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IITRI Project M6101
Final Report

CIVIL DEFENSE SHELTER OPTIONS FOR
FALLOUT AND BLAST PROTECTION (DUAL-PURPOSE)

Contract No. OCD-PS-64-50
Subtask 1613B

for

Office of Civil Defense
Washington, D.C.

May 1967

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IIT Research Institute

IIT RESEARCH INSTITUTE
Technology Center
Chicago, Illinois 60616

IITRI Project M6101
Summary of Final Report

CIVIL DEFENSE SHELTER OPTIONS FOR FALLOUT AND BLAST PROTECTION (DUAL-PURPOSE)

by

A. Longinow

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CIVIL DEFENSE SHELTER OPTIONS FOR FALLOUT AND BLAST PROTECTION (DUAL-PURPOSE)

SUMMARY

A dual-use shelter may be defined as that structure which in addition to performing its primary function is capable of providing protection in times of emergency. The class of such potential shelters is extensive and for nuclear weapons environments having low effects intensities, may include virtually all of the man-made structures (both land based and water borne) having enclosed (protected) space, in addition to natural shelters such as caves.

During the past several years the class of dual-use structures has received a significant amount of attention among the numerous organizations engaged in this area of investigation. Radiation fallout as well as blast protection has been considered, the primary motivation being economic advantages. From an economic point of view dual-use shelters appear to be attractive to the fallout radiation effects region and for the same reason, the extension of this sheltering concept to a blast overpressure environment appears as an obvious route. Separate studies which exist and are of interest are those which consider in some detail all or certain of the major protection and habitability aspects of a shelter or system of shelters with respect to some nuclear weapons environment together with costs thereof. The present effort makes use of a number of such studies having the following objectives in mind.

- To determine for a nuclear weapons environment other than fallout radiation alone, the extent of the economic advantages of dual-use shelter systems with respect to the expected percent of population thus sheltered.

- To bring into sharper focus those areas in which more research is necessary in order to increase the effectiveness of this sheltering concept.

Efforts supplementary to the above objectives include:

- Estimated construction trends in selected types of construction (Appendix A)
- A limited study on the use of expressway grade separations as dual-use shelters. (Appendix B).
- Cost estimating and cost reporting as applies to dual-use shelters.

By the extent of economic advantages in the use of this class of structures as dual-use shelters, we mean that level of costs beyond which the costs of sheltering considerations begin to outweigh those of the primary function As used herein, this definition applied primarily to new construction. Its implications are discussed.

If the expected weapons environment is fallout radiation, a large number of conventional building concepts qualify as candidate shelters If this class is now restricted to include only schools, available information [1,2] indicates that if fallout shelters are considered in the planning state, the additional cost should not exceed 8 percent of the cost without a shelter for an average of 1700 spaces. Thus, if motivation to provide fallout shelters for schools exists, it is most often more economical to include them within the parent structure in its planning stage than to construct single-purpose shelters having the same capacity and resistance. At the other extreme however, i.e., for weapons environments of increasing severity, the problem is no longer as clear-cut and the point at which structural concept ceases to be a candidate is more difficult to establish. In any one case the solution may be found by means of a cost comparison on three different structures:

- Conventional structure.
- Conventional structure with dual-use shelter.
- Equivalent single-purpose shelter.

Such a cost comparison will provide the answer, however, the effort itself is costly and time consuming since these structures may be entirely different in concept depending on the severity of the given weapons environment. Also, in order to do justice to such a cost comparison, it is desirable to establish "survivability" functions in each case. This would add significantly to the overall effort. The importance of establishing "survivability" functions for personnel shelters is discussed below.

The effectiveness of a given shelter or shelter system relative to a weapons environment is its level of ability to provide protection against it. This level may be measured by the number or percent of expected survivors and, for purposes of this discussion, may be termed "survivability." For a given range of weapon environments then, the effectiveness of a shelter may be measured by the rate of survivability decline expressed in functional form. It is evident thus that two shelters having different structural systems but the same design environment will not necessarily have the same survivability functions for any given range of weapons environments.

Survivability, even though not referred to as such, is always considered in the design of conventional structures. In such a design process the designer determines the range of expected load magnitudes and loading conditions and within the scope of their influence selects the structural system most idealy suited to resist them. Under conventional circumstances a great deal of data is ordinarily available on expected loading conditions, so that specifications assuming a high degree of performance-safety and longevity (survivability) may be written.

Thus the problem of predicting loading conditions as well as survivability is ordinarily insignificant.

