- Sheriff's department radio
- Citizens band radio
- Local government radio
- Local police radio
- Local fire department radio
- Standard telephone

The associated RX/TX (receiver/transmitter) may be located on the site or elsewhere. If located elsewhere a remote access is provided in the EOC.

There is no special provision as to the specific types of communication equipment required. A great deal depends on the function of the particular EOC and what the local municipality feels that it requires for its particular needs.

Other systems and equipment required by a qualified EOC includes power, fuel supply, emergency lighting, water supply, filters, heating, ventilation, sanitation and miscellaneous items.

Since commercial electric power might be knocked out, an engine generator is to be included. Engine generator set(s) should have the capacity to operate the following systems as a minimum:

- Ventilation and heating system(s)
- Lighting systems
- Water supply systems
- Sewage ejectors (if required)
- Communications and warning equipment
- Other EOC equipment, as determined essential

Engines can be either water- or air-cooled. Fuel storage facilities should be fire-safe and provide for at least a 14-day operation at full load. Supply of fuel through standard underground distribution mains is not considered reliable.

Emergency generators may be located inside or outside the EOC. If located outside, the generator need not be protected against fallout radiation. Protection against local weather conditions is required.

Potable water, essential for an EOC, may be obtained from an adjacent well, underground storage tanks, trapped water available in the building itself, or water stored in drums. Cutoff valves are required in the delivery system. Capacity of water storage is based on a minimum of 10 gallons per day per person for drinking, sanitary purposes, plus any requirements for mechanical equipment.

Where natural ventilation is not sufficient, a mechanical ventilation system capable of maintaining conditions necessary for continuous operation is to be provided. At least 15 cfm of circulated air per person should be provided, of which 5 cfm should be fresh air. Desirably, the environment in occupied spaces should be kept at 75°F and 50 percent relative humidity.

Filters to protect against entry of radioactive fallout are required. Outside air should pass through filters of the type normally used in commercial ventilation systems.

It is recommended that a qualified shelter analyst be retained in determining fallout protection requirements.

4.1.4 Structural Characteristics of Qualified EOC's

From a structural point of view it is very difficult to speak of a typical EOC. An EOC may be in a new building, a portion of which has been specifically designed for this purpose, or a refurbished, older existing building. Such buildings generally house also the local police department, sheriff's office, fire department or some other pertinent, local government department. Buildings are designed to effectively meet the essential functions at least cost. A typical structural system cannot be readily identified. However, judging by current construction practices it can be safely assumed that new buildings in most local municipalities will have one or two stories. Most will not have full basements. When basements are provided, a reinforced concrete foundation wall will most likely exist. It is not expected to extend beyond the ground surface. Structural systems may include the following: light steel frame, light concrete frame, flat plate system, load bearing or some combination of these. Since concrete or clay masonry still produce the cheapest general purpose wall, a great deal of masonry, both for exterior walls and interior partitions, is expected. Since the current trend is to large window areas, windows on the order of 30 to 50 percent of gross wall area are expected in upper portions but not in areas housing EOC's. Open web joists and precast concrete units are expected to dominate roof systems. Floors over the EOC's are expected to be of reinforced concrete. Cast-in-place flat plates and precast "Flexicore" type units are expected to be very common.

Older buildings converted to EOC's are expected to provide a broad class of different structural systems. Apparently a large number of such EOC's exist. The Illinois State EOC is located in an old "waterworks" building which was refurbished as an EOC.

4.1.5 Interim EOC's

As mentioned previously, in addition to qualified EOC's there exist so-called interim EOC's which include those failing to qualify in one or several of the requirements described previously. There is a large number of these. For example, in the eight northeast counties of Illinois there are 60 DCPA accredited communities of 5000 or more population. Of these, 20 have qualified EOC's, the remaining 40 have interim EOC's (Ref. 4.9).

4.1.6 Vulnerable Components of EOC's

In the light of the previously described functions of an EOC, its vulnerable components can be categorized as follows.

(1) Building or enclosure
(2) Staff (people)
(3) Communication systems
(4) Life support systems

This tabulation is not necessarily in the order of importance of the various functions to an EOC. Subcomponents of these categories are given in Figures 4.1 and 4.2.

The principal components of an EOC are communication systems and people. If people become casualties while the communications system is still operable, it is conceivable that in some communities a backup staff may be available to man communications. If only the communications system is damaged, the situation may be more serious since a vital function has been eliminated. Situations can be conceived where people and communications systems are of equal importance.

Casualties in an EOC can arise due to prompt effects of nuclear weapons, direct effects of natural hazards and secondary effects.

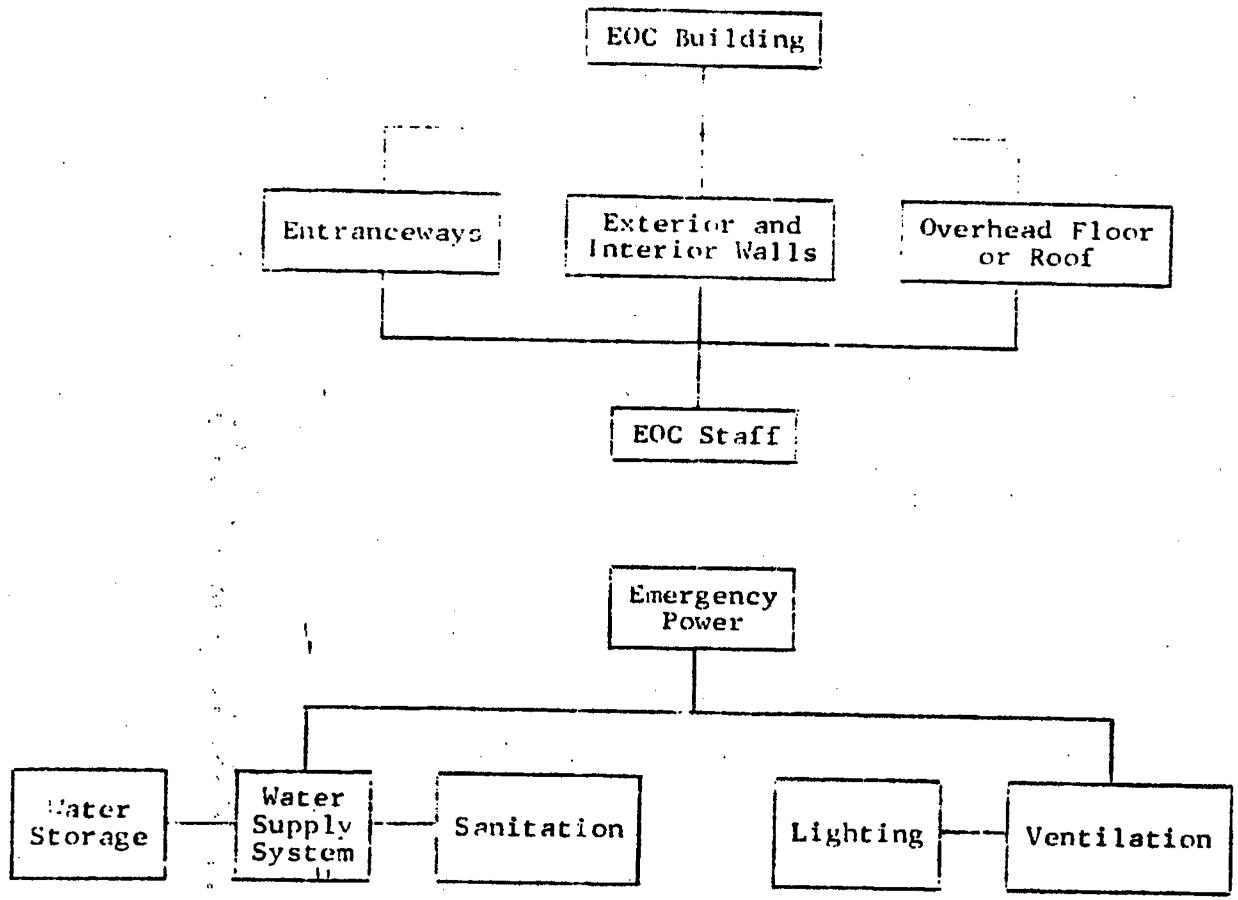


Figure 4.1 EOC Building, Staff and Life Support Systems (Vulnerable Components)

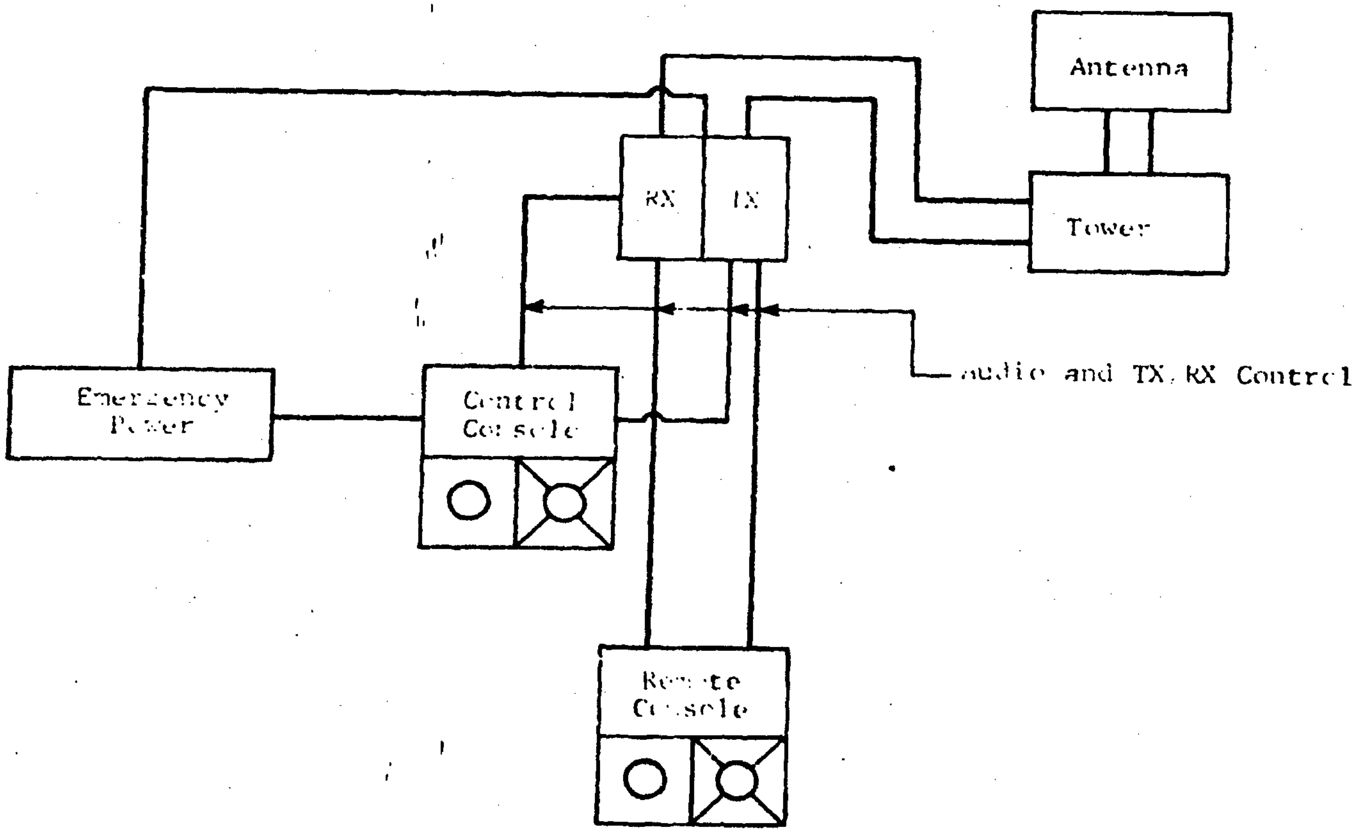


Figure 4.2 Vulnerable Components of EOC Communications System

Prompt effects of nuclear weapons include:

- Prompt nuclear radiation
- Blast effects
  - Translation and impact due to the high velocity winds entering the EOC
  - Impacts with debris from the breakup of the EOC structure

For the range of overpressure of interest, 1 to 15 psi, primary blast is not a problem. Also, since few direct apertures are expected, thermal radiation is not expected to be a problem.

Natural hazards such as earthquakes, local storms, hurricanes or tornadoes will produce primarily impact casualties as a result of building motions and debris. In some regions floods may be dominant.

Secondary casualty effects may be produced by fallout radiation, postevent fires, loss of food and water stores. In the light of primary effects the possible loss of food and water stores is considered as very secondary.

Damage to the communications system (see Figure 4.2) can be produced as a result of the following failures.

Emergency Power -- Emergency generators can be located within an EOC or outside. Special hardening provisions are not expected to be included. An engine generator will cease to function when it is moved off its supports, experiences damage to its leads, or internal components and loss of cooling capacity. This can be produced by debris, blast winds or both. Loss of fuel supply due to rupture of containers or supply lines will also eliminate its function until fuel can be restored. Loss of power can also result due to broken leads at the junction box to the building or within. Loss of emergency power, unless backup generators or batteries are provided, will make the communications system inoperable.

Communications System -- Other causes of communications system loss can be due to damage to the control console, transmitter/receiver, internal and external wiring, junction boxes, connections, antenna and antenna tower. Figure 4.2 illustrates a representative, though not necessarily typical, communications system. Power is provided to the control console and the TX/RX. Should damage be inflicted to the generator or its leads, the system would be inoperable. The system would also be inoperable if TX RX was eliminated, or the leads from TX/RX to the tower were severely damaged. This scheme has one redundancy, i.e., the remote access console. Should this be damaged, the main console could still be used or vice versa. In typical situations such a redundancy may or may not exist. Damage to, or total destruction of, the antenna is not necessarily fatal. Makeshift or substitute antennas may be used to bring the system up to some fraction of its capacity provided that other components are operable.

Major causes of damage, aside from EMP, will be due to structural failure, debris and high velocity winds. In relation to such failures four levels of structural response can be identified:

(1) Minor structural damage
(2) Moderate structural damage
(3) Major structural damage
(4) Total collapse

When blast overpressures are such that an EOC incurs only minor or no structural damage, associated building motions incurred by the blast impact are capable of displacing unattached equipment which may impact hard surfaces. All such dropped equipment will experience some damage. This will include pulled cords, damaged wires and cracked consoles. Solid state equipment should incur trivial damage. Vacuum tube equipment is subject to breakage of tubes or having them pop out of their sockets. A great deal of such damage can be eliminated by making an effort to secure (not necessarily shock-isolate) all loose equipment. At this level of structural response the probability of communication system survival is high.

When blast overpressures are such that an EOC structure experiences moderate damage, i.e., failed entranceways, yielded but not collapsed structural components; damage can be produced by associated dynamic pressures entering the EOC. Unattached equipment will be blown off and will experience impact damage as described previously. In this case other unattached equipment such as chairs, tables, ashtrays, etc. can become damage-producing missiles. For overpressures of interest, much of this damage can also be eliminated by securing all necessary equipment and personnel and removing all secondary equipment. At this level of structural response the probability of communications system survival can be moderately high.

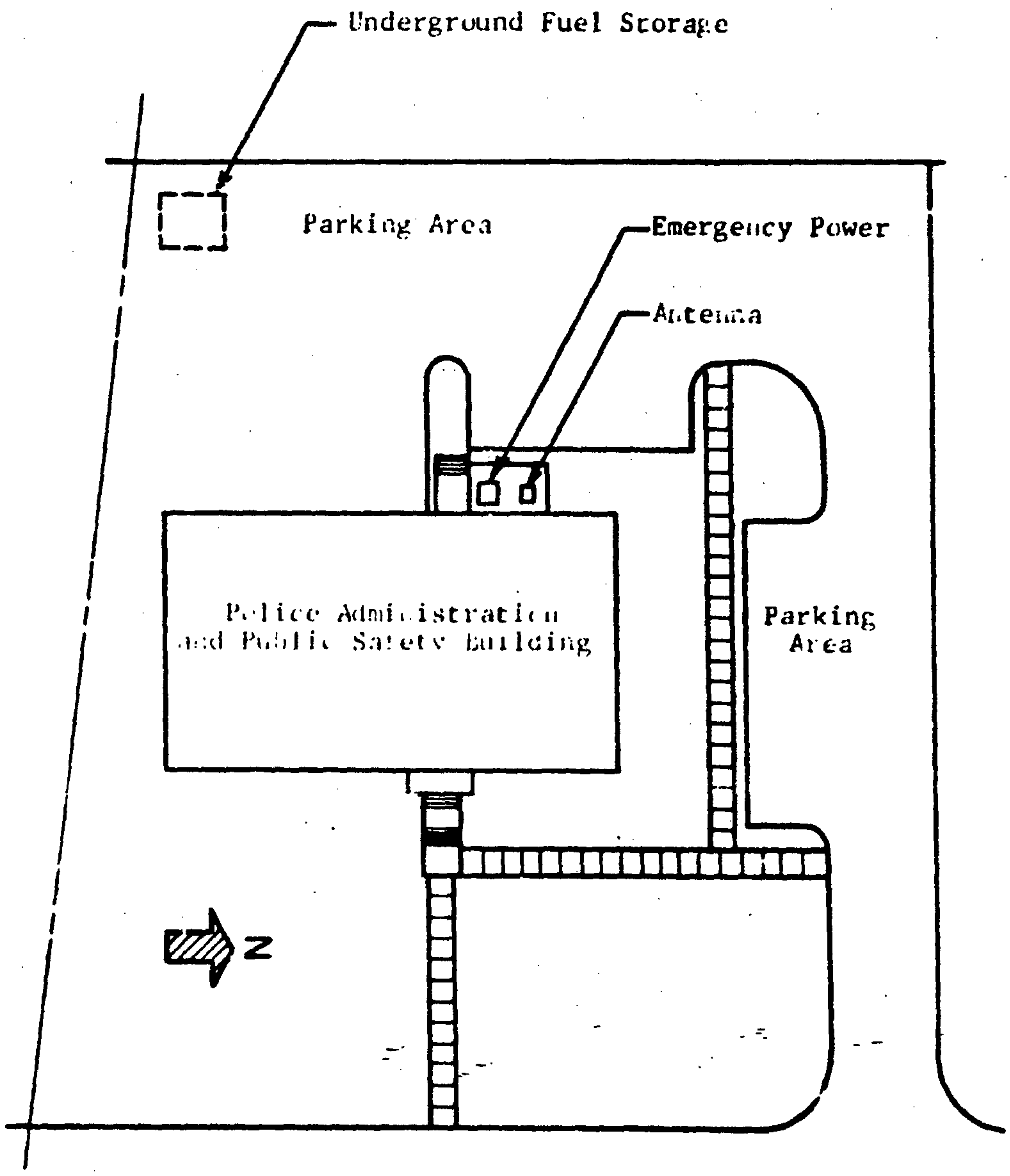
The blast environment which produces major damage to the EOC structure is also capable of producing major damage to communications equipment. Major structural damage would include partially collapsed walls and/or overhead slabs and entranceways. In this instance damage will be produced by gradual structural collapse, loose debris and blast winds. Since electrical leads pass through walls and/or ceilings, the collapse of these components can pull out and/or break such leads. This however is not a hard and fast rule. Cabling can pull out during the gradual collapse of a wall without causing major damage to the wiring system. Also, since structural members are generally not of equal strength, the collapse will be random and not complete. At this level of structural response the probability of communications system survival is expected to be moderately low. In some cases repairs may be possible.

When an EOC experiences total collapse, i.e., when no structural member remains on its original supports, the probability is very high that the communications system will be totally eliminated.

4.2 FUNCTION LOSS AND PEOPLE SURVIVABILITY ANALYSIS OF AN EXISTING EOC

4.2.1 Building Description

The Police Administration and Public Safety Building analyzed herein is located in the village mall which is a relatively large, park-like area that contains several other municipal buildings. A site plan for this building is shown in Figure 4.3.



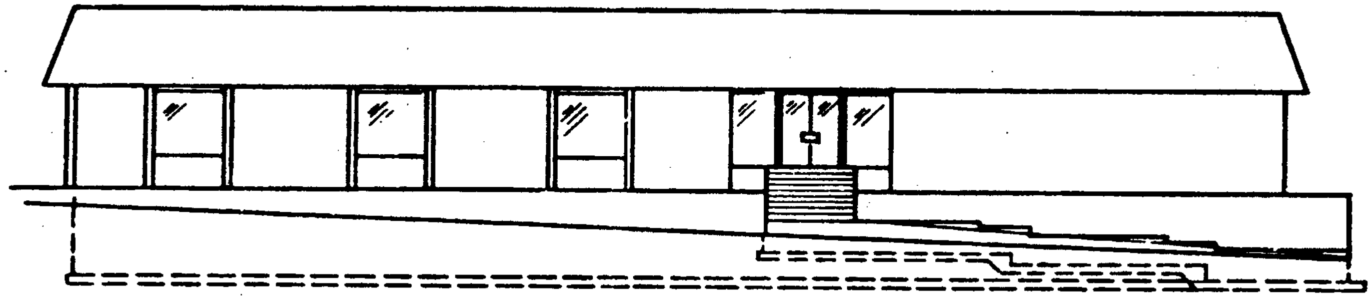
Scale: 1" = 40'-0"

Figure 4.3 Site Plan

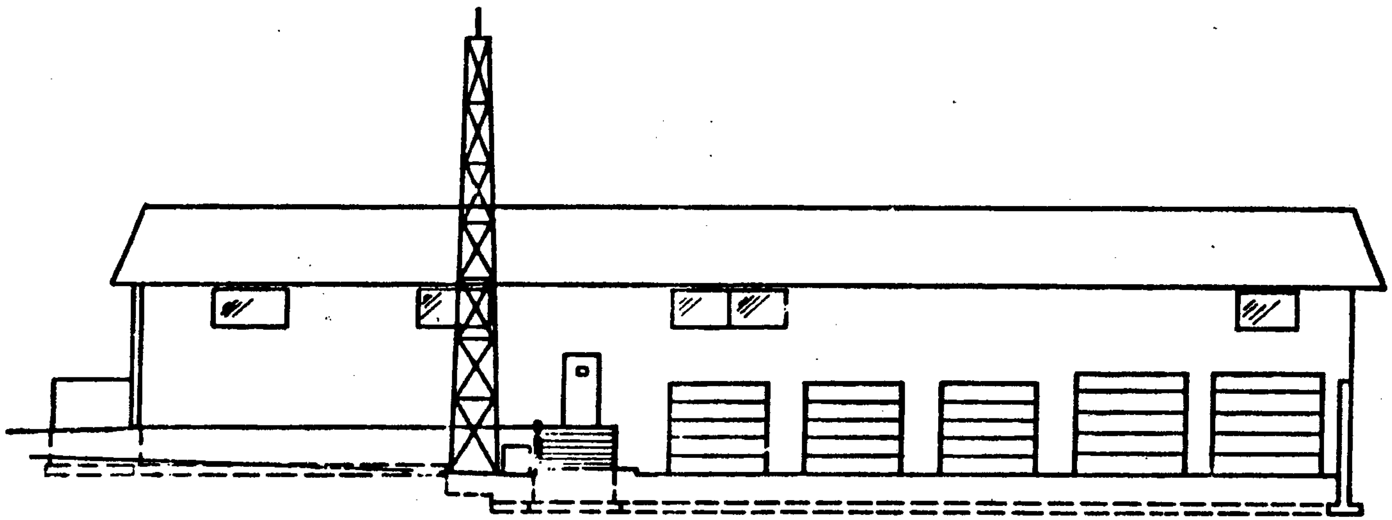
The building is a two-story, combination load-bearing and steel frame structure. It is rectangular and encloses approximately 13,400 sq ft of floor space. The four elevation views are shown in Figures 4.4 and 4.5. The main (front) entrance is located on the east side (see Figure 4.4a) and leads directly into the upper level. The upper level houses the police department; its administrative offices, communications center, squad room, interrogation rooms, prisoner cells, etc. A plan view of the upper level is not included herein. The lower level contains the EOC, garage, mechanical equipment room and pistol range.