In the case of shelters however, loads and loading conditions depend on expected weapon environments. These are extremely difficult to predict and therefore "survivability functions" for possible ranges of weapons environments become important in planning and evaluating potential shelter systems. Such functions may be related to shelter costs, and when thus related become extremely useful planning and analysis tools. They would be especially useful in evaluating the sheltering and economic potential of dual-use shelters. In summary, a meaningful evaluation of the extent of economic and sheltering advantages or potential of a dual-use shelter or shelter systems would include a survivability related cost analysis for an expected range of weapon environments.

Up to the present time, dual-use shelter research has received a significant amount of attention. However, in the light of the previous paragraph, available results capable of meaningful answers on economics or sheltering potential of this class of shelters (especially if the weapons environments include direct effects in addition to fallout radiation) are relatively few. Quantitative evaluation of survivability, as described briefly above, is one area which has received virtually no attention.

Postulating the end result to be a set of data and analysis methods capable of answering the questions posed in the above discussion, it was the object of the effort reported herein to collect directly applicable and related information on the subject, determine and discuss the extent of its usefulness, update it where necessary and possible, and present it in a form usable for further investigation. Also, it was intended to bring into sharper focus those areas of the overall problem where further investigation is warranted.

Applicable data collected and analyzed in the course of this study are useful, even though in many respects it is not as complete as would have been desirable. It is not capable of definitive conclusions, but rather probably disconnected trends.

On the basis of available data it is concluded that a given candidate dual-use structure is to have a large quantity of enclosed space favorably distributed above and/or below grade, favorable foundation conditions, advantageous supporting system, type and materials of construction, as well as favorable location. There is good reason to believe that it is economically advantageous to incorporate blast and radiation resistant shelters in such structures in their planning stage having at least a 20 psi blast overpressure resistance and a "high" level of survivability. By the expression "economically advantageous," we mean that it is still substantially more economical to consider dual-use shelters in such environments than single-purpose shelters.

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IITRI Project M6101
Final Report

CIVIL DEFENSE SHELTER OPTIONS FOR FALLOUT AND BLAST PROTECTION (DUAL-PURPOSE)

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This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

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ABSTRACT

The effort reported herein is concerned with civilian dual-use personnel shelters. Its primary objectives are:

1. To determine for nuclear weapons environments other than fallout radiation alone, the extent of the economic advantages of dual-use shelter systems with respect to expected percent of population thus sheltered.

2. To bring into sharper focus those areas in which more research or analysis is necessary in order to increase the effectiveness of this sheltering concept.

Topics supplementary to the above objectives include:

Estimated construction trends in selected types of construction.

A limited study on the use of expressway grade separations as dual-use shelters.

Cost estimating and cost reporting as applied to dual-use shelters.

Results of this effort dealing with a large number of existing related topics are contained in this report. These results are in the form of assembled and updated costs as well as physical and environmental data and conclusions.

FOREWORD

This is the final report on IITRI Project M6101, OCD Subtask 1613B entitled "Civil Defense Shelter Options for Fallout and Blast Protection (Dual-Purpose)." The effort was sponsored by the Office of Civil Defense, Department of Defense, Washington, D.C. under Contract No. OCD-PS-64-50. Mr. George N. Sisson of OCD functioned as project monitor. The work was performed during the period of March 1965 to November 1966.

Several members of the IIT Research Institute staff have contributed to this study. They include E. Ahlers, who prepared Appendix A, L. Bujalski and A. R. Kardatzke, who prepared Appendix B.

Respectfully submitted,
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CHAPTER ONE

INTRODUCTION

Among numerous conventional type structures, those most ideally suited to provide protection against the effects of a nuclear weapons environment are those which:

- contain the most enclosed space for the largest number of persons,
- have a high level of inherent structural strength, radiation and fire resistance,
- are known to a large number of persons in the immediate vicinity,
- are accessible,
- have a wide geographic distribution and
- are of economic construction.

In the case of a fallout radiation environment, structural strength and fire resistance required by the local building and fire codes is often adequate. With these limitations removed, large numbers of existing conventional type structures qualify as dual-use shelters. Since shield mass and distance from the radioactive source are the governing factors in this environment, qualification of a given structure will depend, among other things, on the distribution and intensity of fallout radiation, the effectiveness of the given shields and the location of the space relative to the source. Structures that don't readily qualify may in many cases be economically and efficiently upgraded to meet the requirements.

The classes of structures which would qualify for dual-use in this environment are extensive; some of the more obvious examples are:

- underground parking garages,
- subway, railway and expressway tunnels,
- multistory basements of large apartment buildings and department stores, and upper stories of multistory buildings,

- basements of schools, community centers and other large public buildings,
- church and hospital basements, etc.