An elevation, section, view through the building is shown in Figure 4.6. As shown in this figure, the roof system consists of open web steel joists supported on steel columns and peripheral walls. It is overlaid with cedar shakes. Exterior walls consist of hollow concrete masonry overlaid with face brick and or face stone. Interior partitions in the upper level are of concrete masonry and hollow metal construction. It will be noted that the lower level is partially below grade and partially exposed. It is essentially fully exposed along the west elevation (Figure 4.4b) and partially exposed along the north elevation (Figure 4.5a).

The floor system over the lower level is not at grade. The reinforced concrete (R/C) foundation wall on which it is supported along three sides extends approximately 1 ft-2 in. past the ground surface along the south elevation, 6 ft along the north elevation, 1 ft-3 in. along the east elevation and 6 ft along the north portion of the west elevation. Its thickness varies. It is 14 in. thick along the south elevation, 9.5 in. along the north and west elevations, and 12 in. along the east elevation. When extending beyond the ground surface, the thickness of the foundation wall is reduced by approximately 4.5 in. to accommodate a stone or brick facing. A typical section through the foundation wall and the lower level overhead floor system is shown in Figure 4.7. The floor system over the lower level consists of precast prestressed concrete units identified by the trade name of SPANCRETE. They are all 40 in. wide. Two thicknesses, 6 in. and 10 in. were used in this building. A typical unit is shown in Figure 4.7.



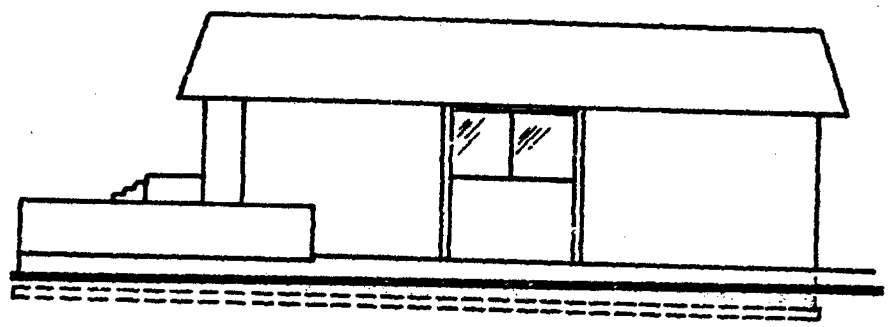
a. East Elevation



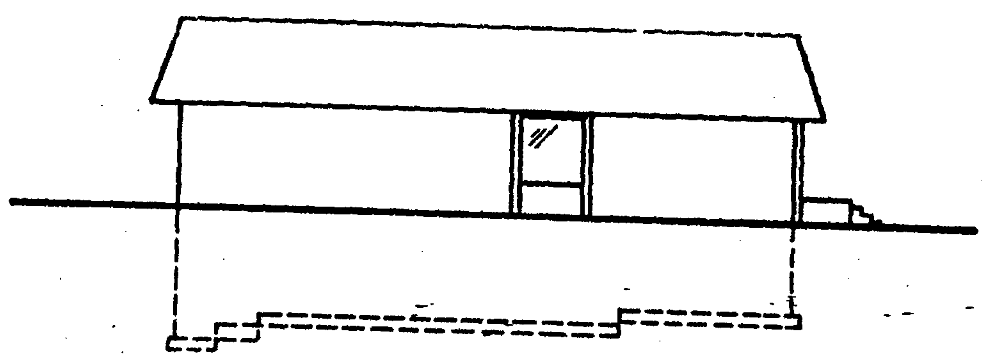
b. West Elevation

Scale approximately:
1/16 in. = 1 ft-0 in.

Figure 4.4 Building Elevations



a. North Elevation



b. South Elevation

Scale approximately:
1/16 in. = 1 ft-0 in.

Figure 4.5 Building Elevations

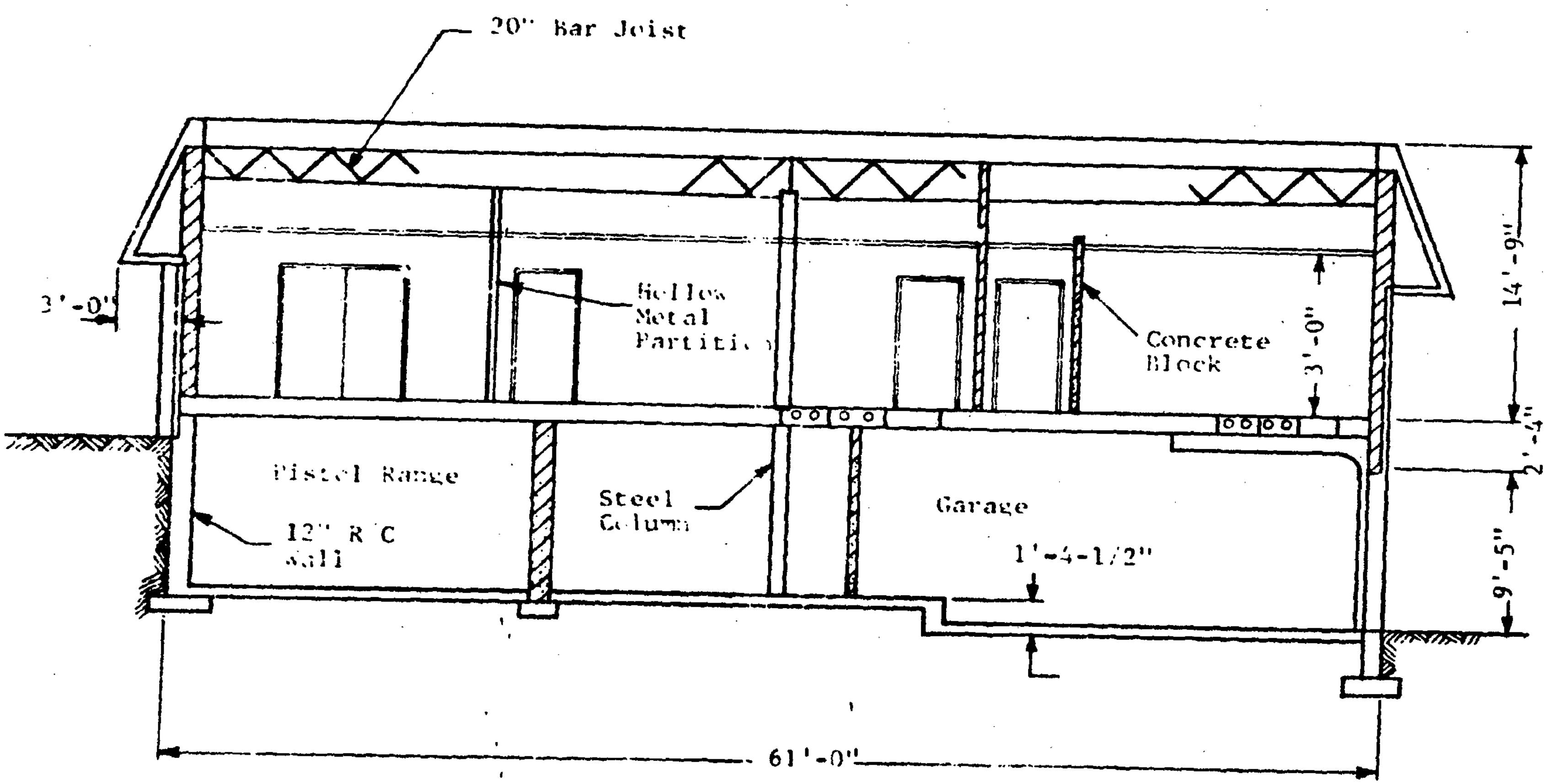


Figure 4.6 North-South Elevation Section
(See Figure 3.9 for location)

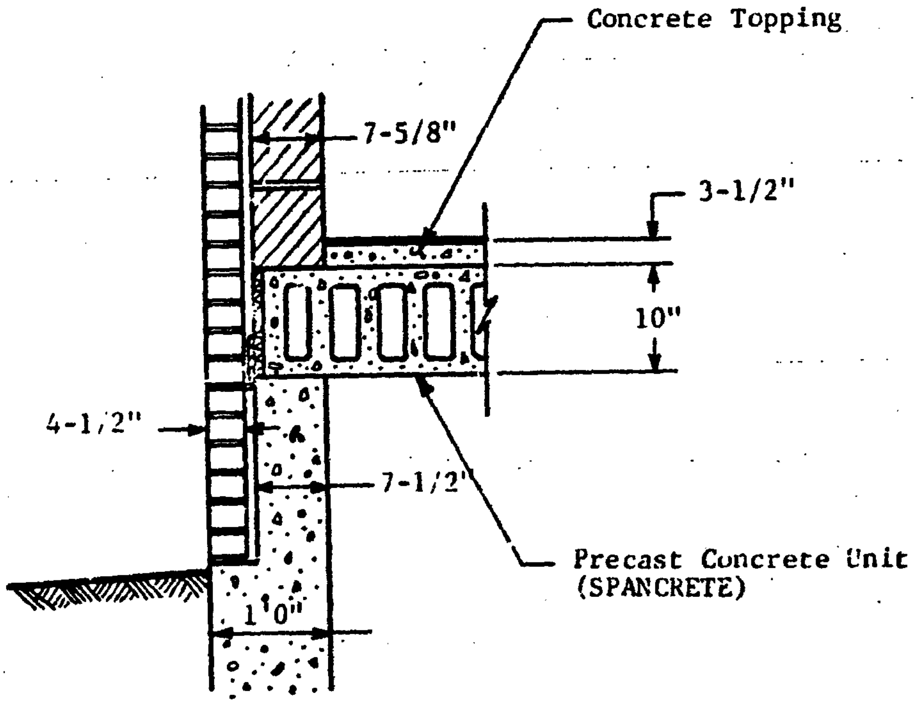
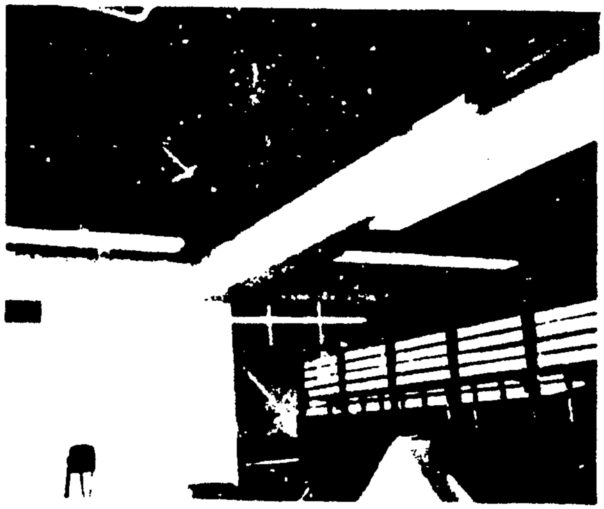


Figure 4.7 Section at South Wall First Floor

The units are also shown in Figure 4.8a and 4.8b which are two views of the garage. Figure 4.8a is a west view and also shows a civil defense emergency vehicle. Figure 4.8b is an east view of the same garage. The door on the extreme left (Figure 4.8b) leads to the EOC. The wall containing this door is of R/C. The other, larger door leads to the mechanical equipment room.

The lower level plan is shown in Figure 4.9. The area designated for civil defense (EOC) purposes is shown shaded. Room designations are given in Table 4.1. Partitions in the lower level are mostly of unreinforced concrete masonry. Two R/C walls separating the EOC from the garage area are provided (Figure 4.9). These are only lightly reinforced. Doors leading into the EOC are of standard hollow metal construction.

(a)



(b)

Figure 4.8 Garage Interior

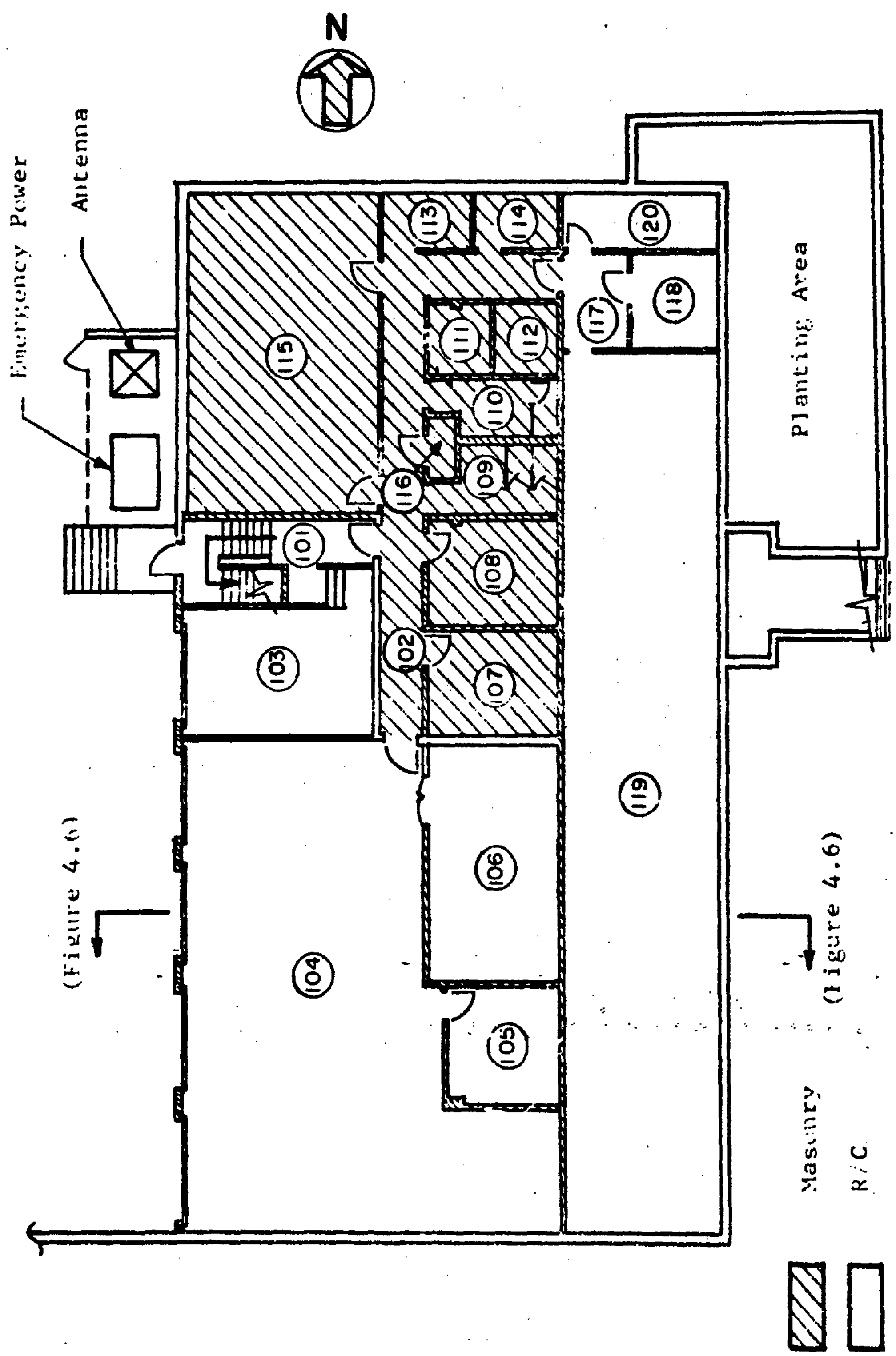


Figure 4.9 Lower Level Plan

Table 4.1

LOWER LEVEL AREA DESIGNATIONS (Ref. 4.7)

Room	Designation
101	Stair No. 1
102*	Corridor
103	Security Garage
104	Garage
105	Bicycle Storage
106	Mechanical Equipment Room
107*	Civil Defense Office
108*	Civil Defense Communications
109*	Women's Toilet
110*	Men's Toilet
111*	Civil Defense Kitchen
112*	Photography Laboratory
113*	Executive Office
114*	Electrical Center
115*	Training Room
116*	Janitor Closet
117	Vestibule
118	Control Room
119	Pistol Range
120	Storage

*Civil Defense Area Rooms

Figure 4.10 shows the framing system for the lower level. Member sizes are indicated. Spancrete units designated by letters A through D span as shown. Their sizes and ultimate flexural capacities for a uniform load are given in Table 4.2. In this table under 'Type', the first number refers to strand cover which in all four types is 0.75 in. The next set of numbers refers to the thickness of the given unit. The A unit is 6 in. thick, while the other three are 10 in. thick. The next number refers to strand diameter in number of sixteenths of an inch. Thus A and B units have 4/16 in. prestressed strand diameters, while C and D have 6/16 in. strand diameters. The last digits refer to the number of strands used. Units A and C have 8 and 12 strands respectively, B and D have 10 strands. Prestressing strands consist of seven helically wound high strength wires, ASTM A82-66.

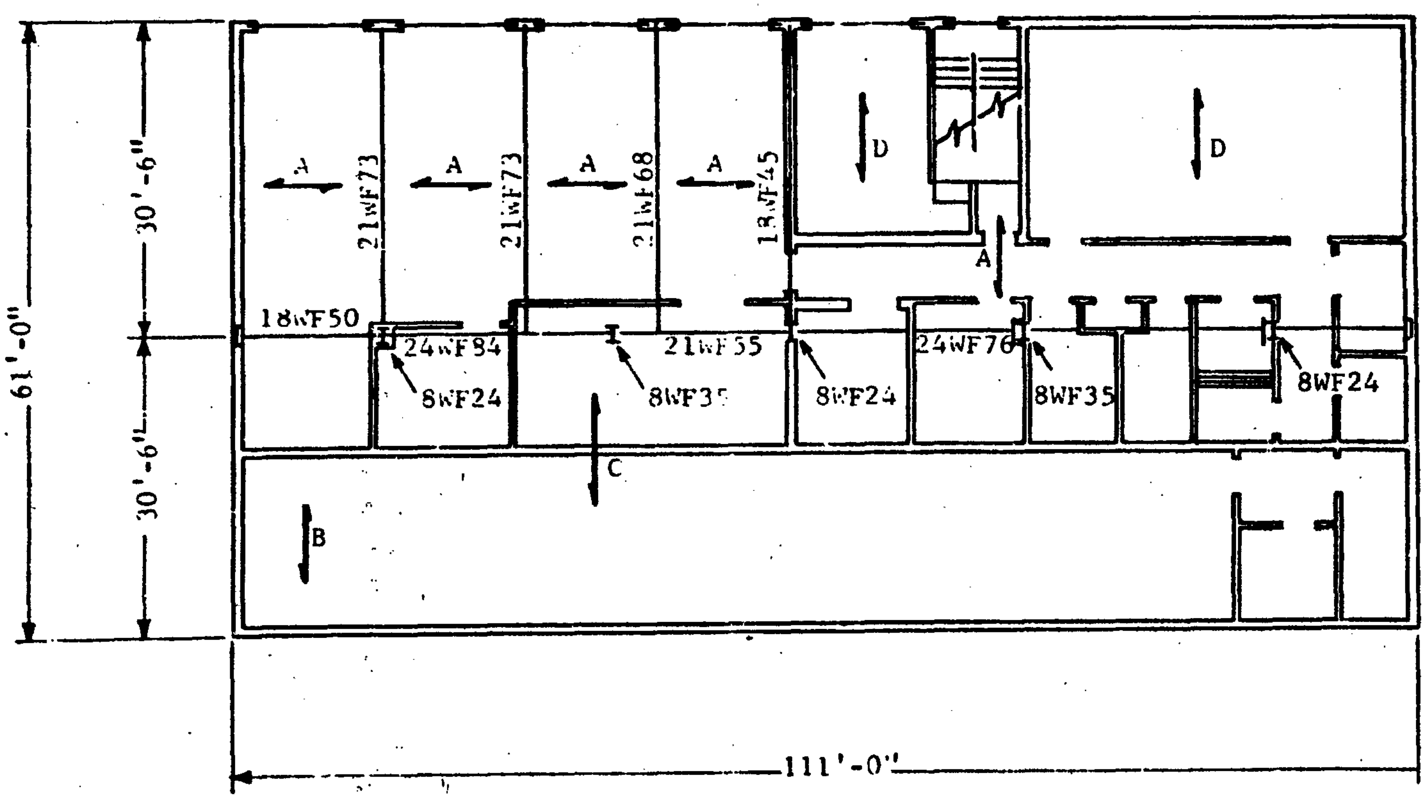


Figure 4.19 Lower Level Framing Plan

They have an ultimate strength of 250,000 psi and are stressed to 65 percent of capacity. Also under 'Type' in Table 4.2, 'T' indicates that a minimum of 2 in. of structural topping concrete is required with these units. Flexural capacity given was computed on the basis of increased thickness. The ultimate compressive strength of concrete used in the precast units is 4,000 psi. The units contain no shear reinforcement.

Table 4.2

SPANCRETE UNIT DESIGNATION (Ref. 4.8)

Symbol (See Figure 4.8)	Type	Flexural Capacity (M_u) kip-ft/ft
A	0.75-6408T	11.11
B	0.75-10410T	21.86
C	0.75-10612T	54.97
D	0.75-10610T	46.47

The ultimate compressive strength of the concrete used for the foundation wall, interior R'C walls, etc., is given as 3,000 psi (Ref. 4.7). Ultimate strength of structural steel is taken as 36 ksi (ASTM A36). Types of masonry used in the building are described as follows:

- Face Brick - ASTM C 216-66, Grade SM, Type FBS, "Fine Art Velour", 8 x 3.75 x 2.25 in.
- Concrete masonry - Hollow load-bearing units ASTM C90-66T, Type 1
  Solid load-bearing units ASTM C145-66T, Type 1

Roof Construction:

- Cedar shakes
- 2-in. lightweight insulating concrete
- 7/8 in. depth corrugated metal deck 24 ga (minimum three span)
- Open web steel joists, 20H6 and 20H5

4.2.2 Emergency Operating Center

The EOC is located in the lower level as shown in Figure 4.9 and occupies 1785 sq ft of floor space. As far as fallout radiation protection is concerned, it is effectively isolated and has a protection factor of over 100. No deliberate blast protection was included in the design. The EOC was designed to operate separately from the upper level. Thus its life support and communication systems are separate from that of the upper level and operate using conventional power under normal conditions, and emergency power when normal power fails.

An emergency power generated (35 KV Diesel, water cooled, Ref. 4.9) is located outside the EOC as shown in Figures 4.3 and 4.9. It is at grade and is fastened to a R/C slab. Aside from conventional sheet metal, shielding ordinarily used for externally located equipment, deliberate blast protection is provided. Fuel supply is located as shown in Figure 4.3.

Communications equipment contained in the police portion of this building is the following:

(1) Local police radio
(2) Local fire department radio
(3) Local government frequency radio
(4) Citizens band (23 channel) radio
(5) State Police radio receiver
(6) Sheriff's department radio receiver

At the present time only some of this equipment has been duplicated in the EOC. In the near future the entire system is expected to be duplicated.

The antenna tower (on which a local government and a citizens band antenna is located) is approximately 35 ft tall and is located as indicated in Figures 4.3, 4.4 and 4.9. Antennas were designed to withstand approximately a 100 mph wind. Auxiliary antennas are not provided at the present time but are in the budget for the coming year.

A view of the communications room is shown in Figure 4.11a. It will be noted that communication equipment; consoles, microphones, etc. is simply located on the shelves and not attached in any manner.

A view of the EOC kitchen is shown in Figure 4.11b. This photograph provides a description of typical masonry wall construction, suspended ceiling system and air supply registers.

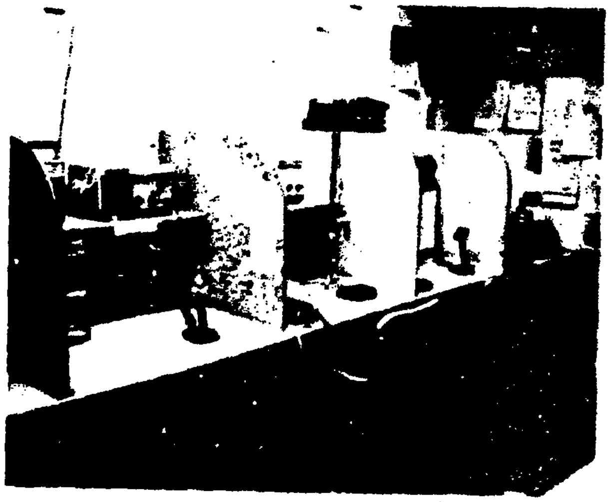
4.2.3 Blast Response Analysis

A blast-structure response analysis was performed on the subject building with the purpose of determining:

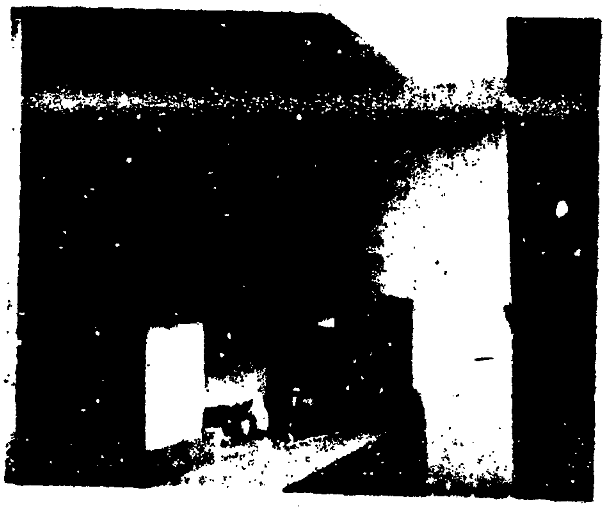
- the probability of function loss for the EOC
- survivability of people located in selected portions of the lower level which contains the EOC

As described in the previous section of this chapter, the upper portion of this building consists of load-bearing walls and a light interior steel frame. It has, on the average, 30 percent window openings. Exterior masonry walls have an estimated resistance of about [illegible] psi. For a megaton weapon at the range of 2 to 3 psi, the communication system in the upper level is expected to lose its function due to high velocity winds and debris from the breakup of the building and contents. This will also bring down exterior electrical lines and fail the antenna.

Resistance capacities of selected lower level walls are given in Table 4.3. Their location is as designated in Figure 4.12. Numbers given in this table are free-field failure overpressures. These are upper bound values and will hold as long as the indicated boundary conditions are maintained. Resistance capacities of the overhead floor system are given in Table 4.4. Corresponding rooms to which they apply are also indicated in Figure 4.12. Again, these are upper bound values and will hold as long as support conditions are maintained. However, since most walls have lower failure overpressures, portions of the floor system in proximity to these walls will also fail at approximately the wall failure overpressure.



a. Communications Room



b. EOC Kitchen

Figure 4.11 EOC Interior

Table 4.3

CHARACTERISTICS OF SELECTED WALLS*

No.	Description	Height (ft)	Width (ft)	Thickness (in.)	Material	Boundary Conditions	Estimated Free Field Failure Overpressure (psi)
1	Garage wall	10.00 & 9.00	3.4	12	4.5 in. brick, 7.5 in. CMU	Fixed top and bottom	1.2
2	Garage door	10.00 & 9.00	10.00 & 9.00	-	Steel, sectional	Simply supported	1.0
3	Pistol range wall	9.25	12.40	7-5/8	CMU	One-way arching	2.5
4	Storage room wall	11.10	12.40	5-5/8	CMU	One-way arching	1.7
5	Equipment room wall	11.10	25.03	5-5/8	CMU	One-way arching	1.7
6	South security garage wall	11.10	20.47	5-5/8	CMU	One-way arching	2.5
7	South civil defense office wall	9.25	14.23	12	R/C, #4 @ 18 in. each face, each way	Simply supported	6.5
8	West corridor wall	9.25	17.03	12	R/C, #4 @ 18 in. each face, each way	Simply supported	5.8
9	West civil defense office wall	9.25	10.90	12	CMU	One-way arching	5.0
10	West civil defense communications room wall	9.25	11.00	5-5/8	CMU	One-way arching	3.5
11	South stairwell wall	9.25	15.55	5-5/8	CMU	One-way arching	3.0
12	North stairwell wall	9.25	21.00	5-5/8	CMU	One-way arching	3.0
13	South communications room wall	9.25	14.23	3-5/8	CMU	One-way arching	4.0

*See Figure 4.12 for wall location.

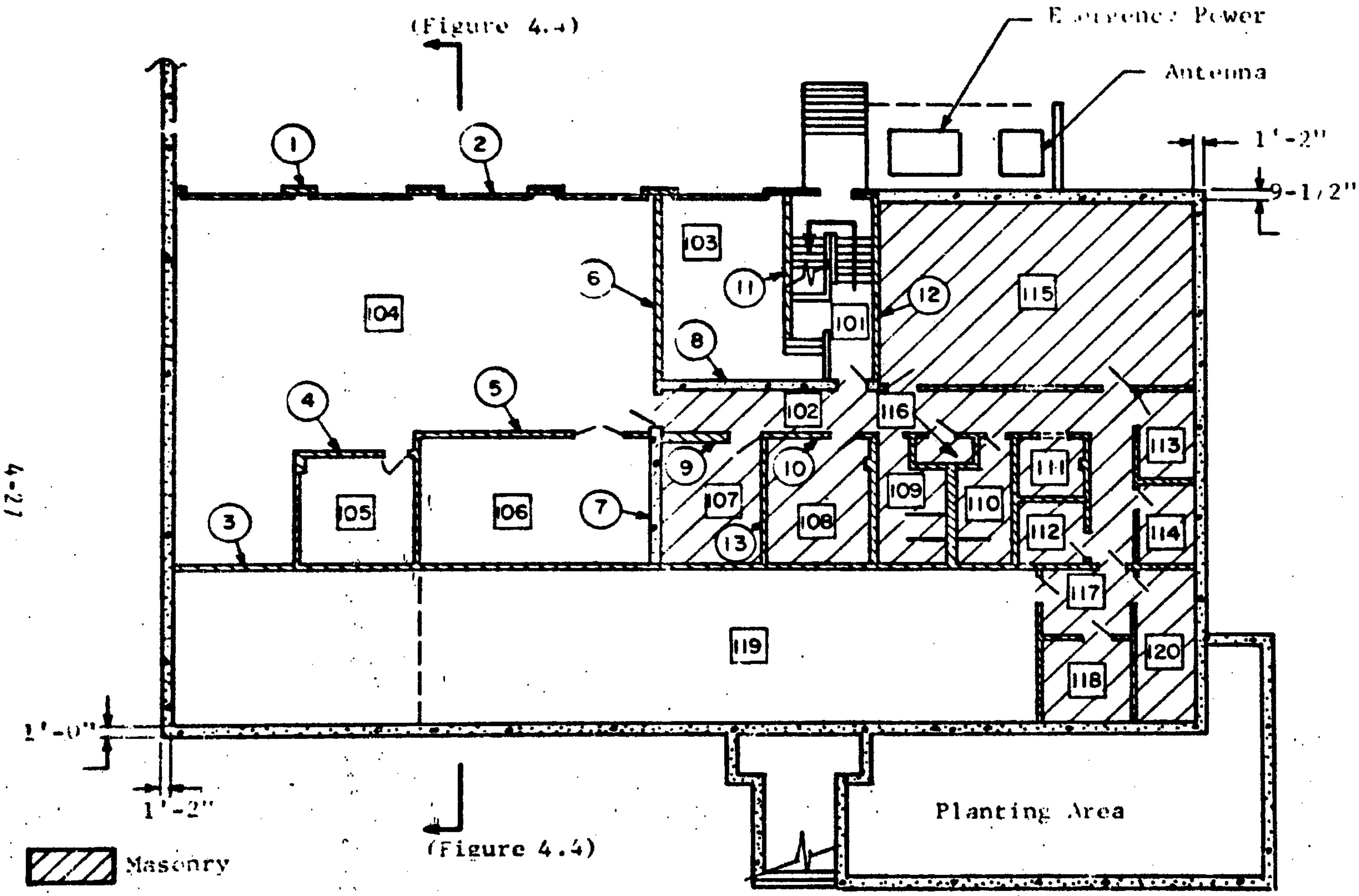


Figure 4.12 Lower Level Plan
(EOC Area is shown shaded)

Table 4.4

OVERHEAD FLOOR SYSTEM FAILURE OVERPRESSURES

Number	Description	Estimated Free Field Failure Overpressure, psi
102	EOC Corridor	25.0
103	Security Garage	4.0
104	Garage	2.0
105	Bicycle Storage	5.8
106	Mechanical Equipment Room	13.5
107	Civil Defense Office	13.5
108	Civil Defense Communications	13.5
109	Women's Toilet	13.5
110	Men's Toilet	13.5
111	Civil Defense Kitchen	25.0
112	Photography Laboratory	25.0
113	Executive Office	13.5
114	Electrical Center	13.5
115	Training Room	4.0
116	Janitor Closet	25.0
117	Vestibule	7.5
118	Control Room	7.5
119	Pistol Range	7.5
120	Storage	7.5

The strength of the floor system over the main garage area is dictated by the strength of the wall containing the garage doors. This is expected to fail at about 1.2 psi. When this happens the majority of the floor over the garage will come down and will thus preclude the use of the emergency vehicles should they be located within.

The wall enclosing the mechanical equipment room (wall 5, Figure 4.12) is expected to fail at about 1.7 psi. The estimated probability of mechanical equipment function loss is 10 percent at this overpressure level. At 2.5 psi this wall is expected to fail catastrophically. The wall directly opposite to it (wall 3, Figure 4.12) will be at the point of incipient collapse. The failure of these two walls will also bring down a portion of the overhead floor system. Mechanical equipment is expected to be badly damaged. Function loss is estimated to be 90 percent at 2.5 psi.

The antenna is expected to be lost at 2.2 psi. However, since an emergency antenna can be implemented, function loss is estimated at 10 percent.

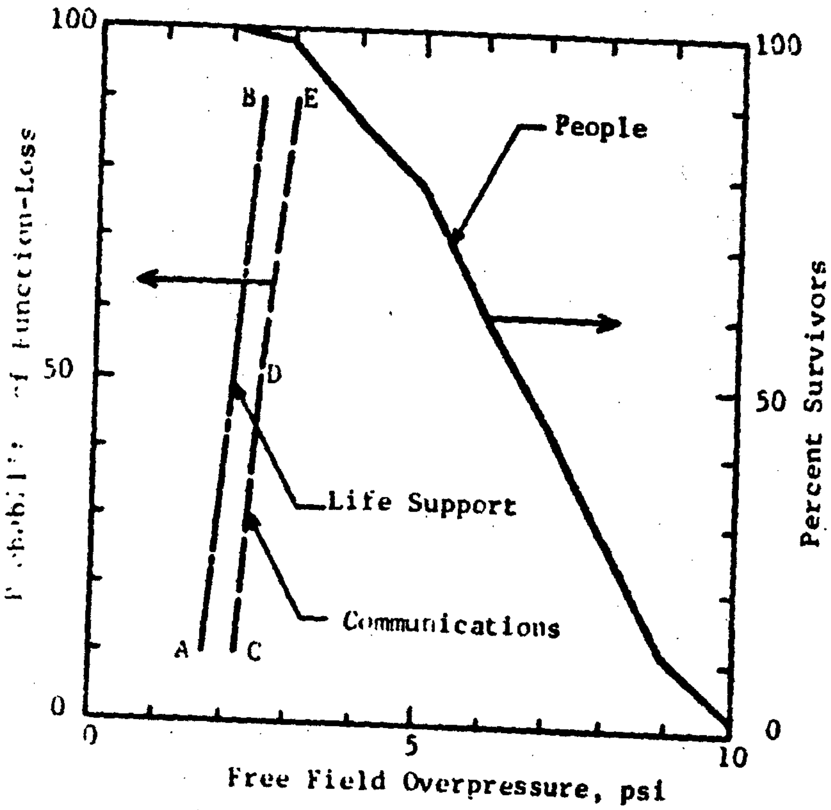
Hollow metal doors leading into the EOC are expected to fail and collapse at about 2.5 psi. Since the door leading into the communications room (room 108, Figure 4.12) opens inward, it provides no resistance to the associated blast winds. Communications equipment is unsupported and will most probably be blown off the shelves and tables. The probability of communications system function loss at 2.5 psi is estimated at 50 percent.

Emergency power is expected to be lost at about 3 psi due to rupture of the fuel line connection leading to the generator which is located outside and is unshielded. Probability of function loss at this overpressure is estimated at 90 percent.

The people survivability analysis is based on the assumption that people are uniformly distributed in all EOC rooms including room 119, i.e., the pistol range. Primary casualty mechanisms considered include debris and translation due to blast winds. Results of the analysis are summarized in Figure 4.13.

4.3 THE EMP PROBLEM

Under the proper circumstances a significant portion of the energy released during a nuclear detonation can be made to appear as an ElectroMagnetic Pulse (hence, EMP) having the same frequencies or wavelengths as those employed by most of our commercial radio and military system equipment.



A Light damage to mechanical equipment

B Severe damage to mechanical equipment

C Loss of antenna

D Moderate damage to communications equipment (consoles, wiring, etc.)

E Loss of emergency power

Figure 4.13 EOC Survivability Estimate

Two unique properties of EMP are of crucial significance -- its extremely great "killing range", EMP being capable of disabling electrical and electronic systems as far as 3000 miles from the site of the detonation; and the fact that EMP can cause severe disruption and sometimes damage when other prompt weapon effects such as nuclear radiation, blast, thermal radiation, dust and debris are all absent at the location of interest. This means that a high-yield nuclear weapon, burst above the atmosphere, could be used to knock out improperly designed electrical and electronic systems over a large area of the earth's surface without doing any other significant damage. The range of EMP is greatly diminished if the weapon is detonated within the atmosphere.

A typical high-level, high-altitude nuclear burst can produce an EMP which is about ten million times stronger than all the electrical fields in a typical metropolitan area. The voltages and currents induced in conductors by the EMP can burn out equipment and components or cause temporary malfunctions. Semiconductors are much more susceptible to EMP than vacuum tubes.

4.3.1 Communications

The facility's communications systems are extremely vulnerable to EMP because no EMP protection has been incorporated. There is no all-encompassing metal shield, therefore the transmitters, receivers, coaxial cables, power cables, etc. are subject to having large voltages and currents induced into them from the EMP. In addition, the transmitting and receiving antennas can pick up large amounts of EMP energy which can be fed directly to the transmitters and receivers. Special filters in the antenna transmission lines could prevent this part of the problem. Since most of the facility's communications equipment uses semiconductors rather than vacuum tubes, the system is very susceptible to antenna-coupled EMP energy.

4.3.2 60 Hz Electrical Power

Most of the 60 Hz electrical power system is less susceptible to EMP than the communications system. However, even such items as the generator could be damaged if enough energy is coupled into it.

For the electrical power system, the cables are subject to high EMP-induced voltages and currents. Semiconductor control elements are extremely susceptible to damage. Relays are less so, but can have their contacts welded or burned out by EMP energy. For example, the automatic change-over relay, which automatically shifts input power from commercial power lines to the standby diesel generator, is subject to all the EMP energy picked up by the commercial lines. Since the amount of EMP energy picked up is a function of line length, the long lines between the facility and the commercial generating station can collect great amounts of energy.

4.3.3 Life Support

The life support items, such as water and sewage lines, air intakes and exhausts, gas lines, etc. are also subject to EMP. If conductive, they can gather EMP energy and conduct it to sensitive equipment.

4.3.4 Telephone and Burglar Alarm Lines

The telephone lines enter the building through conduit. Circuit protection is provided by the telephone company primarily to guard against the effects of lighting. Ungrounded or poorly-grounded conduit can permit EMP to be coupled to sensitive equipment. The lightning protection circuitry may or may not provide sufficient EMP protection.

The burglar alarm lines also enter the building through conduit but no EMP protection devices are provided; therefore, these lines are also subject to EMP pickup.

4.4 PROTECTION DESIGN ALTERNATIVES TO MINIMIZE EMP DAMAGE

The performance of civil defense mission responsibilities by the typical emergency operating center depends on continuous availability of electrical power (whether from the utility company or the emergency diesel generator) to operate essential communication equipment. With the present electrical and communication system arrangement, the operational survivability probability after exposure to a nuclear detonation (assuming that equipment survives blast effects) is quite low. The utility electrical service will most likely cease. Normally operated communication transceivers (police equipment) which are of recent, solid state design [redacted] will undoubtedly sustain EMP damage. Available civil defense communications equipment is of the vacuum tube design which is inherently less vulnerable to EMP damage and has a higher probability of survival. Incoming telephone lines are connected to carbon surge arrestors to protect circuitry from transient voltages induced by lightning. Although response times of normally employed lightning arrestors are not fast enough to limit the peak voltage that can be expected from EMP to the lightning design breakdown voltage, some measure of protection will be realized. Whether this protection is adequate cannot be ascertained without appropriate tests.

Since telephone lines are provided with surge arrestors which may be adequate to meet the level of protection desired for such a facility as this, no reference to telephone lines will be made in the discussion on EMP protection.

To increase the probability of operational survivability of the facility, three practical alternatives of varying levels of protection are available. The first involves the incorporation of a shielded shelter and protection components (surge arrestors and filters); the use of surge arrestors, filters and disconnect switches is the second alternative. The third makes use of just protection components.

4.4.1 First Design Alternative

The first alternative which employs the use of a shielded shelter (room) offers the highest level of EMP protection practical for this facility. The shielded shelter which could be installed in the existing lower level communication room or other suitable area would be used to house all communication transceivers. Within this enclosed shielded environment, the transceivers will be much less vulnerable to EMP. For the shielded room to be effective, all cables (antenna, electrical power and control) entering or leaving the shielded room should be connected to properly installed protection components, surge arrestors and filters. Surge arrestors (amplitude limit) and filters (frequency limit) serve to attenuate any EMP that is coupled on these cables to tolerable levels. Also, shielded room apertures, doors and air vents must be designed so as to maintain electrical continuity and not degrade the shielding performance. With the proper treatment of cables and shielded room apertures, a shielded environment is achieved in which the probability of survival of transceivers is increased by orders of magnitude over the present arrangement.

Survivability of communication transceivers is of no mission value if electrical power is not available for their operation. Therefore the increase in probability of transceiver survivability should be matched by an increase in survivability of the 60 Hz power system. Survivability of the 60 Hz power system from EMP can significantly be increased by the effective installation of surge arrestors and filters on the primary side of the utility input transformer.

The protection design alternative just outlined provides the best probability of survival that can practically be considered (relative to economy and facility mission) for the facility.

4.4.2 Design Alternative Two

Whereas in the first alternative a volume of protected space was provided to protect communication transceivers, the second alternative is to protect all or selected transceivers individually. Protection of individual transceivers would involve the use of surge arrestors and filters on entry cables (antenna and electrical power) to prevent conduction of collected EMP to sensitive circuit components. This protection could take the form of junction boxes, containing the necessary protection components, properly adapted to transceiver connectors.

In addition to surge arrestors and filters, suitable antenna disconnect switches can be provided so that if an attack alert is given, switches of selected transceivers (those not being used to carry out necessary communications) can be opened to minimize coupling of antenna collected EMP.

The 60 Hz electrical power system under Alternative Two would also employ surge arrestor/filters on all input lines (transformer primary side) to minimize damage to sensitive circuit components. As with the antenna disconnect switches, if an attack alert is given, an additional measure of protection can be provided by the use of a suitable disconnect switch (possibly the use of surge arrestors also) at the utility feeder pole. Upon receipt of an attack alert, the procedure followed would be to open the disconnect switch at the feeder pole and switch to diesel generator power. With the opening of the disconnect switch at the feeder pole, the facility's electrical system is isolated from the public utility network which can be a large collector of EMP energy. Thus, with the proper use of surge arrestors, filters and disconnect switches, probability of operational survivability is significantly increased over the present existing system configurations.

4.4.3 Design Alternative Three

The third alternative employs the use of surge arrestors and filters as in the second protection alternative but deletes the use of disconnect switches. This arrangement offers somewhat of a lesser probability of operational survival than the second alternative because of disconnect switch deletion. However, this second alternative protection advantage only exists because a warning prior to an attack is assumed which provides the necessary time to open disconnect switches. The validity of such an assumption is a matter of conjecture and given scenario. As a result, if no warning is given, alternatives two and three offer the same probability of operational survivability. The best approach to the EMP problem is to assume no warning and make the EMP protection design scenario independent.

4.4.4 Lightning Aspects

The incoming telephone lines incorporate standard telephone company lightning protection devices. It is assumed that the commercial 60 Hz power lines are similarly protected as standard practice by the utility company. The diesel emergency generator does not require lightning protection since its power lines are short and will not pick up much energy.

Lightning protection should be incorporated into the antennas by ensuring that the antenna towers are grounded properly to the earth and that spark-gap type lightning arresters are installed at points where antennas connect to their transmission lines.

4.5 CONCLUSIONS AND RECOMMENDATIONS

(1) The typical police administration and public service building that was chosen is a well designed and a very functional structure for the purpose intended. The EOC is located in the lower level and both physically and functionally it is fairly well isolated. If fallout radiation is the primary and only threat then this EOC should perform its function with a high degree of confidence. However, when it concerns blast this structure is expected to provide very little protection as discussed previously and illustrated in Figure 4.11. A building concept in which the basement is partially below and partially above grade if a very poor choice for a blast environment. It is especially poor if the wall enclosing the exposed portion of the lower level

is weak. In this particular case the wall enclosing the exposed portion of the lower level contains five overhead garage doors. These, by the nature of their construction are very weak when subjected to blast pressures. Had the basement been designed to be entirely below grade the situation could have been greatly improved.

The lower level exposure along the west elevation (Figure 4.4b) is the major weakness of this structure. Very little can be done at this time to enhance its strength without resorting to a major building retrofit effort. One approach would be to replace masonry walls 3, 4, 5, 11 and 12 (see Figure 3.12) with R/C walls, and replace the three doors leading into the EOC with more substantial, blast resistant doors. It would also be necessary to increase the strength of the floor system over room 115 (see Figure 4.12) by cutting the span, provide protection for emergency power, secure all communications equipment, remove the suspended ceiling, and provide an emergency antenna. This is obviously a costly undertaking.