Every community has at least one of the structures listed above and perhaps several others which may be characteristic of that community and may be identified as potential candidates.

In the case of a blast overpressure environment, the problem is not as well defined and the number of conventional structures that would qualify as shelters even in the regions of low overpressures is considerably reduced as compared to the "fallout only" environment. Conventional structures are constructed to meet the requirements of local building and fire codes. These, even though conservative in many cases, are most frequently not adequate for reliable protection even in the low overpressure regions. In some instances earthquake motions and high wind velocities are considered; however, in general these are very localized cases.

From an economic point of view, dual-purpose shelters appear to be attractive in the fallout radiation effects region. For the same reasons, the extension of this sheltering concept to a blast overpressure environment appears as an obvious route. However, at increasing levels of overpressure, economic advantages are not expected to remain constant and a point will be reached at which for a given conventional structure this sheltering concept is no longer economical, even though a portion of the total cost is borne by the structure's primary function. This may be illustrated as follows. Strictly from the constructional cost point of view, if the cost of incorporating a shelter in a given structure is 5 percent of the cost of the parent structure, and 20 percent of the cost of a single purpose shelter with the same capacity and resistance, then the advantages are obvious. On the other extreme, however, if the shelter cost is as much as the cost of the single purpose structure itself, it may be advisable to seek different sheltering concepts. A single purpose shelter may be a better choice. The point at which such a crisis occurs will not be reached at the same overpressure level for all structures. The cost of hardening a warehouse or an airplane hanger, where large spans and a minimum number of load-carrying columns are requisite for its primary function, will become uneconomic at a lower overpressure level than in the case of hardening a school with a full basement. A school structure allows a great deal more freedom of maneuver by means of various slanting and strengthening techniques and materials, even to the point of not altering its conventional type architectural concept.

The planning and development of a specific community type protective shelter system may be limited by available funds. Having defined the nuclear environment within the limitations of the state-of-the-art, it becomes desirable to know, without expending a great deal of time and effort, which of the existing structures and those planned for future construction may be utilized within the given economic limitations and with what sheltering results.

The questions posed by this problem are pertinent to this study and thus deserve a closer look. The general problem and its solution for a blast overpressure environment may be outlined as follows:

1) Definition of the Nuclear Weapons Environment

    Sizes of Nuclear Weapons

    Design Levels of

        Incident Overpressure
        Initial Radiation
        Fallout Radiation

    Expected Fire Conditions

2) Description of Community (residential or industrial)

    Urban, Suburban or Rural

    Number of Persons Requiring Sheltering

Area Covered

Population Distribution

3) Shelter Mix and Site Selection

Available Shelter Space and Equipment (potential candidate structures, existing and planned)

Available Area

Levels of Inherent Protection

Equipment Adaptable for Shelter Use

Cost of Adaptation

Additional Required Shelter Space and Equipment

Cost of Upgrading Existing Structures

Cost of Incorporating Shelters in Planned Construction

Cost of a Single Purpose Shelter

Cost of Equipment

The effort implied in item 3, aside from identifying potential candidate shelters, is formidable. For emphasis it may be broken down into the following tasks:

1) Evaluation of existing candidate structures in order to determine their inherent levels of protection.

2) Determination of the cost of upgrading those candidate structures which do not meet the requirements of the given nuclear weapons environment.

3) Determination of the cost of incorporating shelters in conventional structures planned for construction in the near future.

4) In the event that shelter space(which offers the required degree of protection) obtained by tasks 1,2 and 3 is insufficient, then it is necessary to cost additional shelters.

When the nuclear weapons environment is fallout radiation, sufficient information is available such that fairly quick and reliable estimates may be made. However, in the case of a blast environment, corresponding information is available to a considerably lesser degree and decreases with increasing severity of weapons effects. This is not to imply that no work has been done in this area; on the contrary, the subject of dual-purpose civilian blast shelters has received considerable attention among numerous organizations engaged in this area of investigation. Separate studies which exist and are of direct interest here are those which have considered in some detail all or certain of the major protection and habitability aspects of a shelter or a system of shelters with respect to some nuclear weapons environment, together with costs thereof. Such existing studies include:

- Existing schools and other structures built with fallout radiation protection.[1,2,5,8,15,16]
- Schools designed for fallout radiation protection and subsequently upgraded and costed for low level blast overpressure environments.[9,10]
- Case studies of single purpose shelters (blast overpressure environment).[29]
- Comparative cost studies of dual-purpose shelters for fallout radiation and blast overpressures up to 60 psi for the following classes of conventional structures:

  Schools[13,14,15]

  Community Centers[19,20]

  Expressway Grade Separations

  Parking Garages[22]

  Warehouses[24]

  Administration Building[24]

  Communications Building[24]

  Office Buildings[25]

  Vehicular Tunnels[27,28,31]
- Other miscellaneous studies concerned with providing technical and cost estimating guidance for placing protective shelters near single family dwellings, in churches, etc.