In a crisis period the survivability of this EOC may be somewhat enhanced by providing baffles in the entrance area, securing communications equipment, removing the suspended ceiling, providing an enclosure for emergency power and obtaining a backup antenna. It may also be useful to cut the span length of the overhead system in room 115 by the use of timber beams and columns. These measures will help in extending the communications function though not necessarily the life support system. The basic problem is that this EOC has too many structural weaknesses for any hastily implemented measures to be very effective.

(2) There are many areas in which reliable information is required for the planning of effective civil defense options in a crisis period. Two basic areas include EOC's and personnel shelters. For purposes of planning the continuity of government and community the civil defense planner needs to know how each of the EOC's in his area is expected to function and survive when exposed to a probable attack condition. At the same time for the purpose

of saving lives, he needs to know what shelter spaces exist in his area and what their life saving capabilities are. The problem of classifying shelter spaces in terms of their life saving potential has been considered. At the present time, at least basic information on the protective capabilities of conventional buildings is available. Some of this is discussed in the preceding chapter of this report. When it concerns EOC's, parallel information does not exist. This EOC is the first to be analyzed in any detail relative to prompt effects of nuclear weapons.

The civil defense planner at any level knows, or at least has access to, information as to what functions EOC's in his area are capable of performing, what equipment they contain and what level of fallout protection exists in each. He has no knowledge on how long and how effectively these EOC s will function when subjected to direct effects produced by nuclear weapons. Without such information it is extremely difficult to plan and assign functions to the various EOC's without introducing costly redundancy in the system as a whole. There exists a need for technical guidance capable of

- predicting the survivability of EOC s when subjected to a range of nuclear weapon environments
- providing basic information on how existing EOC's can be strengthened (retrofitted) in a crisis period at little or no cost
- providing information on how EOC's can be designed and equipment implemented so that functional survival to some acceptable level is assured.

Before guidance in any one of these areas can be developed it is our opinion that a field survey of existing EOC's is required. The purpose of such a survey would be to establish the characteristics of existing EOC's, i.e., structural parameters, life support equipment, communications equipment, staff functions. Once the results of such a survey become available, technical guidance in each of the three areas can be developed.

The field survey should consider approximately 100 EOC's appropriately distributed in, and representing each DCPA region. Data collected should include the following categories.

EOC EVALUATION DATA REQUIREMENTS

(1) General Information

Location of facility in which EOC is housed

Date built

Type of facility (police station, fire department, EOC, etc.)

Single or dual purpose

Location of EOC in facility (basement, upper stories)

Number of stories in facility

Fallout protection factor

(2) Building Vicinity

A sketch (plan view) describing the immediate site on which the EOC is located. This should include pertinent neighboring buildings, types and plan dimensions; objects that can be turned into hazardous debris; trees, etc., and separation distances.

(3) Building Geometry

Number of stories and average height per story

Plan of parent building (appropriately dimensioned with major building components identified).

Plan of EOC (appropriately dimensioned with major structural components identified)

Elevation views (drawings and photographs)

Aperture sizes in each elevation.

(4) Structural

Type(s) of structural system(s)

Materials of construction and where used

Overhead floor system(s): type, thickness, aspect ratios, support conditions, reinforcement percentages

Reinforced concrete members (beams and columns): sizes, spans, support conditions, reinforcement ratios

Steel members (open web joists, beams, columns): sizes, spans, support conditions, steel types

Walls (exterior and interior): materials, sizes, thicknesses, hollow or solid, reinforcement ratios, support conditions

Doors (overhead or standard, exterior or interior): materials, sizes, thicknesses, hollow or solid, is door window provided? If standard, indicate if the door opens in or out.

Types of suspended ceilings in EOC area

(5) Emergency Power

Location of unit(s) (indicate on plan sketch or drawing)

Type of unit (size, capacity, trade name, description)

Supports (mounting) - number of bolts, bolt size and spacing. Indicate if shock-isolated.

Location of fuel supply (indicate on plan sketch or drawing).

Types of fuel containers and fuel delivery system.

(6) Communications and Warning System

Provide a sketch of the communications network superimposed on the EOC floor plan and site plan if applicable. Include a list of communication systems, i.e., local police radio, citizens band radio, etc.

Identify and describe the physical units and indicate mounting conditions.

Describe antenna and antenna tower.

(7) Life Support Systems

Provide a sketch of the major components of electrical, ventilation, water supply and sanitation systems superimposed on the EOC floor plan and parent building plan if applicable. Briefly describe the major physical units (water storage tanks, etc.) and their location.

Much of the information indicated above will be available in the regional offices for qualified EOC's. However such information may not be complete for the following reasons.

- In cases where an EOC is part of an older building, necessary information on the parent building may not be available in the regional office.
- Many of the EOC's were constructed some time ago, and since then changes could have been implemented which may or may not be reflected in the original plans.
- In cases where the major components of the communication system are located in buildings other than the EOC, information on these buildings may not be available in the regional office.

For these reasons, and probably others can be cited, a field data collection effort is not only desirable but necessary.

REFERENCES

4.1 "Development of Emergency Operating Centers", Federal Civil Defense Guide, Part E, Chapter 2, Appendix 1, September 1966.

4.2 "Technical Guidance on Emergency Operating Centers", Federal Civil Defense Guide, Part E, Chapter 2, Appendix 2, September 1966.

4.3 "Direction and Control of Emergency Operations", Federal Civil Defense Guide, Part E, Chapter 2, September 1966.

4.4 "Emergency Operating Center Operations, Organization, and Staffing for Municipalities and Counties with Less Than 300,000 Population", Federal Civil Defense Guide, Part E, Chapter 2, Appendix 4, April 1967.

4.5 "Financial Assistance for Emergency Operating Centers", Federal Civil Defense Guide, Change 1 to Part F, Chapter 5, Appendix 1, Ann. 3, September 1970.

4.6 "Federal Contributions for Civil Defense Equipment", Federal Civil Defense Guide, Part F, Chapter 5, Appendix 1, with Annexes 1-5, January 1970.

4.7 Private communication provided by F. C. Egland, Resident Engineer Support Group, DCPA, Region 4, Federal Center, Battle Creek, Michigan 49016.

4.8 SPANCRETE, Milwaukee, Wisc.

4.9 Private communication from the Illinois Civil Defense Agency and Office of Emergency Preparedness, 136 N. County Farm Road, Wheaton, Illinois

CHAPTER 5

ANALYSIS OF A FALLOUT SHELTER AGAINST THE DIRECT EFFECTS OF NUCLEAR WEAPONS

5.1 INTRODUCTION

The purpose of this chapter is to determine how much direct effects protection is provided by a 50-person, gable roof shelter primarily designed for fallout protection. This analysis focuses on how the structure succeeds or fails to withstand the effects of blast. An estimate of occupant survivability is made on this basis. Direct effects of a single megaton range weapon are assumed.

5.2 SHELTER DESCRIPTION

The shelter (Figures 5.1 and 5.2 (Ref. 5.1) is approximately 49 ft long, 19 ft wide and 12 ft high. It is of wood framed construction with sloping rafters supported on a center ridge beam and at ground level. The actual floor elevation is 2 ft below grade. Ventilation is provided by a stack type vent at the rear. The shelter was designed mainly for the long range effects of radioactive fallout. Earth mounding on the shelter and a sandbag or concrete block wall in front of the door provide the necessary shielding.

5.3 ANALYSIS ASSUMPTIONS

Since the shelter is closed and mounded, thermal radiation is not expected to produce casualties. Also, since the structure is expected to fail at low overpressures and we are dealing with a megaton range weapon, prompt nuclear radiation is not expected to be a significant casualty producer. These effects are therefore neglected. Effects considered include diffraction and drag loading on the structure, dynamic pressure and debris (from the breakup of the structure) on the shelter occupants.

In analyzing the shelter with regard to the significant indirect blast effects the structural integrity of the shelter becomes important. Structurally the shelter was designed with

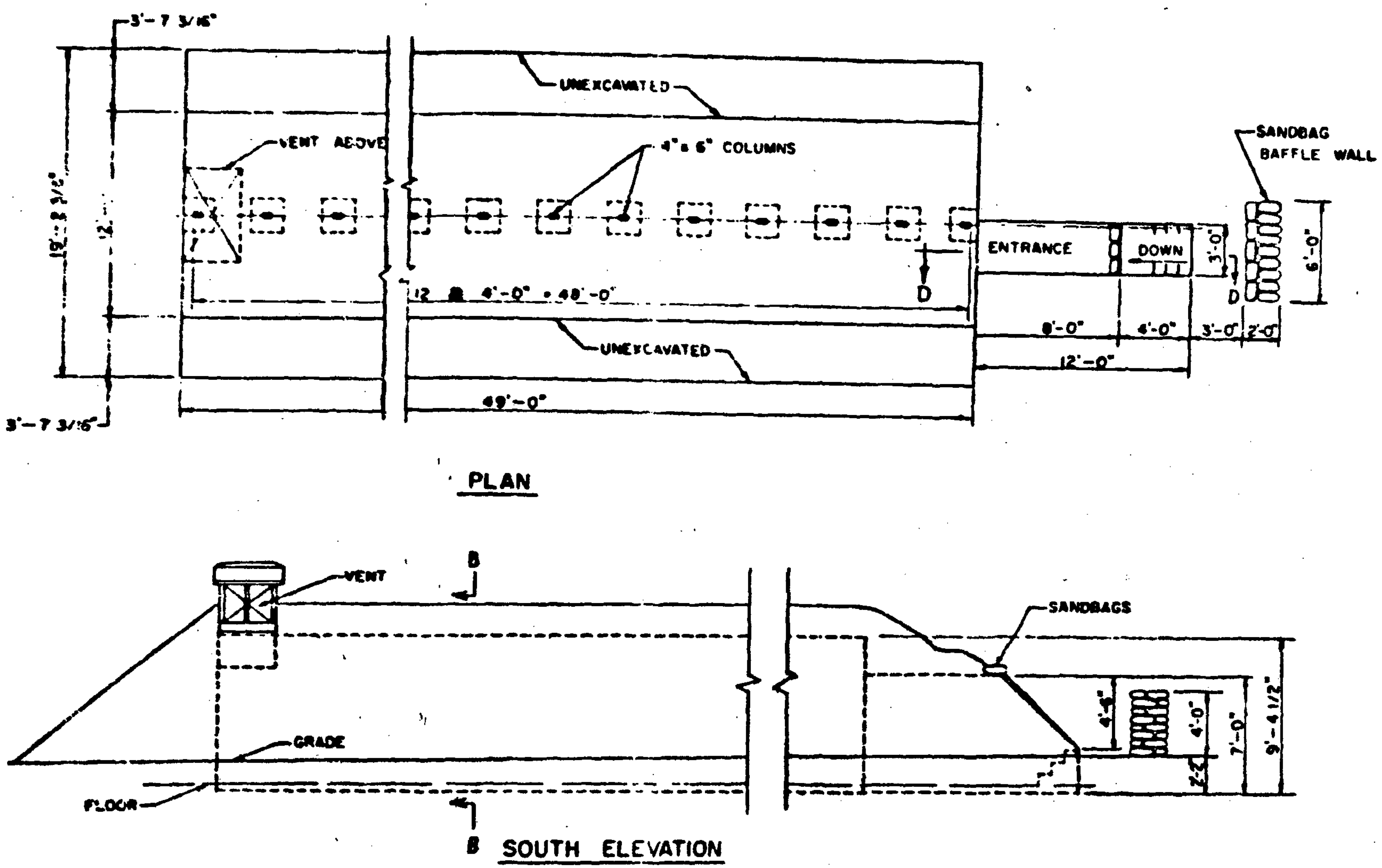
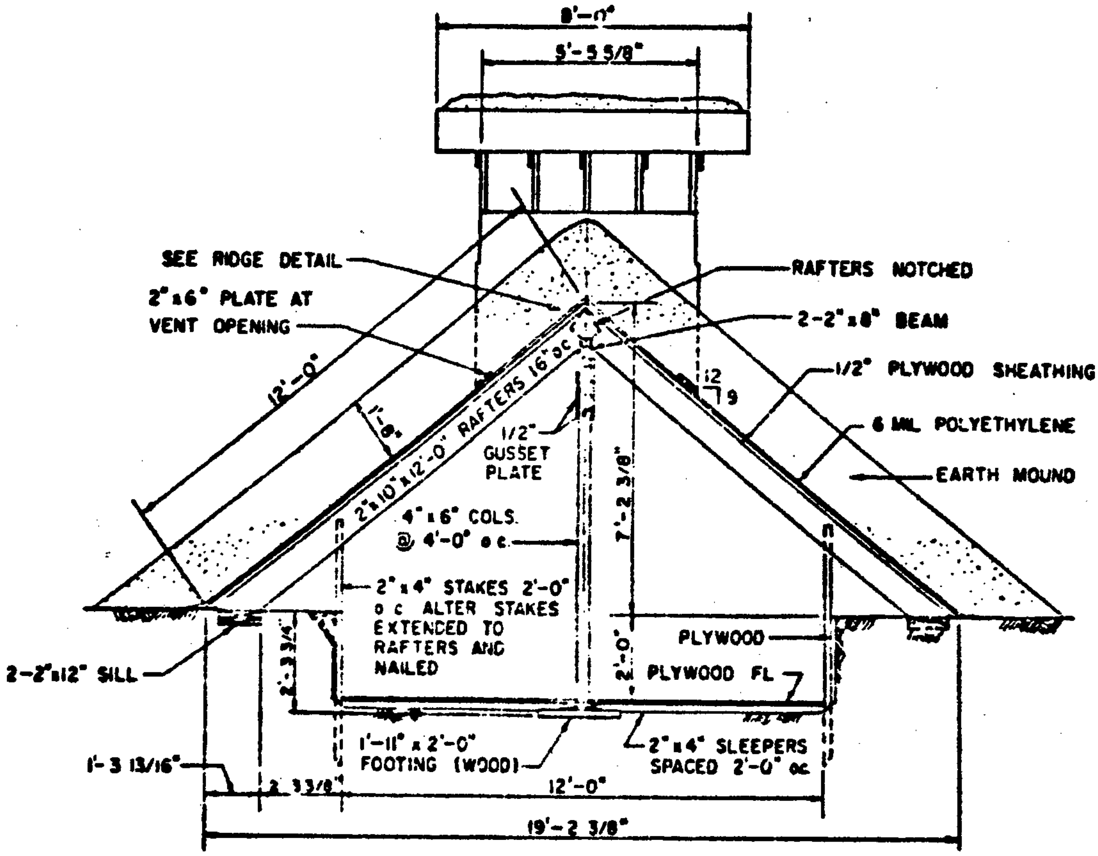
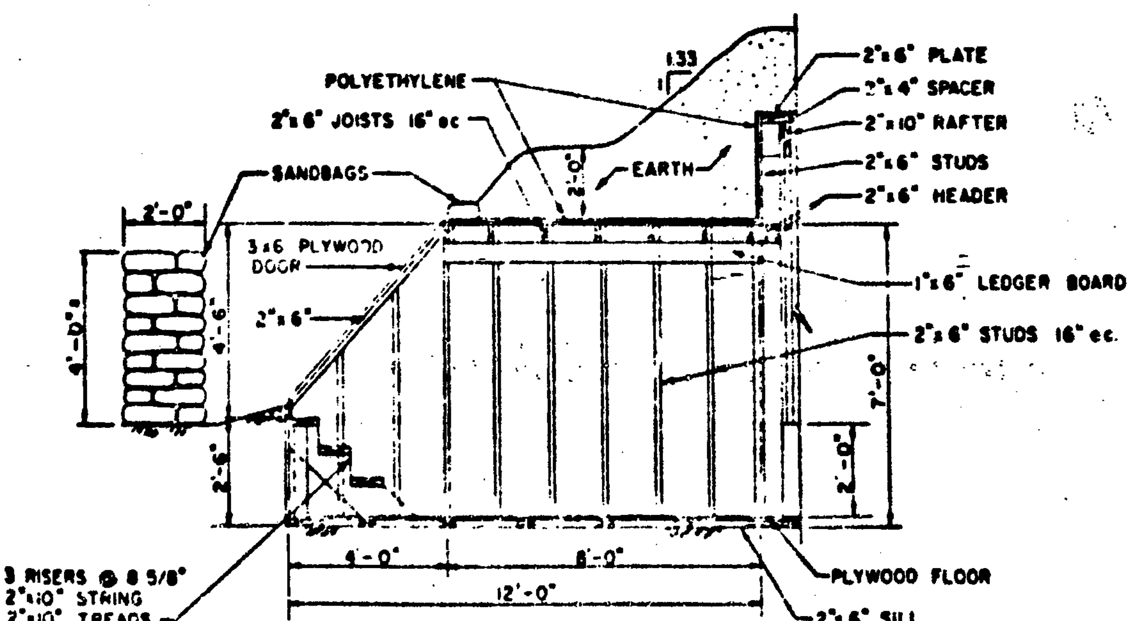


Figure 5.1 Plan and Elevation



SECTION B-B



ENTRANCE
SECTION D-D

Figure 5.2 Interior and Entrance Details commonly used allowable stresses. These often provide large factors of safety against failure. Any extra stresses produced by the blast will have to be absorbed by the difference between the allowable stress and the maximum or rupture stress of the material.

The shelter is mostly a timber structure. This makes the determination of maximum stresses hard to obtain since wood has widely varying properties dependent on moisture, defects, type of wood, locality, etc. Pine is the most likely type of wood to be used. Southern pines were suggested for the construction of the shelter and are also assumed in this analysis. (It should be noted though, that Southern pines are stronger than most other types of pine; lower values will be obtained with substitution of other pines.) Failure values for Southern pine were obtained from material handbooks (Refs. 5.2 through 5.5). Samples that were green (moist) with defects were used for a lower bound, and samples that were clear (no defects) and dry were used for an upper bound. Chances are the wood actually used will not be at either extreme, but rather somwhere in between. Therefore, an average value based on the two extremes was used in this analysis Table 5.1).

5.4 ANALYTIC PROCEDURE AND STRUCTURE RESPONSE

The first step followed was to obtain an idea of the order of failure of individual structural members. To this end, primary members were each analyzed to determine overpressures that they could withstand assuming none of the supporting members fail. This is good for a first approximation which is later modified to account for supporting members.

For the initial step in the analysis the following members and modes of failure were investigated. Rafters failing in bending and longitudinal shear, columns buckling and crushing, ridge beam failing in bending, rafter notch failing in compression and front and back walls failing in longitudinal shear and bending.

Table 5.1

ULTIMATE STRENGTH VALUES FOR SOUTHERN PINE, PSI

	Bending	Compression Parallel to the Grain	Compression Perpendicular to the Grain	Shear Parallel to the Grain
Lower Limit				
Full size, green with ordinary defects	4600	3300	440	360
Upper Limit				
Small, dry, clear specimens	13750	7650	1075	1350
Average Value	9175	5475	760	855

Simple strength of materials relationships were employed such as the flexure formula, horizontal or longtudinal shear formula, Hankinson's formula (for compression at notch) and Engessor's column equation for buckling. All the maximum wood stresses were increased 25 percent to account for the ability of wood to absorb impact. Significant dead loads were considered, and values obtained were expressed in terms of maximum free field overpressure.

Because the air intake vent has an area of approximately 10 sq ft, pressure is capable of building up within the shelter during the passage of the blast wave. Using results from Ref. 5.6, this influence on the response of the structure considered was considered. Table 5.2 lists failure overpressures for individual members.

Now it is necessary to look at the results in terms of people survivability, remembering that most of the members listed in Table 5.2 interact with each other. The shelter is intact and all occupants are safe up to 3.5 psi when the door fails in flexure, blowing into the shelter.

Table 5.2

FAILURE OVERPRESSURES FOR INDIVIDUAL SHELTER COMPONENTS

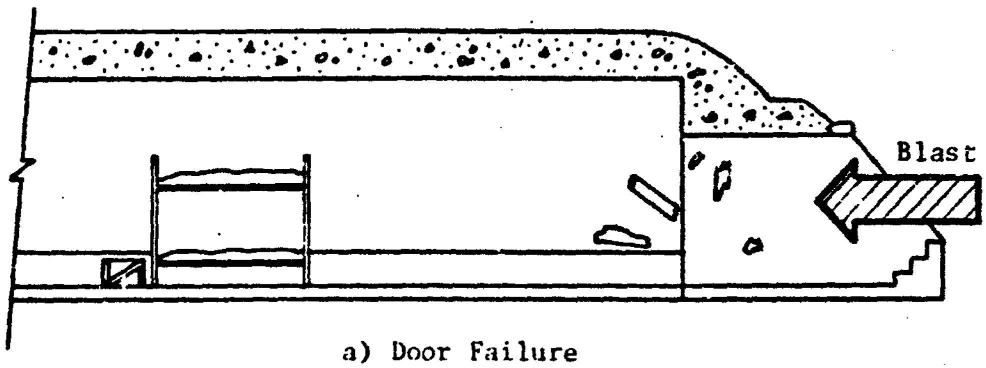
Member	Failure Overpressure
Door (bending)	3-1/2
Notch in Rafters (compression)	5
Rafters (bending)	6
Columns (buckling)	8-1/2
Rafters (longitudinal shear)	8-1/2
Side Wall (bending)	∿8-1/2
Side Wall (longitudinal shear)	∿ 10
Ridge Beam (bending)	12
Rafters (secondary failure, bending)	13

Debris effects initiate, objects or people may be translated (Figure 5.3a) and first casualties are expected.

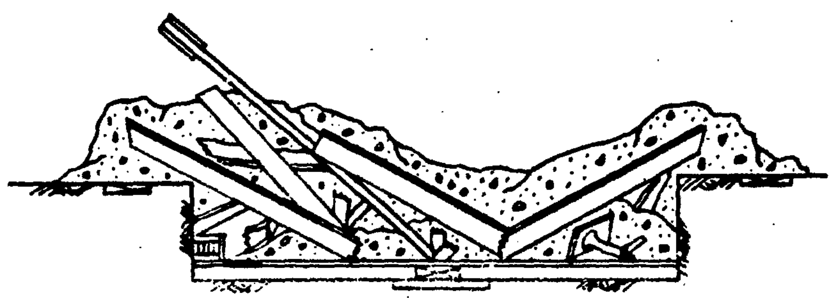
Compression failure of the rater notch is not significant since rafters are expected to fail at 6 psi. They are expected to fail in flexure at midspan, collapse and leave relatively small areas along the sidewalls as indicated in Figure 5.3b. Figure 5.3c illustrates the assumed final state of the structure indicating secondary failures produced at approximately 12 psi.

5.5 PEOPLE SURVIVABILITY ESTIMATE

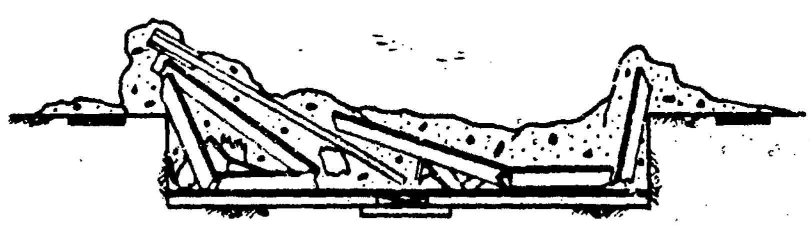
From these three primary failure modes, i.e., door, initial rafter failure, and secondary rafter failure an estimate of people survivability is produced and is illustrated in Figure 5.4. Casualties are first expected at 3.5 psi when the door fails. At 6 psi the rafters fail leaving approximately 33 percent survivors in pockets along the side walls. The third point, 13 psi, is when secondary failure of the rafters is expected to occur leaving no survivors. It should be noted that although no survivors are expected after 13 psi, fewer than expected or none may remain after 6 psi if individuals are trapped or if injured cannot be removed.



a) Door Failure



b) Rafter Failure



c) Final Rafter Failure

Figure 5.3 Anticipated Failure Modes

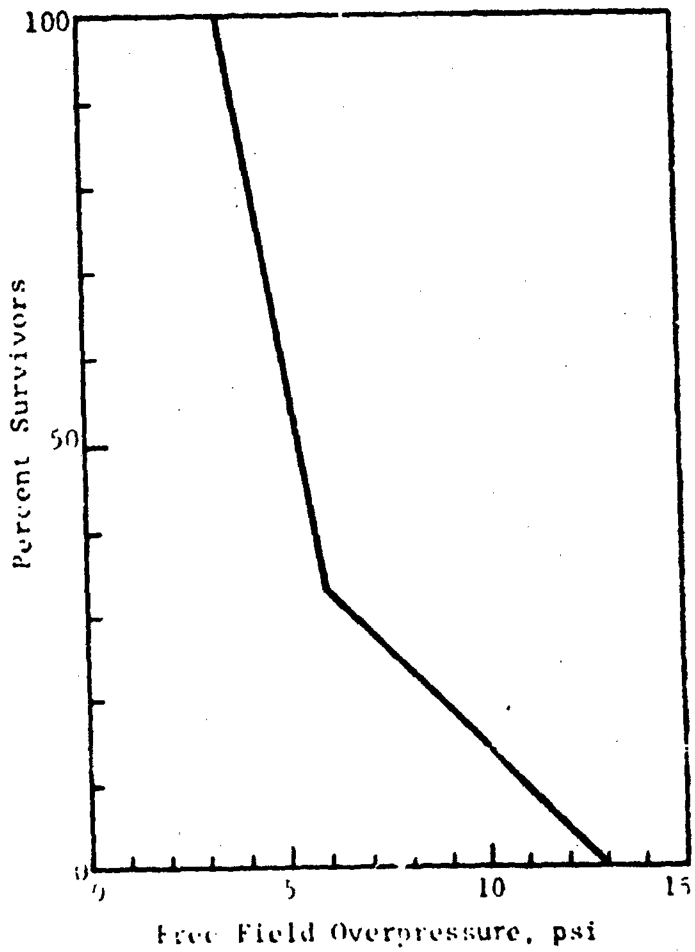


Figure 5.4 People Survivability Estimate

5.6 RECOMMENDATIONS

1. The first recommendation is that neither a sandbag nor a block wall be used to shield against radiation. The blast will send pieces of the wall crashing through the door causing more casualties and at lower overpressures. (The results of this analysis were determined assuming the wall was not there.)

2. The door is mounted in the weak direction. By mounting two half size panels with grain in the opposite direction on top

of the existing door, it can be strengthened. It would also be beneficial to add top and bottom supports to the door in addition to the support provided on the sides.

3. Rafters can be strengthened by mounting them closer together, using 2 x 12's or doubling up on some of them. Rafters can also be strengthened by adding a bolt joining them at the top thus preventing their slipping off and taking load off the notch and columns.

4. Columns should be securely fastened to the flooring to prevent slipping out when the blast is applied to the shelter.

REFERENCES

5.1 Protective Structures Development Center, et al, Expedient Community Fallout Shelter Gable Roof, for OCD, PSDC-TR-9, February 1965.

5.2 Moore, H. F.; Materials of Engineering, McGraw-Hill Book Co., 1941.

5.3 Hool, G. A.; Kinne, W. S.; Steel and Timber Structures, McGraw-Hill Company, 1942.

5.4 Mantell; Engineering Materials Handbook, McGraw-Hill Book Co., 1958.

5.5 Miner and Seastone; Handbook of Engineering Materials, John Wiley and Sons, Inc., 1955.

5.6 Longinow, A., et al; Civil Defense Shelter Options: Deliberate Shelters Vol.II, For OCD, Contract DAHC-68-C-0126, Work Unit 1614D, IIT Research Institute, December 1971.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The study described herein has been useful in the following respects:

1. Casualties Produced by Impact -- For the first time the "impact casualty" problem is capable of being examined in reasonable detail. This has resulted in a clearer understanding of the relative importance of the various blast induced impact casualty mechanisms that would be produced in the upper stories of framed buildings located in the Mach region of megaton range nuclear weapons. The effort is described in Chapter 2.

A significant portion of the impact analysis task was devoted to developing the impact analysis computer program, generating debris and people trajectories and selecting appropriate statistical methods for interpretation of results. Although the problem to which the analysis method was finally applied is fairly large, it was not possible to perform all of the necessary parameter variations.

This study was limited to debris produced by exterior walls. For a thorough understanding of the impact problem, it is necessary to consider exterior and interior wall debris, furnishings and vertically mounted equipment for a reasonably large range of sizes and weights. In order to assign reliable modes of evasive action to individuals, it is also necessary to consider a reasonably large range of people distributions and initial (preparatory) body positions.

It is worth mentioning that the debris interaction process described (see Chapter 2) has wider applicability than the particular problem for which it was developed. The basic approach can be effectively used in blast-fire interaction studies, determination of debris vulnerability of military targets, casualties and damage produced by accidental detonations of stored explosives, etc.

2. Classification System for Conventional Buildings -- The feasibility of developing a classification system for conventional buildings in terms of best available shelter space was explored (see Chapter 3). It is concluded that a reliable classification system is feasible and timely. However to be generally applicable, the effort should be preceded by a statistical analysis of available field data which currently exists. Such an analysis would seek to categorize all building parameters, eliminate insignificant parameters, rank significant parameters in their order of importance and express the influence of commonly unavailable parameters (wall strength, for example) in terms of those which are generally available i.e., wall type. The significance of building parameters would be judged on the basis of their influence (positive or negative) on people survivability. Stepwise regression analyses may be used for this purpose.

3. Casualty Criteria -- A literature search of currently available casualty criteria and data was conducted to determine if the criteria used in performing people survivability studies relative to prompt effects of nuclear weapons are sufficiently within the state-of-the-art. On the basis of the limited effort is is concluded that although several different methods for estimating casualties exist, they are not necessarily superior to the "impact velocity" approach considered herein.

Readily available impact casualty criteria are very limited. The current emphasis in the open literature is on impact casualties produced in automobile accidents. The approach taken by most investigators is one which is problem oriented. In a problem oriented approach to automobile occupant survivability, the emphasis would be on practical methods capable of reducing the acceleration or motion (forward or rearward) experienced by the vehicle occupant during collision to tolerable levels. This is done by preventing seat collapse, and providing impact attenuators, a harness, backrest and a soft frontal head impact surface. Tolerable levels of motion and impact are determined on the basis of previous accidents, full scale crash experiments with instrumented anthropomorphic dummies or computer simulation of the process. <u>Casualty criteria based on generalized impact are of limited applicability and are therefore seldom used</u>. When used, the application is to very specific situations which are difficult to scale to remotely related problems.

Casualty criteria which are specifically oriented to casualty mechanisms prevalent in shelters (NFSS upper stories and basements) are for the most part nonexistent. The majority of currently used criteria were derived on the basis of a great deal of engineering judgment on so-called related experiences such as scaled animal data, war related bomb data, military aircraft pilot ejection studies, etc. The extent oa pplicability of these criteria to individuals in shelters beyond the two categories, i.e., survivors and fatalities considered in this report, requires further study.

Separation of affected individuals in only two categories can and often will produce misleading conclusions on the sheltering potentail of buildings. As defined in this study, survivors include injured and uninjured individuals. However, the number of each is not evaluated. Thus when comparing individual buildings on the basis of expected percent survivors, the comparison may or may not be valid. For example, casualty mechanisms produced in the upper stories of framed buildings will include thermal radiation, prompt nuclear radiation and blast effects, i.e., dynamic pressures and debris. In closed basements the primary casualty mechanisms would be debris from the breakup of the overhead slab. It is intuitively clear that a comparison of the sheltering potential of basements and upper stories is not valid on the basis of percent survivors in each, since survivors in the upper stories are expected to include more injured individuals than their counterparts in basements. Comparisons on this basis are valid only if we compare shelters which are physically similar, i.e., the class of steel framed buildings, the class of load-bearing buildings, etc. For a comparison of all shelter space, with confidence, a more detailed breakdown of survivors is necessary.

Although existing casualty criteria are crude, it is believed that a further categorization of survivors in two groups, i.e., injured and uninjured, is possible. The task which is expected to lead to a reasonable categorization of injuries in a direct effects environment was initiated in this study. To provide for a better understanding of the response of individuals to blast effects, and thus of the type of injuries that would occur, a simulation model was developed. This model represents the individual as a seven-link (part) articulated man interconnected by extensional and torsional springs. Individual parts include the head, torso, arm, forearm, thigh, lower leg and foot. These are modeled by means of rigid, elliptic cylinders. The formulation is two-dimensional. The articulated man is capable of being impacted by debris, and can also impact the floor, walls or the ground surface with any portion of his idealized body. The computational process keeps track of his motion, time dependent forces acting at his joints, impact velocities and impact forces. The model provides for a more detailed breakdown of the response of individuals in a blast environment than does the rigid blodk model used in this and previous studies.

At the present time this simulation model is incomplete and therefore is not described in detail in this report. It is described briefly in Ref. 6.1. It is incomplete because it lacks a formal computational routing capable of relating response to a corresponding level of casualty, i.e., injury or fatality. Such a routine is expected to be developed in the study subsequent to the one described.

4. BUILDINGS Computer Program -- One task of this study was devoted to updating the computational process (Simulation Model of People Survivability in Conventional Buildings) described in Appendix C of Ref. 6.3. This process was substantially revised and made into a self-contained computer program entitled "BUILDINGS" which is described in Appendix A. This program was used in generating results discussed in Chapter 3 and those presented in Ref. 6.3. The following revisions were incorporated.

The program was restructured to provide for simplified usage and more efficient operation. Routines to read and check input data were added. The subroutine which estimates debris casualties was revised to include representative debris-people interaction data based on those given in Chapter 2.

Modifications were also made to allow for automatic analysis of fully load-bearing buildings and buildings with exterior load-bearing walls. In the case of fully load-bearing buildings, the computer program assumes that after the strongest exterior or interior walls are breached no survivors are expected in the upper stories.

For buildings with exterior load-bearing walls and interior frames it is assumed that when the peripheral walls fail, the exterior rows of rooms collapse leaving no survivors in the collapsed portions. The interior framed portion is treated as a typical framed building [illegible] is discussed in more detail in Appendix A.

[illegible] drawbacks. It does not consider the possible collapse of framed buildings and the influence of this on people survivability. It provides people survivability estimates for upper stories only. Basements are not considered. It does not distinguish between injured and uninjured personnel. It is recommended that these deficiencies be eliminated. Capabilities for [illegible] exist at this time.

5. Emergency Operating Centers.--One segment of this study was devoted to the analysis of an existing typical emergency operating center (see Chapter 5). The analysis considered equipment function loss and operating personnel survivability in a blast environment produced by a megaton range nuclear weapon. A procedure for the [illegible] of existing EOC's was developed and is presented herein.

6. Computer Program Update -- The people survivability analysis computer program described in Ref. 6.2 which is used on a routine basis for the analysis of people survivability was revised and updated. Revisions include simplified input and output options plus a routine which checks input data for possible errors. The debris survivability routine was revised on the basis of results obtained in Chapter 2.

7. Dynamic Pressures in a Large Mine Complex -- A limited task of this study was devoted to determining dynamic pressures in a large, existing limestone mine produced by a megaton range nuclear weapon. It was concluded that where they exist, such mines provide excellent direct effects and fallout shelter spaces for neighboring or evacuated populations. In this context they are significantly superior to expedient community shelters and especially to the "log-ditch" shelters recently analyzed by the Oak Ridge National Laboratory civil defense group. Results of this task are given in Appendix B.

On the basis of the study described herein, the following recommendations are made.

1. Blast Generated Debris -- There exists a need to gain a better understanding on "real world" size distributions of wall debris and their influence on people survivability. For this purpose we need more data on the initial crack patterns experienced by masonry walls (with and without windows), having a variety of different "real world" support conditions (simple, fixed, arching, etc.) when subjected to a range of different overpressure levels and durations. These data should be capable of providing estimates on initial debris-size distributions as a function of incipient overpressure to collapse overpressure ratios.

This experimental information should be used in a sensitivity study to determine variations in people surviability produced by variations in debris size distributions, incident overpressures and wall collapse overpressure. The influence of debris from interior furnishings and vertically mounted equipment should also be included.

2. Casualty Criteria -- As was mentioned previously, currently available casualty criteria for people in shelters (NFSS upper stories and basements) are very crude and the extent of their applicability with confidence is not known. There is a need to systematically review all currently used casualty criteria in the light of the current understanding of the overall prompt effects problem. Special consideration should be given to impacts produced by debris. Since debris sizes can range from small window glass fragments to large pieces produced by the breakup of masonry walls, it is not clear that the same criteria apply for the entire range of debris sizes and impact velocities.

The shelter casualty problem is significantly different from that manifested in automobile accidents or by pilot ejections from military aircraft. Since each of these two fields has been and is being studies mostly in a problem oriented fashion, the response of people in shelters relative to a prompt effects environment warrants a separate investigative effort. Bioengineering studies should be initiated to examine currently used criteria and to develop new criteria where deficiencies are found.

Computer simulation studies (using computer graphics) of people in shelters subjected to blast effects should be initiated to provide a better understanding of the complex phenomena. This would aid in devising means for increasing people survivability in a problem oriented fashion.

Computer graphics provide a useful and powerful tool for studying the problem of debris formation and distribution, translation and impact of people with hard surfaces and debris. For civil defense problems the potential of this tool remains largely unexplored.

3. Blast Environment -- It is recommended that experimental studies be conducted to determine the distribution of time-dependent dynamic pressures in rooms having configurations similar to those found in the upper stories of framed buildings and basement spaces.

Yielding and nonyielding walls should be used. Experimental results obtained would aid in verifying the results determined by means of theoretical procedures.

4. Classification of Shelter Spaces -- As was mentioned previously, a classification system for conventional buildings in terms of best available shelter space is feasible and timely. It is recommended that a study leading to its development be initiated along the lines described in Chapter 3.

REFERENCES

6.1 Longinow, A., et al, Personnel Survivability in a Blast Wind Environment, ASCE National Structural Engineering Meeting, April 22-26, 1974, Cincinnati, Ohio, Meeting Preprint 2241

6.2 Longinow, A., et al, Personnel Survivability in a Direct Effects Environment and Related Topics, Contract DAHC20-72-C-0318, for DCPA, IIT Research Institute, January 1973.

6.3 Longinow, A., Survivability in a Direct Effects Environment (Analysis of 50 NFSS Buildings), Contract DAHC20-73-C-0227, for DCPA, IIT Research Institute, July 1974.

APPENDIX A

DESCRIPTION OF BUILDINGS COMPUTER PROGRAM

A.1 INTRODUCTION

This appendix contains a description of the computer program entitled "BUILDINGS". It was developed for the purpose of predicting the survivability of people located in the upper stories of conventional buildings of the National Fallout Shelter Survey (NFSS) type when subjected to the effects of megaton range nuclear weapons. The program has evolved over several years of work for DCPA and has been used to predict the survivability of people in a nuclear weapon environment in connection with two studies (Refs. A.1 and A.2).

This computer program is the revised and updated version of that previously described in Appendix C of Ref. A.3. The intent of this appendix is to acquaint the reader with its capabilities, limitations and usage. The basic computational algorithm is discussed in general terms. Program usage is illustrated by means of an example problem.

Figure A.1 presents a general flow chart of this program which indicates the major program operations and identifies which routines are used in each. Individual subroutines are briefly described in the following section.

A.2 DESCRIPTION OF PROGRAM ROUTINES

This computer program consists of one main program and 13 subprograms, i.e., subroutines and functions. Many of these consist of data statements containing previous computed results for a range of parameters. These subprograms are described next in the order in which they appear in Figure A.1.

INPUT

This routine is called by MAIN to read input data and transmit it to MAIN.

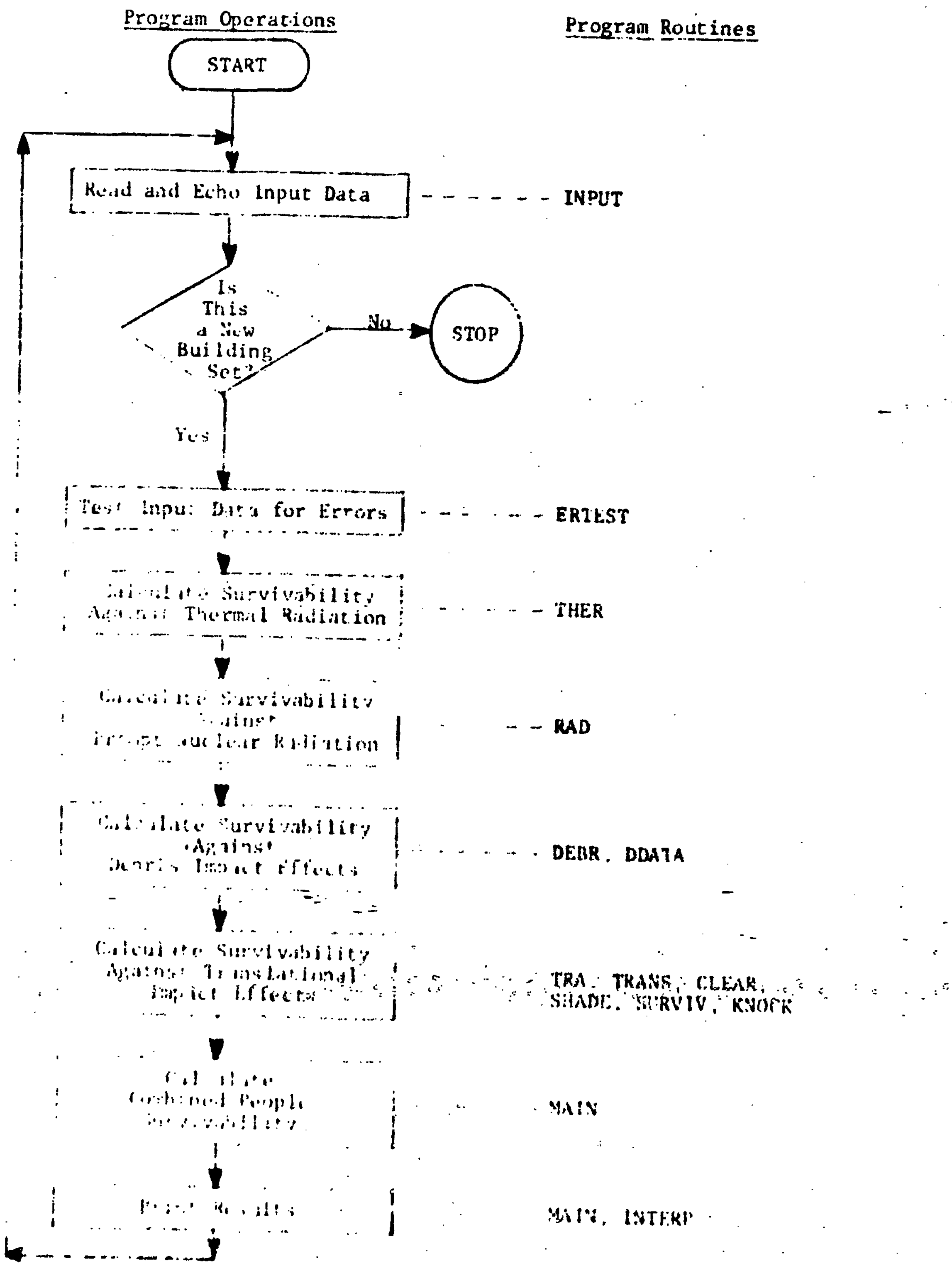


Figure A-1 General Flow Chart of BUILDINGS Program

ERTEST

This routine examines input data with the object of eliminating input errors and physically impossible situations in modeling various problems of buildings. If errors are found, an error message is printed and the run is aborted. This routine is called by MAIN.

THER

Determines people survivability estimates (percent survivors) estimates against thermal radiation. This routine is a simplified version of that previously used in the SEP code (Ref. A 4). Percent occupants exposed to thermal radiation are determined by comparing an approximate, unshaded area for peripheral (outside) rooms. Percent of body area exposed is then determined as a function of sill height. Exposed body area burned is based on quantity of radiant exposure which is then used to determine the burn mortality and the corresponding percent survivors.

RAD

Determines people survivability estimates against prompt nuclear radiation. Previously computed results are interpolated by this routine for particular situations. It is called by MAIN.

[illegible]

Determines percent survivors relative to wall debris impact using previously computed results.

DDATA

For the given room length and aperture (window) percent this routine determines room areas affected by wall debris impact. This information is returned to DEBR (which calls it) for interpolation of debris survivors.

TSA

Calculates [illegible] from input data. It provides preliminary information for TRANS which is called by TSA. TSA is called by MAIN

[illegible]

[illegible] due to translational effects (impact) produced by dynamic pressure in the given [illegible] area. TRANS calls SHADE, [illegible]

SHADE

Identifies room areas in which personnel are subject to dynamic pressure induced translational effects.

KNOCK

This function is called by TRANS to determine dynamic pressure intensity as a function of front wall window area and specified weapon environment.

CLEAR

Provides people survivability estimates against being cleared (blown) from the building area after walls fail as a function of building length and story height.

SURVIV

This routine is called by TRANS to provide percent survivors (initially prone and standing) as a function of information provided by SHADE, KNOCK and CLEAR. This routine provides the required estimates by interpolating from previously computed and stored results.

MAIN

The main program initializes the problem and calls INPUT to read data. It performs preliminary tests on input data and calls ERTEST to check the data for errors. It coordinates the individual people survivability results and modifies them according to the type of building being analyzed, i.e., framed, combination framed and load-bearing, fully load-bearing. It combines survivabilities against individual effects to get total survivability in each building area and then determines weighted (combined) people survivability estimate for the building as a whole. It calls subroutine INTERP to determine overpressures for 90, 50 and 10 percent survivors from the final results. MAIN also coordinates the printing and plotting of results.

A 3 PROGRAM CAPABILITIES

This computer program estimates percent survivors (injured and uninjured personnel) in the upper stories of conventional (NFSS type) buildings when subjected to the direct effects of a single, 1 MT surface burst. The program analyzes individual buildings which are assumed to be located in the Mach region of the weapon. Percent survivors are estimated by assuming that building occupants are uniformly distributed in selected portions of the building in either initially prone or initially standing positions. The following casualty mechanisms are considered individually

- Translational effects produced by dynamic pressure. This includes impact of personnel on portions of the building (floor and walls) and the ground plane when they are blown out of the building.
- Debris effects, i.e., impact of debris on people. Debris is produced from failing building walls in framed buildings and collapsing walls and floors in [illegible] buildings.
- [illegible]
- [illegible]

The program requires that each building analyzed be broken down into [illegible] for each component area percent survival [illegible] to each of the above mentioned [illegible] combined to obtain total [illegible] total result for the building as a [illegible] the location of the building [illegible]

[illegible] described in part in Chapter [illegible] and A-5. The [illegible] largely [illegible]

[illegible]

to choose the attack direction, i.e., the direction from which the blast wave is expected to originate. Usually this direction is chosen as being normal to a vertical plane through the weakest portion of the building. This generally results in a lower bound estimate of people survivability.