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* Superscript numbers refer to references listed at the end of the report, page 153.

Conventional type structures considered in the studies listed are some of the more obvious candidates in the category of dual-use shelters.

As has been pointed out earlier, below certain nuclear weapons environment levels as yet not established, this class of shelters possesses certain distinct economic advantages, namely:

- many of the candidate structures occur frequently and in large numbers throughout the country,
- possess large areas of enclosed potential shelter space,
- contain during large portions of the day large numbers of potential shelter occupants,
- will continue to be constructed at some rate in order to meet future peacetime needs.

With a number of such separate studies dealing with this subject available, it appears advisable to review them at this time, rather than increasing their inventory, and to note their advantages and short-comings and reduce their costs to a common basis for purposes of a comparative analysis. Two primary objectives of such a study are given below.

1) To determine for a nuclear weapons environment other than fallout radiation alone, the extent of the economic advantages of dual-purpose shelter systems with respect to the expected percent of population thus sheltered.
2) To bring into sharper focus those areas in which more research or analysis is necessary in order to increase the effectiveness of this sheltering concept.

The results of such an effort, dealing with studies listed previously are contained in this report.

In all dual-purpose shelter concepts considered, it was assumed that the shelter space in question would be available to the public in times of emergency. This is an important planning criterion, but not necessarily a realistic assumption. These structures do not fall into a single category of ownership. Some of them may be owned by Federal and State Governments, some by the local community; however, the great majority of them are privately owned by individuals and groups of individuals. Thus the problem of incorporating as well as devising an optimum protective shelter system in any geographic area or community may be a substantial portion of the overall problem of protective shelter systems. Since it is dependent on the awareness of a substantial number of individuals, this problem is formidable, and if sufficient motivation of individuals cannot be mustered, one solution may be by means of some form of federal legislation with a partial funding provision as has been proposed in Western Germany. The following is a quotation from a current source dealing with Civil Defense Systems in Western Germany.

> "The German civil defense program has relied heavily on private citizens and on land and local governments to make voluntary preparations for defense. But, in the opinion of the German government, this approach has not resulted in the development of an adequate system. Despite intensive efforts by the government to educate the public to the danger of thermo-nuclear war and to the effectiveness of possible countermeasures, the voluntary system has failed. The government has therefore sponsored legislation prescribing a compulsory system with almost total federal control. Under this legislation, the government would be authorized to establish all-embracing emergency organizations, to conscript cadres to man these organizations, and to prescribe extensive training and realistic exercises in peacetime. The proposed laws would also grant sweeping emergency powers to the government to enable it to respond effectively in an emergency.
>
> Despite the problems of program implementation, German civil defense planners have developed a complete and well-integrated concept of emergency operations. The concept involves a system that has been devised to cope with the effects of a possible thermo-nuclear war, but which may also function during a limited war or natural disaster." 30

This legislation, put before the German Parliament in 1965, covers only compulsory shelters in new buildings and incentives for building shelters in existing buildings. All shelters will be required to have at least a 14-day supply of food and water. Public shelters must allow at least 7.5 sq ft per person, including ventilation equipment and sanitary and living space. Studies are currently under way to construct public shelters in subways, and due to the large programs in many German cities for the construction of underground garages, public shelters are either being built in these facilities or are under consideration.

CHAPTER TWO

COMPENDIUM OF PROTECTIVE SHELTER STUDIES

2.1 INTRODUCTION

The objective of this chapter is to present the data and conclusions of a comparative cost analysis of a number of existing dual-purpose personnel protective shelter studies. References considered include case studies of structures characteristic of specific geographic regions as well as those having the facility of wide application. In some cases the structures discussed have been built and are in use at this time. The nuclear weapons environments considered, range from fallout radiation alone to a blast overpressure environment of 60 psi.

All studies considered herein are presented and discussed separately. Each reference is summarized and pertinent data presented in tabular form. For each shelter concept the data include:

- Structural and constructional characteristics.
- Materials of construction.
- Shelter capacity.
- Nuclear weapons environment considered in design.
- Total and incremental costs.