Further information required by the program consists of building characteristics and distribution of occupants. Building characteristics include dimensions such as bay width, room length, building width, window size, etc. Knowledge as to the type of building construction, i.e., framed, load-bearing or a combination framed and load-bearing, etc. is also necessary. Although the program does not require data on the collapse overpressure for the building as a whole, it does require collapse overpressures for exterior walls and interior partitions. It is also useful to know how the building occupants are expected to be distributed in various portions of the building.

The actual modeling process is accomplished by breaking the subject building into component regions (areas) each having different characteristics. Each such component region is assigned a factor (a number less than or equal to 1.0) which indicates its size and occupancy as a fraction of the entire building area and total population. The number of personnel occupying each region is estimated as a percentage of the whole building population. Building characteristics along with region factors are punched onto data cards with one card per component region. The program computes percent survivors in each region described and then takes a weighted average of these results (by the use of region factors) for the building as a whole.

A.4.1 Component Areas

A component area in a building can be chosen as a story having the same or almost the same characteristics. It must pass through the entire length of the building at whichever point it is chosen, length being the distance parallel to the direction of blast. The three types of component areas that this program can handle are described in the following paragraphs. A kn wldege of the computational process is useful in choosing component areas and of avoiding extension of the program beyond its limitations.

- Building Region Type 1

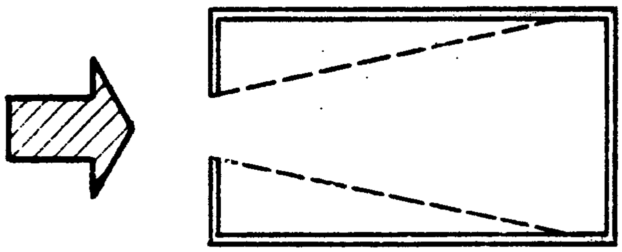
This component area is illustrated in Figure A.2 as a room or a large portion of a building in which the front and the rear walls are of equal strength. No interior walls are included. When the blast loading is not high enough to fail the walls, casualties are produced by dynamic pressure, prompt nuclear and thermal radiation. When the walls fail, then in addition to these mechanisms, casualties are also produced by debris impacts on people and impact of people with the ground plane, i.e., those who are swept out of the building by the high velocity winds.

- Building Region Type 2

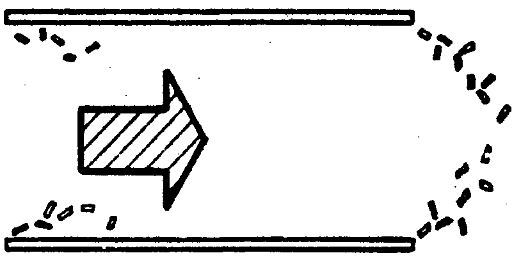
This case is illustrated in Figure A.3. Both exterior walls have the same strength and are assumed to be stronger than the interior walls which are of equal strength. At low overpressures, i.e., when the walls do not fail, only area A (see Figure A.3a) experiences weapon effects. Areas B and C are assumed to have 100 percent survival. At higher overpressure levels interior walls fail (Figure A.3b) and casualty mechanisms which applied to area A previously now apply to areas A, B and C. In addition to these we now have debris effects produced by the failure of the interior walls. When the weapon environment is such that all walls fail (Figure A.3c) then the case is similar to that described previously in connection with Figure A.2b.

- Building Region Type 3

In this case, exterior walls are weaker than interior walls. At low overpressures when no walls (with the exception of window glass) fail, weapon effects are considered in area A only (Figure A.4a) and are similar to those described previously in connection with Figures A.2a and A.3a. Areas B and C are assumed to have 100 percent survivors and the program computes a weighted average of survivors for the total of areas A, B and C.

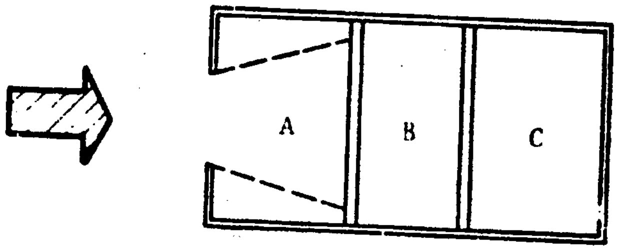


a) Exterior Walls Intact

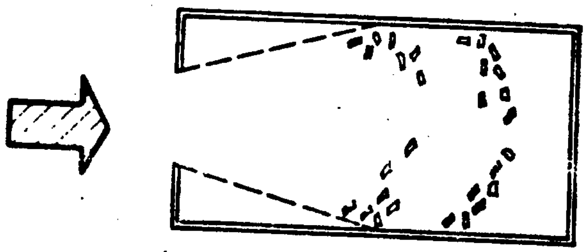


b) Exterior Walls Fail

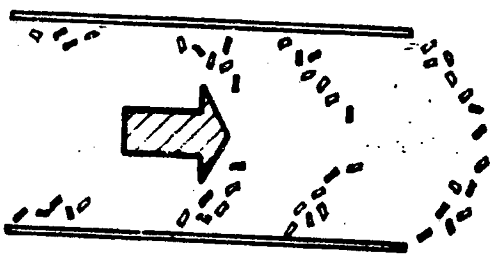
Figure A.2 Building Region Type 1



a) All Walls Intact

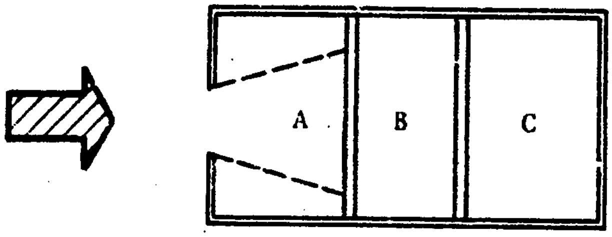


b) Interior Walls Fail

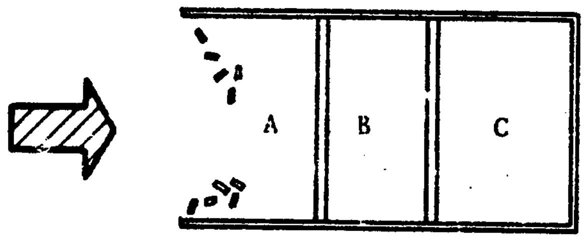


c) All Walls Fail

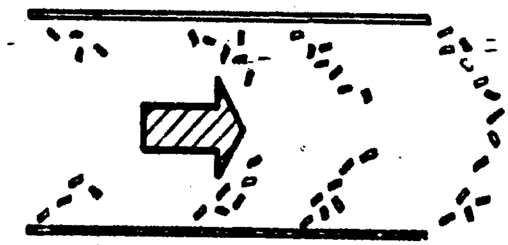
Figure A.3 Building Region Type 2



a) All Walls Intact



b) Front Exterior Wall Fails



c) All Walls Fail

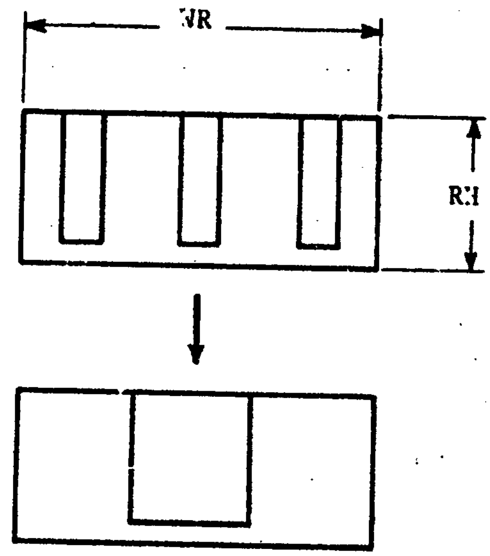
Figure A.4 Building Region Type 3

When the overpressure is increased such that the front wall fails then debris effects are considered in area A (Figure A.4b) in addition to casualty mechanisms considered previously. Areas B and C are still assumed not to experience any blast casualties. Finally, when the overpressure is sufficiently great to fail the interior walls (Figure A.4c) then all areas are affected.

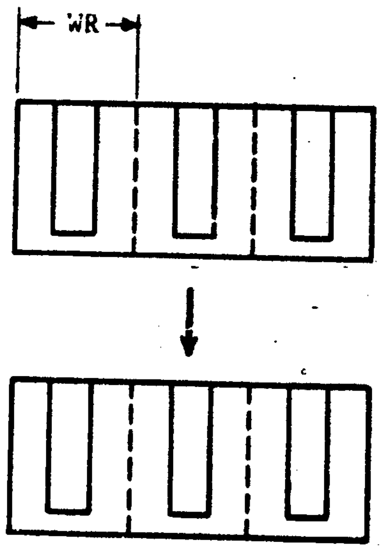
A.4.2 Special Considerations

Strengths of interior partitions and exterior walls are expected to be different and the program does allow for it. However, the program does not allow for differences in the strength of the two exterior walls. Interior partitions must also have equal strengths. This does not introduce serious problems in most analysis efforts since exterior walls on any given story of most buildings are very close to having the same strength. The same holds true for interior partitions. Where differences in the strength of interior walls exist, such as massive elevator tower walls and light partitions, problems can be avoided by judicious selection of individual regions. For this, knowledge of the computational process is very useful in avoiding errors.

Window dimensions are not input but are instead computed using other input data such as room width, room height, sill height, upper sill height (top of window to ceiling distance) and percent apertures. Window height is automatically fixed by specifying room height, sill height and upper sill height. Window width is the variable in this process. One potential mistake that can result from this is illustrated in Figure A.5. In making up input data for a front wall with three windows we arbitrarily choose the width WR, of the whole room as shown in Figure A.5a. We also arbitrarily choose an aperture percentage equal to the sum of the three windows. When the program computes window dimensions based on these data, it places one large window in the center of the wall whose area is equal to the sum of the three individual windows. The problem as interpreted by the program is obviously not correct and somewhat different results will be produced.



a) Incorrect



b) Correct

Figure A.5 Considerations in Modeling Window Apertures

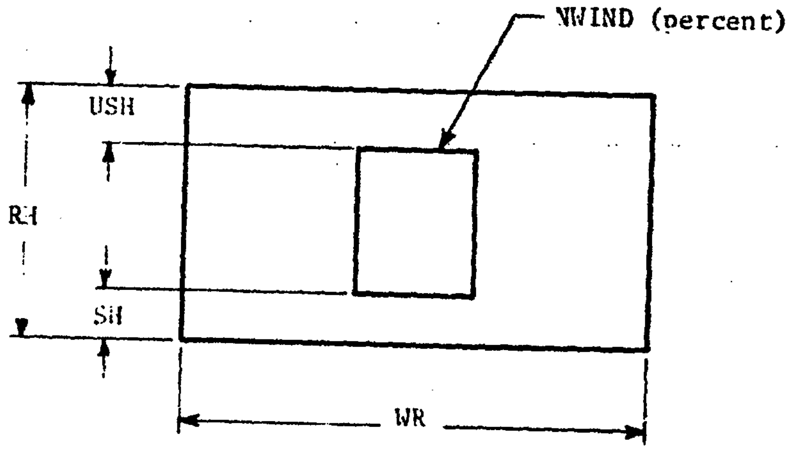
The correct way to model this particular situation is to choose the width of room (WR) such that each of the windows is individually considered as shown in Figure A.5b. In the program the room width parameter does not necessarily imply actual room width, but what is chosen as the width of the component area.

It is important to distinguish between three types of buildings, i.e., framed (steel or reinforced concrete), combination framed and load-bearing and fully load-bearing. In the case of combination framed and load-bearing buildings, i.e., buildings with exterior load-bearing walls and interior frames it is assumed that when the peripheral walls fail, the exterior rows of rooms collapse leaving no survivors in the collapsed portions. The framed portion is then treated as a typical framed building. In the computational process the program subtracts twice the distance to the back wall from the length and width of the building. Debris results (percent survivors due to debris impact) are multiplied by the ratio of this adjusted plan area to the original area. This approximation is quite adequate if the building is rectangular, has load-bearing walls all around and the distance to the first interior wall is also the distance to the structural frame. If there are large deviations from this description, then results will not be correct and adjustments need to be made.

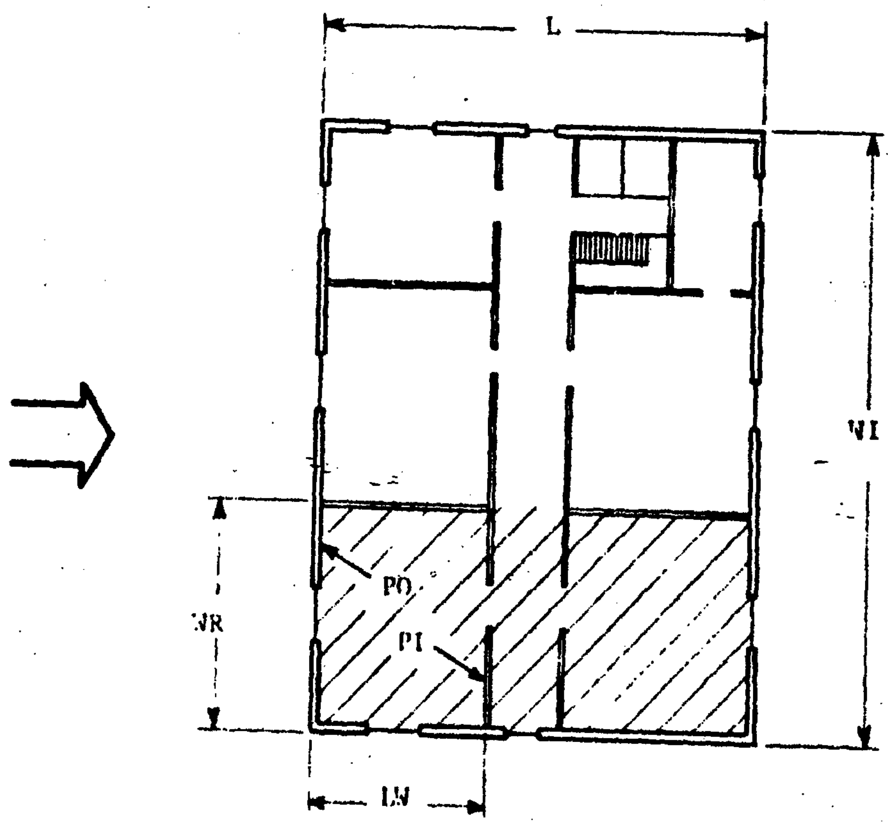
Fully load-bearing buildings are treated in a similar fashion. No survivors are assumed to exist once the exterior walls fail.

A.5 INPUT FORMAT

Input consists of a title card followed by as many data cards as there are component areas comprising the given building. This comprises one building set. Any number of building sets can be placed back to back and inserted as the data deck. No special end card is required. Input format is described in Table A.1 and illustrated in Figure A.6.



a) Front wall elevation



b) Plan View

Figure A.6 Illustration of Input Parameters

Table A-1

INPUT FORMAT

Card	Col.	Format	Name	Description
1 (Title Card)	1-78	13A6	NAME(I), I-1 13	Title of problem - first 30 columns are used for plot title if plotting is done.
2 (Data Card)	1-2	I2	NPLT	=1 plot results =0 no plotting
	3-5	I3	NDAT	number of data cards to be read including first data card, but not title card
	6-7	2X		
	8	I1	LCODE	0 frame building 1 load-bearing walls with frame 2 load-bearing walls
	9	1X		
	10	I1	WTYPE	wall type code for radiation 1 - 8 in concrete block [illegible] - 12 in concrete block 3 - 8 in concrete block, [illegible] brick [illegible] - 12 in R/C [illegible] R/C [illegible] - 16 in R/C
	[illegible]	[illegible]	[illegible]	[illegible] component area selected (ft)
	[illegible]1-25	F[illegible]	WT	total building width (ft) (WT is perpendicular to blast direction)
	[illegible]	[illegible]	[illegible]H	upper wall height (distance from ceiling to top of window)(ft) ([illegible] should never be so large that the top of the window would be lower than 6 ft off the floor)
	31-35	[illegible]	[illegible]	window aperture is zero to 100 percent [illegible]
	36-40	I[illegible]	[illegible]	floor level 1, 2, 3 or 4 and above
	41-45	F5.0	SH	sill height (distance from window sill to floor)(ft)
	46-50	F5.0	RH	room height (floor to ceiling height) (ft)
	51-60	F10.[illegible]	LW	distance to first interior wall (ft)
	61-65	F5.0	PO	exterior wall failure overpressure (psi)
	66-70	F5.0	PI	interior wall failure overpressure (psi)
	71-75	F5.0	WR	width of component area or room selected
	76-80	F5.0	FAC	factor percent of building or occupants to which this data card applies

There should be NDAT number of cards similar to card 2 (including card 2) such that ΣFAC = 1.0

A.6 OUTPUT FORMAT

The first page of output for a given building (building set) consists of an echo printout of data with headings added. Results consist of percent survivors for two body positions as a function of free field overpressure for the building as a whole and are contained on pages 2 and 3. Page 2 contains individual percent survivors for each casualty mechanism considered. Page 3 lists total survivors. As an additional piece of information the program prints out overpressures at 90, 50 and 10 percent survivors.

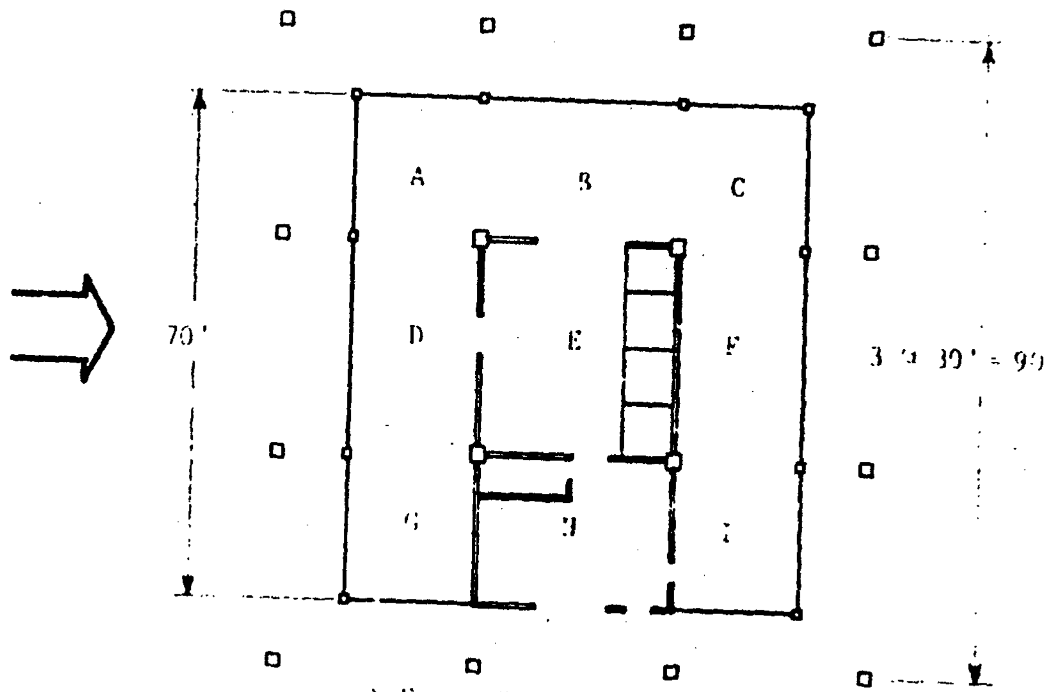
A.7 SAMPLE PROBLEM

This section illustrates the use of BUILDINGS program in analyzing a framed building for people survivability. The building considered is a ten-story office type building. Typical floor plans are given in Figure A.7. Building characteristics required by the program are given in the following table.

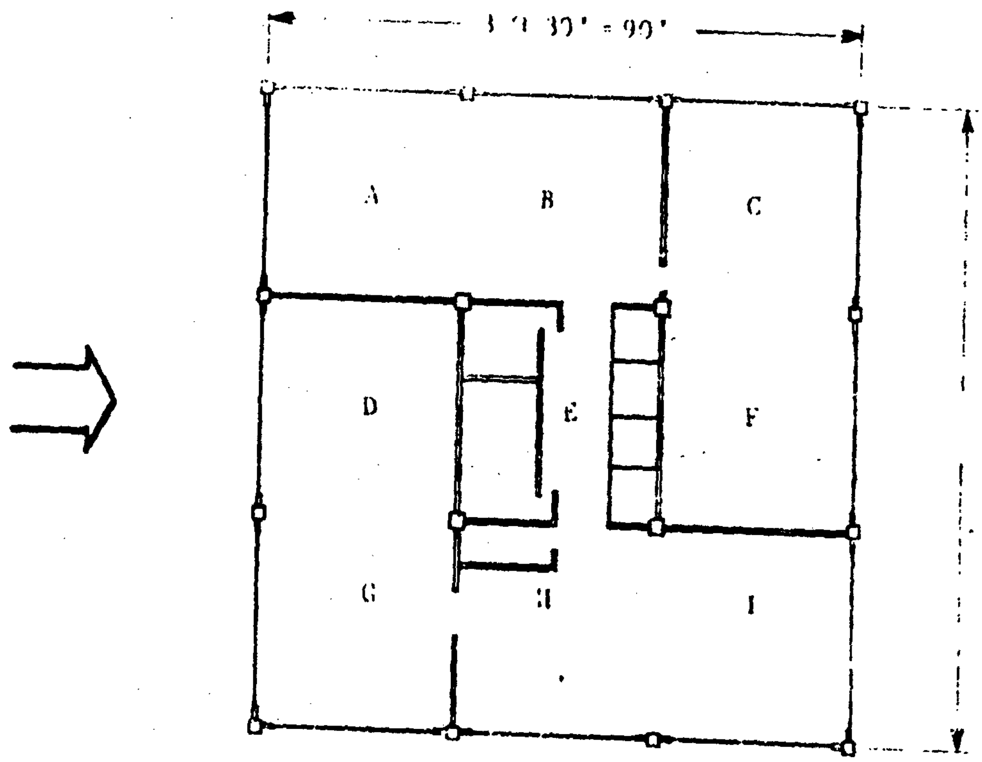
The blast direction was chosen as shown in Figure A.7. Since building is very close to being symmetric in plan (especially the upper stories), the results should be representative as far as the four directions are concerned.

At first the upper stories (2 through 10) were broken down into three component areas, i.e., ABC, DEF and GHI (see Figure A.7b). However since the computer program only considers the first interior wall, areas DEF and GHI are assumed to be essentially the same, as far as protection is concerned, and are combined in this analysis to form a single area, i.e., DEFGHI. This would not be done if the situation were less uniform, i.e., unequal strength partitions, lack of uniformity in window arrangement, etc. In such a case, more component areas would need to be considered.

Selection of component areas on the first story is somewhat easier than the upper stories and was done as shown in Figure A.7a. Again, two areas were considered, ie., ABC and DEFGHI.



a) First Story Level



b) Upper Story Level

Figure A.7 Building Plan

BUILDING DATA

a) Building Description

Number of stories	10
Floor area per story	8100 sq ft total 7200 sq ft occupied
Plan dimensions	90 ft by 90 ft
Building height	102 ft
Story height	12 ft, first story 10 ft, stories 2 through 10
Type of construction	Steel frame, steel deck, masonry wall and interior partitions

b) Exterior Walls

Story	Description	Strength*
1	-	-
2 to 10	4-in. and 8-in. brick nonload bearing walls, one-way arching	9.1 psi

c) Interior Partitions

Story	Description	Strength*
1 to 10	8-in. concrete masonry non-reinforced, nonarching	4.0 psi

d) Windows

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

The next step in this process is to assign weighting factors to each of the component areas selected. In this particular case this is done by assuming that one-tenth of the building occupants are located on each story. It is further assumed that under normal conditions few people would be located in the core area

*Strength relative to normal to the plane, nuclear weapon blast induced loads area E. Figure A.7a.b). Thus out of nine areas (A,B,C,D,E,F,G, H,I), seven are assumed to be occupied on the first story and eight on the upper stories. In each of the occupied areas people are assumed to be uniformly distributed. One further distinction is made. The computer program distinguishes between the first, second, third and fourth story by virtue of height. It does not distinguish between the fourth and higher stories as far as free-fall survival is concerned. Based on this discussion, the weighting factors are computed as shown below.

COMPUTATION OF COMPONENT AREA WEIGHTING FACTORS

Floor Level	Component Area	Weighting Factor
1st	ABC	1/10 of building x 2/7 of floor area = 0.028
1st	DEFGHI	1/10 of building x 5/7 of floor area = 0.072
2nd	ABC	1/10 of building x 3/8 of floor area = 0.038
2nd	DEFGHI	1/10 of building x 5/8 of floor area = 0.062
3rd	ABD	1/10 of building x 3/8 of floor area = 0.038
3rd	DEFGHI	1/10 of building x 5/8 of floor area = 0.062
4th	ABC	7/10 of building x 3/8 of floor area = 0.262
4th	DEFGHI	7/10 of building x 5/8 of floor area = 0.438
		Sum = 1.000

A.8 SAMPLE PROBLEM RESULTS

An echo printout of data used in the sample problem is shown in Table A.2. Survivors relative to the individual effects, i.e., debris, thermal radiation, translation and prompt nuclear radiation are given in Table A.3, as a function of free field overpressure. It will be noted that thermal and prompt nuclear radiation effects as considered herein do not distinguish between standing and prone personnel. Total (combined) survivors are given in Table A.4 together with free field overpressures at 10, 50 and 90 percent survivors. These results are also plotted in Figure A.8

Table A.2

ECHO PRINTOUT OF DATA

EXAMPLE BUILDING NO. 1

WALL TYPE	LENGTH	WIDTH	FLOOR LEVEL	WINDOW PERCENT	SILL HEIGHT	ROOM HEIGHT	ROOM DEPTH	ROOM WIDTH	WALL FAILURE PRES. EXTERIOR	INTERIOR	FACTOR	UPPER SILL HT
0 3	70.0	70.0	1	100.0	.0	12.0	70.0	20.0	.00	.00	.0780	.0
0 3	70.0	70.0	1	100.0	.0	12.0	20.0	50.0	.00	4.00	.0720	.0
0 3	90.0	90.0	2	70.0	3.0	10.0	60.0	30.0	9.10	4.00	.0380	.0
0 3	90.0	90.0	2	70.0	3.0	10.0	30.0	30.0	9.10	4.00	.0620	.0
0 3	90.0	90.0	3	70.0	3.0	10.0	60.0	30.0	9.10	4.00	.0380	.0
0 3	90.0	90.0	3	70.0	3.0	10.0	30.0	30.0	9.10	4.00	.0620	.0
0 3	90.0	90.0	4	70.0	3.0	10.0	60.0	30.0	9.10	4.00	.2620	.0
0 3	90.0	90.0	4	70.0	3.0	10.0	30.0	30.0	9.10	4.00	.4380	.0

Table A.3

PERCENT SURVIVORS FOR INDIVIDUAL EFFECTS

EXAMPLE BUILDING NO. 1

PERCENT SURVIVORS

OVERPRESSURE	DEBRIS (STANDING)	DEBRIS (PRONE)	THERMAL	TRANSLATION (STANDING)	TRANSLATION (PRONE)	IONIZING RADIATION
1	100.0	100.0	100.0	100.0	100.0	100.0
2	100.0	100.0	99.2	99.9	100.0	100.0
3	100.0	100.0	99.2	94.2	100.0	100.0
4	99.2	99.0	98.8	99.0	100.0	100.0
5	76.2	68.9	97.9	80.5	100.0	100.0
6	66.9	55.7	97.1	56.9	100.0	100.0
7	62.5	54.6	94.4	49.5	100.0	100.0
8	58.8	53.6	92.5	47.6	100.0	100.0
9	57.1	53.1	91.1	31.7	100.0	100.0
10	53.9	40.0	91.0	.0	38.9	100.0
11	48.8	37.4	91.0	.0	19.8	100.0
12	43.8	34.1	91.0	.0	17.5	100.0
13	41.2	32.6	91.0	.0	15.3	100.0
14	38.8	31.1	91.0	.0	13.1	100.0
15	39.2	31.4	91.0	.0	6.6	100.0
16	39.8	31.7	91.0	.0	.0	78.2
17	41.3	32.4	91.0	.0	.0	52.8
18	42.6	33.2	91.0	.0	.0	27.4
19	45.0	35.0	91.0	.0	.0	1.9
20	48.4	36.8	91.0	.0	.0	.0

Table A.4
TOTAL SURVIVORS

EXAMPLE BUILDING NO. 1

OVERPRESSURE	TOTAL SURVIVABILITY STANDING	PRONE
1	100.0	100.0
2	99.1	100.0
3	98.4	100.0
4	96.6	99.0
5	60.0	68.9
6	56.9	55.7
7	29.3	54.6
8	25.9	53.6
9	16.5	53.1
10	.0	15.9
11	.0	7.4
12	.0	6.0
13	.0	5.0
14	.0	4.1
15	.0	2.1
16	.0	.0
17	.0	.0
18	.0	.0
19	.0	.0
20	.0	.0
10 PERCENT	9.39	10.69
50 PERCENT	5.43	9.08
90 PERCENT	4.18	4.30

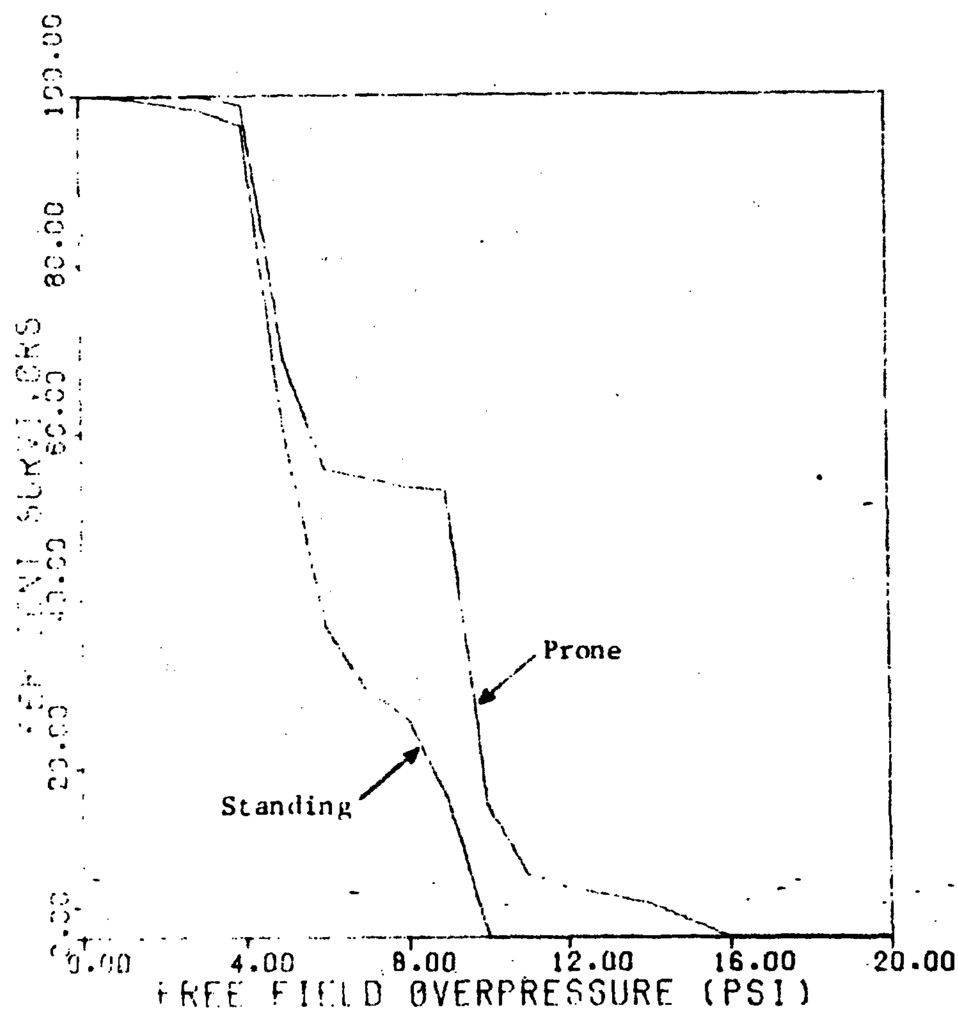


Figure A.8 Estimate of People Survivability
(Sample Building Number 1)

Referring to Table A.3 it will be noted that no debris casualties are produced prior to 4 psi. At 4 psi interior walls fail producing the first debris casualties. Wall failure also contributes to translation casualties (standing personnel) since the interior walls are cleared out. Additional translation casualties (initially standing and prone personnel) are produced after the exterior walls fail; note the jump from 31.7 to 0 percent (standing column) and 100 to 38.9 percent (prone column) Table A.3.

The reader is referred to Ref. A.2 which conains results of 50 buildings that were analyzed using this computer program. A data sensitivity study using this program is discussed in Ref. A.1.

REFERENCES

A.1 Longinow, A.; Ojdrovich, C.: Survivability in a Direct Effects Environment (Analysis of 25 NFSS Buildings), for DCPA. Contract DAHC20-72-C-0318. IIT Research Institute, January 1973

A.2 Longinow, A., Survivability in a Direct Effects Environment (Analysis of 50 NFSS Buildings), for DCPA, Contract DAHC20-73-C-0227, IIT Research Institute, July 1974

A.3 Longinow, A.; et al. People Survivability in a Direct Effects Environment and Related Topics, for DCPA, Contract DAHC20-68-C-0126. DCPA Work Unit 1614D, IIT Research Institute, May 1973

A.4 Feinstein, D. I.; et al; Personnel Casualty Study, for OCD, Contract OCD-PS-64-201, Work Unit 1125A, Subcontract B-10923 (4949A-24)-US, IIT Research Institute, July 1968

A.5 Longinow, A.; et al; "People Survivability in a Blast Wind Environment", presented at the ASCE National Structural Engineering Meeting, Cincinnati, Ohio, April 1974, Meeting Prepring 2241

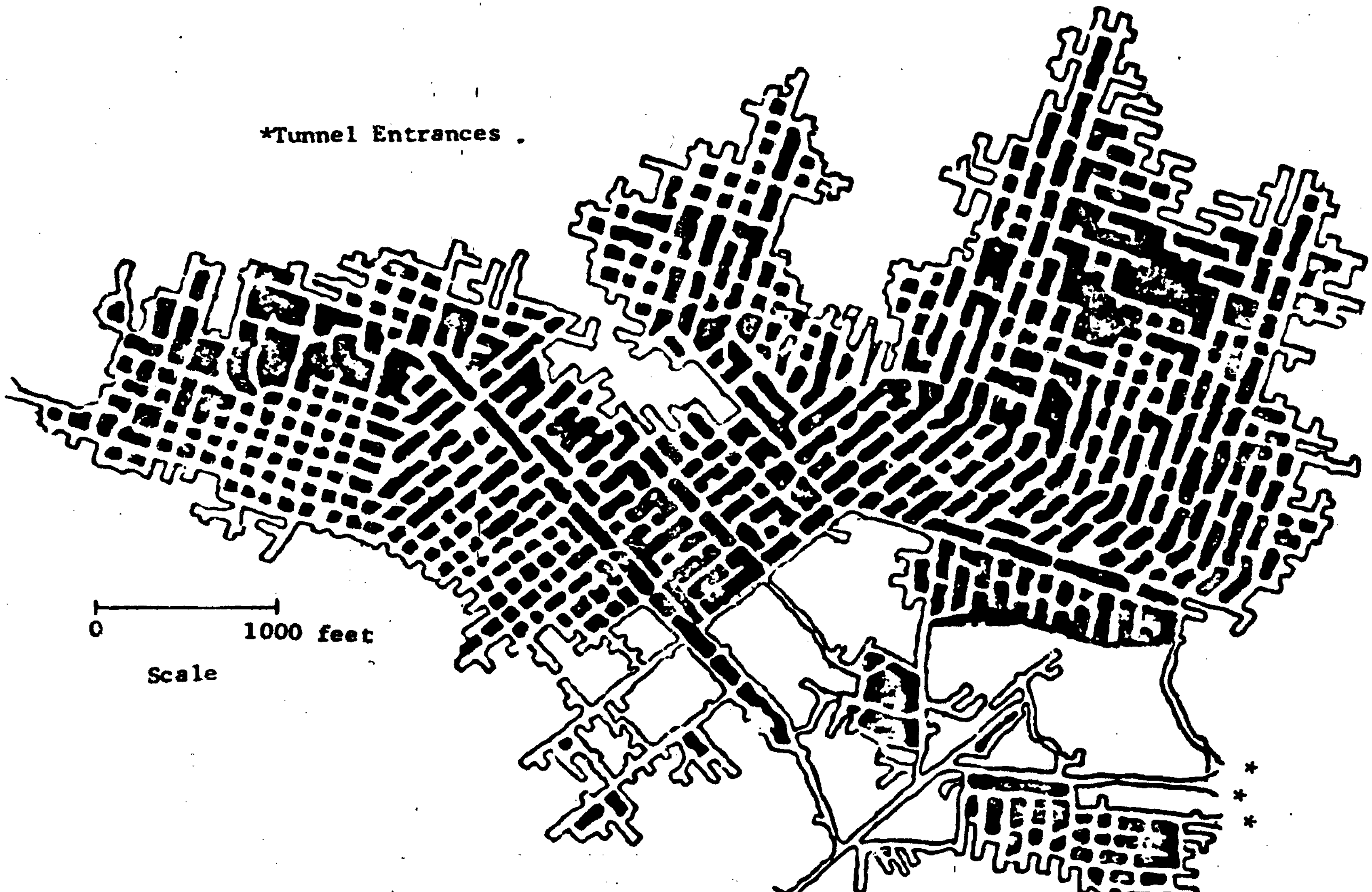
APPENDIX B

AIRBLAST ENVIRONMENT IN LARGE MINE SYSTEMS

The existence of very large limestone mines naturally raises the question as to their suitability as personnel shelters during a nuclear weapon attack situation. The answer to this question lies, in part, in the nature and intensity of the airblast environment which will exist in these mines under nominal attack conditions. Two specific mines were analyzed and predictions of blast environments were made. Details of these analyses are presented here and they show that the blast environments within these mines are relatively mild with the exceptions of certain limited regions, such as in or near the entranceways and in some instances at the back end of long mine systems.

Two specific mines were examine; one which is referred to as a large mine is illustrated in Figure B.1, the other is a substantially smaller mine. The large mine, or mine network, is of the "pillar and post" type and is thereby characterized by a complex interconnection of passageways (or air regions). This mine system has a total floor area of approximately 10 million square feet and a nearly uniform ceiling height of 15 ft. There are a number of entranceways or entrance tunnels which are approximately 40 ft wide (approximately 600 ft^2 cross-sectional area). The passageways within the tunnel system are also approximately 40 ft wide. The tunnel system is about 1 mi long and 1 mi wide.

The nuclear weapon threat treated in this analysis was the 20 psi overpressure level from the surface burst of a 1 MT weapon or more specifically a 20 psi blast wave with a 3.3 sec positive phase duration. This represents a rather high overpressure range and thus the evaluation can be considered as a somewhat worst case condition. The blast wave will interact with the local topography (considered to be somewhat hilly) and attenuate with increasing range. Any mine system, such as the "large" mine, which has many separated entranceways, will be exposed to a very complex blast input.



'igure B.1 Large Mine Complex

This blast input will depend upon the burst direction as well as topographical details and will manifest itself in that blast waves of various intensities will enter the mine system at different locations and at different times. Clearly the present analysis cannot treat the effects of all these variables, hence a near worst case situation was identified and used.

Before this worst case problem is discussed it will be significant to discuss the restrictions and applicability of the methods of analysis which are available. The simplest treatment which is available is the quasi-steady cavity filling analysis in which the mine is characterized by a volume and an inlet or flow area. In such an analysis pressure gradients within the system are assumed to be small. This analysis method is inadequate due to the rather long flow paths (approximately 5000 ft) within the system. The entering blast wave system will be weak (i.e., near sonic waves) and have a total length of approximately 3000 ft. Thus significant pressure gradients will exist in the interior regions of the mine and a wave analysis must therefore be used.

The nearly uniform roof height of the mine system simplifies the problem in that vertical pressure gradients will be very small. Thus a two-dimensional nonsteady analysis is indicated. Such an analysis would be extremely costly and difficult to perform due to the many interconnecting flow paths. Thus a one-dimensional nonsteady wave analysis must be used together with the use of certain approximations to account for the complex system of the mine. The blast wave which enters the relatively narrow entranceways of the mine will spread out as the number of passageways or flow areas increases. The blast wave disturbance will also interact with the pillars and many local shock reflections and rarefaction wave systems will be generated. These disturbance systems will only modify the pressure field in the immediate vicinity of the pillars and their time averaged effect will tend to vanish. Thus the most significant geometric characteristic of the mine system is the effective flow area as observed by the pressure disturbances.

Lines of constant minimum propagation time (based on weak waves traveling at sonic velocity) were determined for a variety of blast wave entering conditions and were used to establish the cross-sectional flow area of the mine as a function of a flow distance; the spacial variable for the one-dimensional variable area analysis used. These isochronal lines are illustrated in Figure B.2 for the four entranceways clustered in the lower right-hand corner.

The problem which is illustrated in Figure B.2 was considered to be the worst case due to the fact that the maximum entrance area condition is considered. This parameter is not the only consideration as the expansion area (ratio of flow area to entranceway area) is also a factor. Nonetheless this case is the worst case and should represent the most severe blast environment occurring within the mine system.

The expansion area, or area factor is presented in Figure B.3 as a function of distance from the entrance. A one-dimensional variable area nonsteady wave analysis was performed subject to a 12.3 psi overpressure blast wave condition at the entrance location ($x = 0$). This overpressure magnitude results from the interaction of a 20 psi overpressure wave at the tunnel portals and corresponds to a side-on wave orientation. Such a wave orientation is the most probable orientation. More severe orientation would only produce locally higher pressures which would rapidly decay due to clearing effects. These higher pressures would be restricted to the entrance region ($x < 500$ ft) of the tunnel system. The peak overpressure occurring within the mine is also presented in Figure B.3 for the case evaluated. The maximum overpressure for the central region of the mine is approximately 2 to 2-1/2 psig and should be acceptable for personnel exposure. The pressure reduction, when measured by the outside overpressure level is a factor of approximately 20.

The pressure history at two locations in the mine are presented in Figure B 4. Quite clearly the region near the entranceway is unacceptable as is a narrow region near the back of the mine.

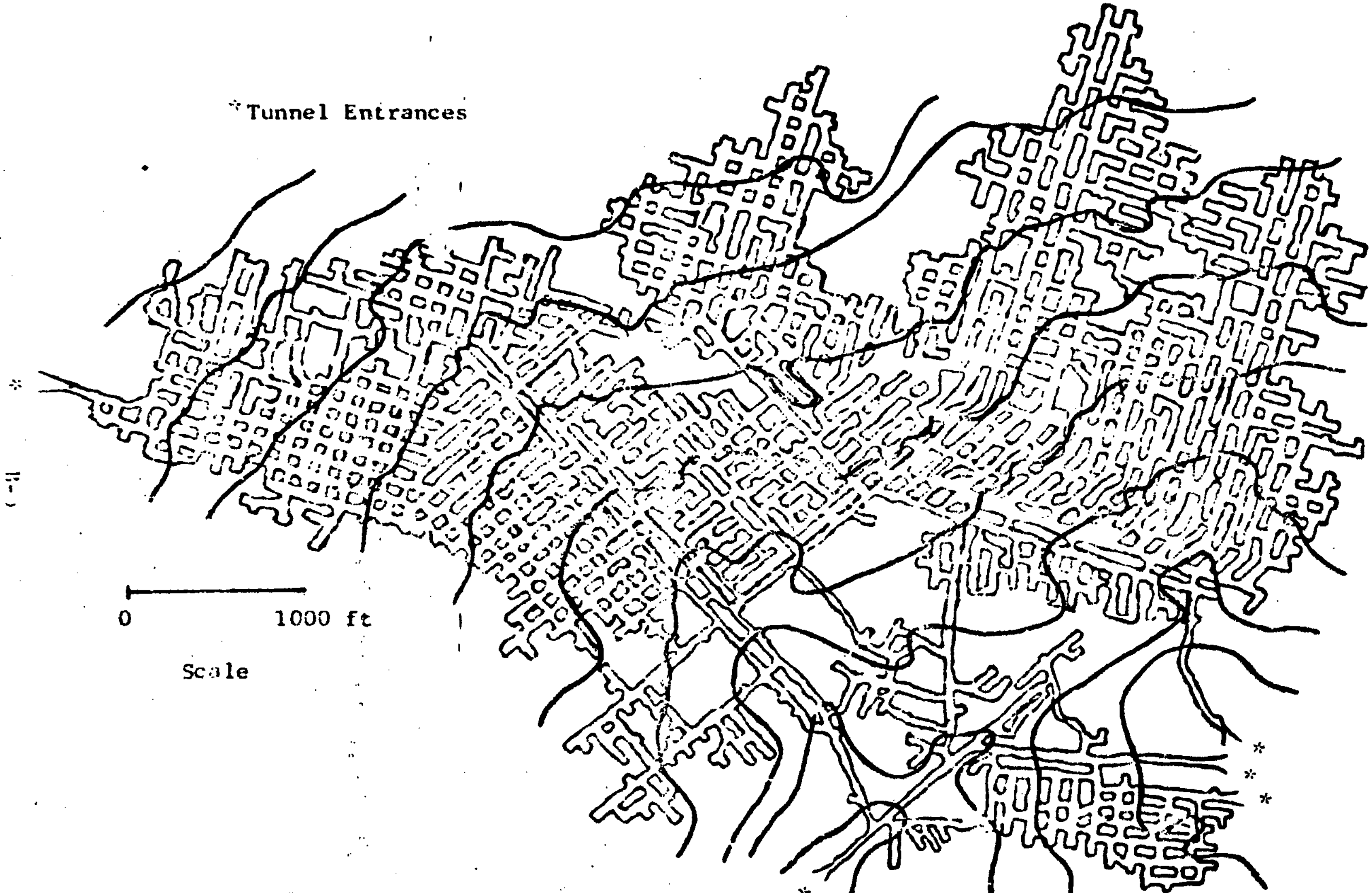


Figure B.2 Lines of Constant Minimum Propagation Time

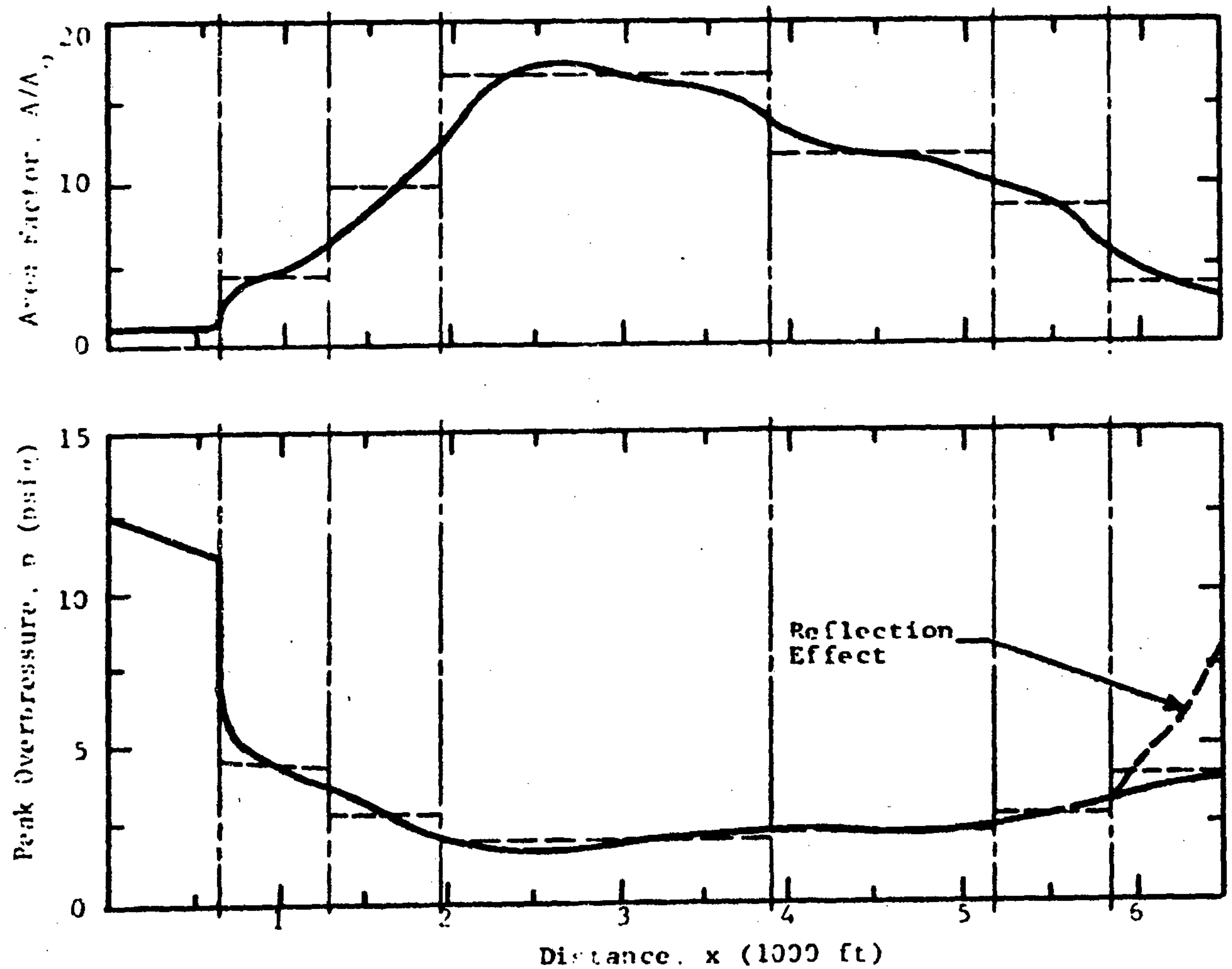


Figure B.3 Geometry and Blast Environment - Large Mine

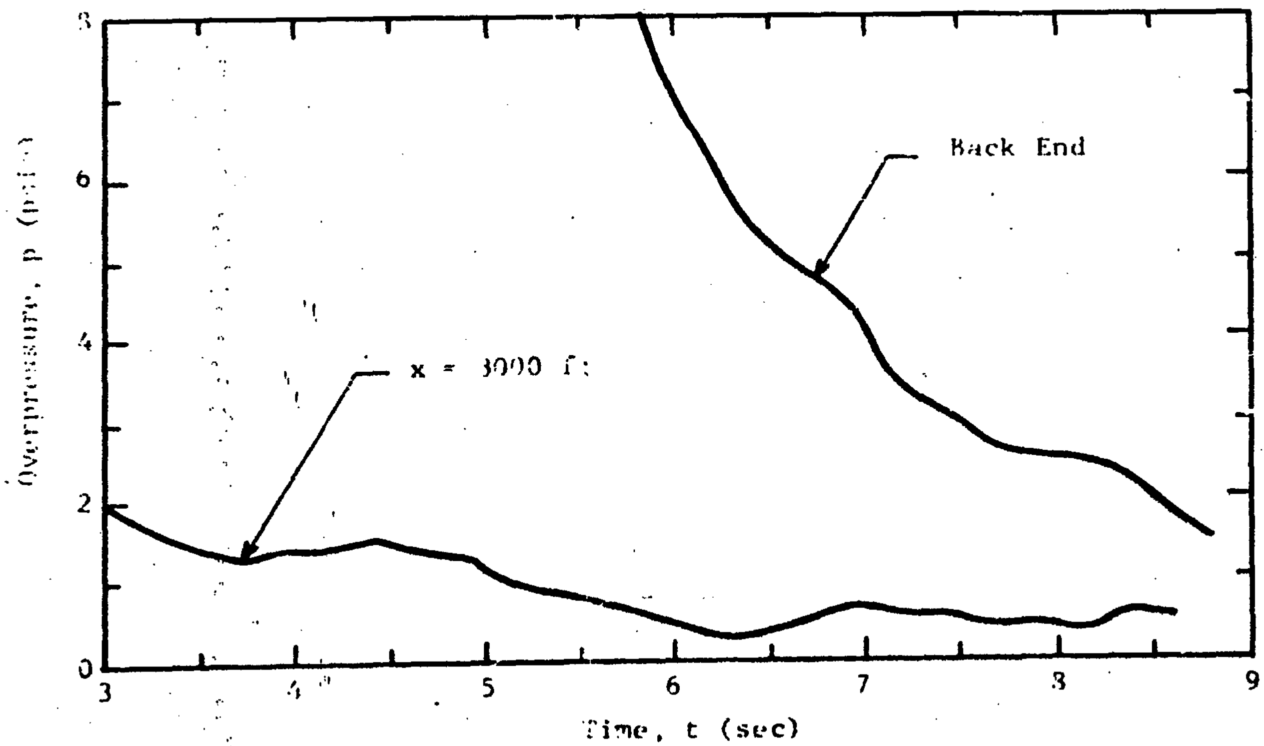


Figure B.4 Pressure Histories in Large Mine

The pressure in this "rear region" is amplified due to large scale reflection effects. This rear region can be identified in Figure B.2 as that region near the entrance at the left end. This region would be considered an exclusion area for the case of a blast wave entering the mine system from this entranceway. The analysis does not bring out the fact that other semilocal reflection areas may also exist. It would be advantageous to eliminate any rear regions which are somewhat confining such as that narrow region which is at the very top of the mine as illustrated in Figure B.2.

The second mine (the small one) which was examined is illustrated in Figure B.5. No details of this mine were available, however some conclusions about its acceptability as a personnel personnel shelter can still be made. A quasi-steady cavity filling analysis would be applicable for this mine since the length of the mine is considerably less than the wave length of the free field blast wave (approximately 3000 ft) and in general the pressure gradients should be small. Some moderate pressure gradients or shock effects will exist in and near the entrance tunnel. The peak cavity pressure can be estimated by evaluating the value of the parameter, ι

$$\iota = \frac{V}{A\, c_o\, t_o} \approx 30$$

where

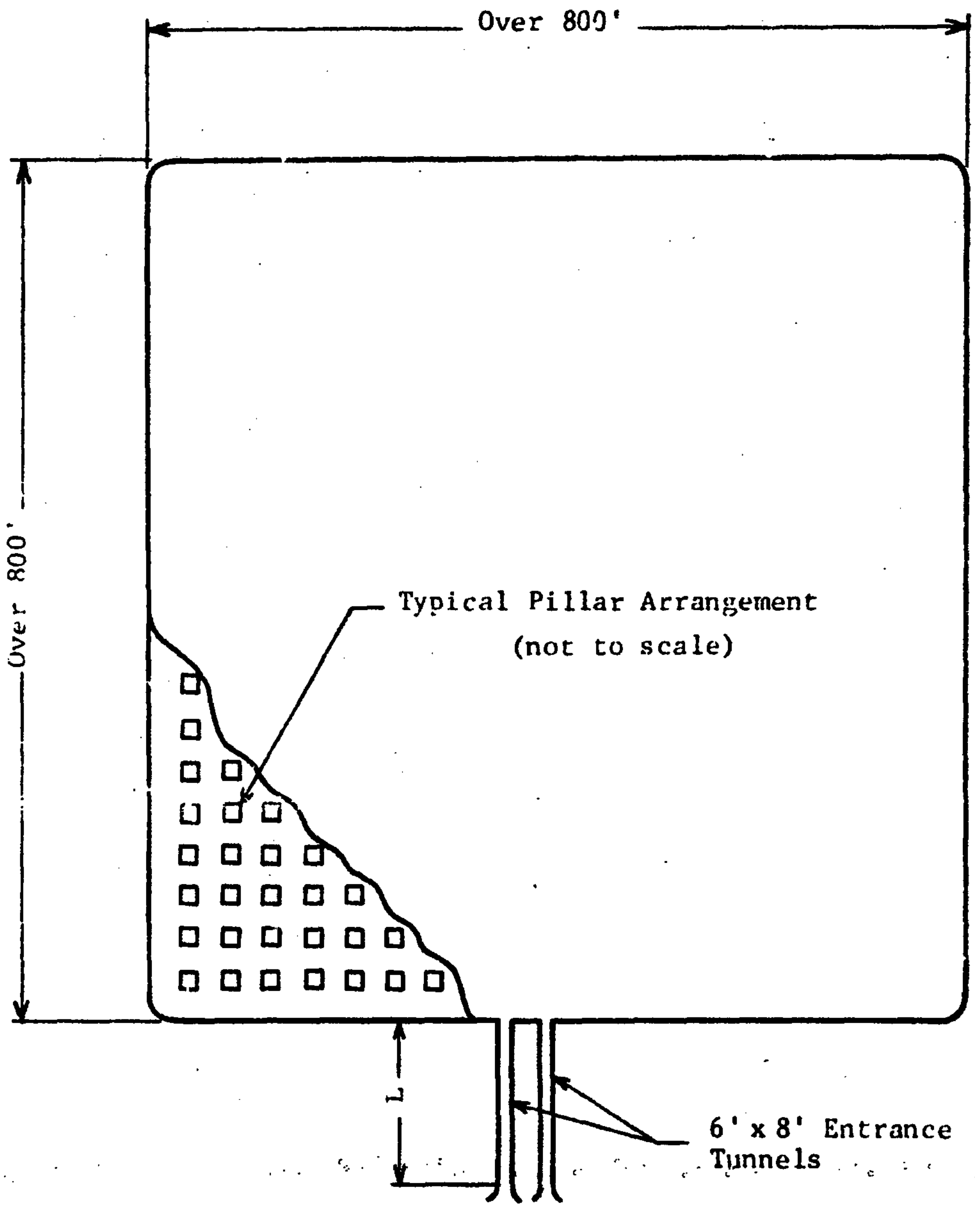
V = cavity volume (9.8×10^5 cu ft)

A = entrance flow area (96 sq ft)

c_o = sonic velocity (1130 fps)

t_o = positive phase duration of blast wave (3.3 sec)

Such a large value indicates that the peak cavity pressure will be equal to approximately 0.05 times the free field overpressure or about 1.0 psig. A simple wave evaluation considering the area enlargement (approximately a factor of 100) of the mine tunnel location indicates a shock attenuation factor of approximately



Floor Area:	15 acres = 653,400 ft^2
Ceiling Height:	15 ft
Total Volume:	9.8×10^6 ft^3
Total Entrance Area:	96 ft^2

Figure B.5 Small Mine

0.02 hence the 12.3 psi wave which enters the tunnel will be reduced to approximately 0.25 psi. This reduction will occur gradually hence an exclusion area in the vicinity of the sudden area enlargement should be established. This region could be defined by a radius of approximately 40 ft ($\sim 5 \cdot \sqrt{A}$).

Both of the mines examined should be adequate as personnel shelters for large yield nuclear attack conditions when free field overpressure is moderate (no greater than 20 psig) to low in intensity. Certain regions in the vicinity of the entrance tunnels should be excluded to avoid the locally higher blast pressures which are associated with the inlet region. Furthermore, for long mines, a small region near the rear of the mine should also be excluded due to shock reflection effects. The low intensity waves which enter the mine should be acceptable in terms of the response of humans to such a stimulus. The strength of the wave can be reduced by further restricting the size of the entranceway. It should be noted, that although the intensity of the blast environment is sufficiently low to render these mines acceptable with respect to blast overpressure effects, other shelter requirements must be considered. These mines may be unique in that rather large quantities of dust are potentially available on the floor and other interior surfaces and the blast wave will loft some of this particulate matter during the filling phase. This dust environment could be rather severe unless the mine surfaces are cleaned or stabilized.

SUMMARY

CASUALTIES PRODUCED BY IMPACT AND RELATED TOPICS OF PEOPLE SURVIVABILITY IN A DIRECT EFFECTS ENVIRONMENT

Final Report

DCPA Contract DAHC20-73-C-0196
DCPA Work Unit 1614D

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Washington, D. C. 20301

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Approved for public release;
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DCPA Review Notice

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SUMMARY

CASUALTIES PRODUCED BY IMPACT AND RELATED TOPICS OF PEOPLE SURVIVABILITY IN A DIRECT EFFECTS ENVIRONMENT

For the purpose of planning for the safety of the population in the event of an emergency the civil defense planner requires knowledge on best available shelter space in his community. Conventional buildings constitute the only significant, current sheltering resource. Each of them possesses some level of inherent ability in providing protection not only against the effects of nuclear weapons but also against natural disasters such as earthquakes, tornados and hurricanes. It is therefore 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 so as to gain full advantage of these capabilities in any emergency situation.

In line with this, the emphasis of this study is on the survivability of people in the upper stories of conventional buildings when subjected to the blast effects of nuclear weapons. Specifically it seeks to determine the relative importance of various types of impact in producing casualties. This aspect of the problem is described in Chapter 1. Subsidiary topics include classification of shelter spaces, analysis of an Emergency Operating Center, analysis of a fallout shelter against the effects of blast and the feasibility of using mines as personnel shelters. A computer program used (Ref. 1) in analyzing the survivability of people in conventional buildings is also described.

Casualties Produced by Impact

Blast environment-people interaction in the upper stories of conventional buildings is a complex problem. In this environment casualties are produced predominantly by impact which results from the following effects and casualty mechanisms.

> Dynamic Pressure (high velocity winds) associated with the passage of a blast wave will cause people to lose balance, be rotated, and translated, terminating in impact

on hard surfaces (floor, walls, furniture) with various parts of the body. In addition to setting people in motion, dynamic pressures will also set loose or attached objects in motion. Building components such as window frames and glass, mounted equipment, walls and partitions loo ened or separated by the blast wave become moving, lethal debris under the action of blast winds. These can interact with people located in their paths producing impact casualties.

To determine the relative importance of various categories of impact to which people in the upper stories may be subjected when exposed to the blast effects of nuclear weapons, an analysis method capable of approximating the complex environment was developed. It is illustrated in flowchart form in Fig. S-1. As indicated in this illustration, the procedure makes use of previously computed and stored information, i.e., debris trajectories and people (building occupant) trajectories. Debris trajectories were calculated for a range of free field overpressures, debris sizes, initial coordinates, and times to separation. People trajectories were also calculated for a range of free field overpressures, initial coordinates and initial body position, i.e., standing, prone and parallel to the direction of blast, prone and perpendicular to the direction of blast.

This analysis procedure allows one to define a building area in terms of physical parameters such as story height, bay width, floor level, window percent, sill height and wall failure overpressure. Building area occupancy is defined by specifying coordinates at which people (in the three initial body positions) are located. Respective trajectories are then compared at each time step to determine if interactions occur. If interactions occur, points of contact are determined and relative velocities between the person and debris at the point of contact are computed. This is done for each person and each piece of debris providing that impact occurs within the building (bay) length. By the location of the contact point, three types of impact are identified, i.e., head impact, thorax-abdomen impact, lower limbs impact. Relative velocity values for each impact and person are compared with casualty criteria to establish the level of casualty.

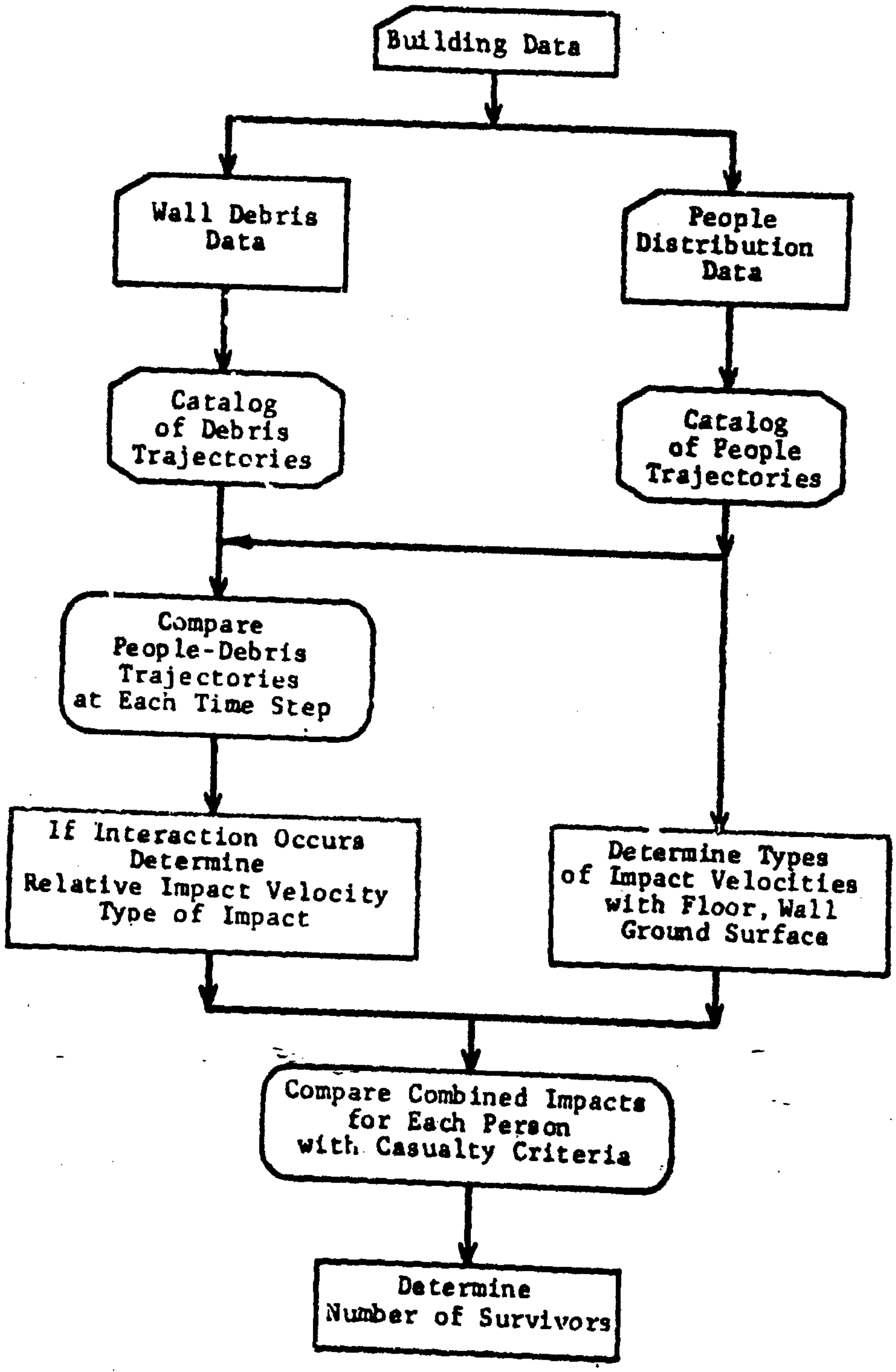

Fig. S-1 Impact Casualty Analysis Process

Having completed the debris interaction analysis, the procedure then goes to determine floor and ground plane impact velocities for each building occupant subjected to these casualty mechanisms. Results are compared with casualty criteria and corresponding levels of casualty are combined with those determined for debris impact. This information is then used to predict the combined probability of survival.

Using the procedure described, people survivability analyses were performed for a variety of different building areas characterized by bay width, building length, story height, wall failure overpressure, assumed wall debris and window size. Results indicate that debris produced by the breakup of building walls can be a significant casualty producer for people in the upper stories of conventional buildings.

Classification of Shelter Spaces

This portion of the study was concerned with the feasibility of developing a classification system for conventional buildings in terms of best available shelter space. An existing computer program (described in Appendix A) developed for the purpose of predicting the survivability of people in conventional buildings, was used to generate results for ranges of building parameters. A regression analysis was performed to rank the building parameters and thus determine their significance in contributing to people survivability. Resulting regression analysis equations were then used to generate a basic classification system in terms of six building parameters.

It is concluded that a general classification system is feasible and can be developed. However, for it to be usable at any civil defense level, the effort should be preceded by a field data analysis study. Its purpose would be to categorize all significant building parameters and to establish the significance of their variability on the final results, i.e., people survivability.

Function Loss Analysis of an Emergency Operating Center

This portion of the effort was concerned with the analysis of an existing Emergency Operating Center (EOC) to determine its "function loss" and people survivability when subjected to the direct effects of a single, megaton range nuclear weapon. A recently constructed Police Administration and Public Safety building which houses an EOC was analyzed. The probability of function loss was determined based on the response of mechanical and communications equipment to the effects of blast pressures and debris.

Analysis of a Fallout Shelter
Against the Direct Effects of Nuclear Weapons

The purpose of this effort was to determine how much direct effects protection is provided by a 50-person, gable roof shelter primarily designed for fallout protection. The analysis performed focuses on how the structure succeeds or fails to withstand the effects of blast. An estimate of occupant survivability was determined on this basis.

"BUILDINGS" Computer Program

The simulation model for predicting people survivability in conventional buildings against the direct effects of nuclear weapons, previously developed and described in Appendix C, Ref. 2., was revised and made into a self-contained computer program. This computer program is entitled "BUILDINGS" and is described in Appendix A. This appendix contains a brief discussion on the capabilities and limitations of the program, a user's manual and an example problem illustrating its usage.

Existing Mines as Personnel Shelters

A limited effort was devoted to the task of estimating dynamic pressures on the interior of two large existing mines when subjected to a 1 MT surface burst at the 20 psi range It is concluded that at least as far as dynamic pressures are concerned, such mines provide very adequate shelter space.

REFERENCES

1. Longinow, A., Survivability in a Direct Effects Environment (Analysis of 50 NFSS Buildings), Contract DAHC20-73-C-0227, for DCPA, IIT Research Institute, July 1974.

2. Longinow, A., et al, People Survivability in a Direct Effects Environment and Related Topics, Contract DAHC20-68-C-0126, Work Unit 1614D, for DCPA, IIT Research Institute, May 1973.