Explicitly omitted are considerations of siting and evaluations of vulnerability. These aspects were not treated in the references discussed. In all cases, an attempt was made to reduce the costs to a common base for purposes of comparison. In doing this, a certain amount of difficulty was encountered. This was primarily because of the fact that no uniform or standard procedure of cost estimating exists among the community of investigators concerned with the design and analysis of shelters. In order to circumvent this difficulty in the future, a recommended cost reporting procedure is outlined and discussed in detail in Appendix C of this report. Coupled with the difficulty mentioned before is the fact that the objective of the various studies considered herein was not the same in all cases. Some were specific case studies that were concerned with sheltering and habitability, others with the integrity of the essential structure and basic equipment, etc. Several of the references were concerned with demonstrating to the interested citizen that a high degree of fallout protection in conventional structures can be obtained at little or no additional cost. The latter were not intended to be research reports, and thus lack the detail that would add greatly to their value. For reasons given previously, in certain cases assumptions needed to be made in order to reduce the data to a common base and make a cost comparison possible. Conclusions arrived at as a result of the comparison are given at the end of this chapter.

2.2 <u>SCHOOLS BUILT WITH FALLOUT SHELTERS</u>[1,2]

2.2.1 <u>General Description</u>

Data listed and itemized in Tables 2.1 and 2.2 have been extracted from references 1 and 2. The structures in question are existing schools, portions of which have been designed to provide protection against the fallout effects of nuclear weapons. Incorporation of shelter areas appears to have caused no obvious interference with their primary function. In fact, all such areas are in use as part of normal school facilities. Many of the schools have basements; these house classrooms, cafeterias and other normal facilities which double as shelters in times of emergency. Schools without basements provide shelter space in various centrally located areas. In the case of an emergency, this class of structures possesses several advantages, namely:

- Schools have staffs which are trained to handle groups of people.
- Food service facilities and stores ordinarily exist.

Table 2.1

SCHOOLS WITH FALLOUT SHELTER[1]
(Existing Structures)

	1	2	3	4		5	6		7	8	9	10	
				Capacity (Number of Persons)			Shelter Area						
	Name and Location	Type of Shelter Construction	Shelter Location Above or Below Grade	Based on Normal Function	Shelter	Total Area of Parent Structure Gross sq ft	Gross sq ft	As Percent of Total Area	Shelter Volume cu ft	Minimum Headroom ft	Shelter Area per Occupant	Volume per Occupant	Fal F
1.	Blackwell Senior High School Blackwell, Oklahoma	R/C	Below Grade	600	406	68,100	4,880	7.2	39,000	8.0	11.95	96.2	4
2.	Denis J. O'Connel High School Auditorium Arlington, Va.	Masonry walls R/C roof	Above and Below grade	1,600	500	*	5,000	*	40,000	8.0	10.00	80.0	4
3.	South Salem Elementary School Salem, Va.	Circular inside corridor, R/C roof, masonry walls	Above grade	630	630	37,700	6,300	16.7	50,400	8.0	10.00	80.0	4
4.	S. Joseph Grade School St. Joseph, Ill.	R/C	Below Grade	650	650	17,000	6,800	40.0	54,400	8.0	10.45	83.6	4
5.	South San Antonio School Cafetorium San Antonio, Texas	R/C with brick finish	Above Grade	500	680	6,900	6,800	98.6	61,200	9.0	10.00	90.0	4
6.	Lorenzo Senior High School Lorenzo, Texas	R/C	Below Grade	300	700	54,100	7,000	12.9	63,000	9.0	10.00	90.0	4
7.	Somers Elementary School Somers, Connecticut	Steel frame and masonry, 8-in. R/C overhead shelter slab	Below Grade	600	700	54,800	7,100	13.0	60,400	8.5	10.02	85.0	4
8.	Homer High School Homer, La.	R/C	Below Grade	700	930	39,100	9,560	24.4	76,500	8.0	10.03	80.0	40
9.	Henry A. Bradshaw High School Florence, Alabama	Dome structure walls - concrete block, overhead shelter slab R/C	Above Grade	1,000	1,000	150,000	10,000	6.7	85,000	8.5	10.00	85.0	40
10.	Ledyard High School Ledyard, Conn.	R/C	Below Grade	*	1,100	92,000	15,000	16.3	120,000	8.0	13.6	109.0	40
11.	Bemidij Junior High School, Bemidji,Minn.	R/C shelter (basement and tunnels)	Below Grade	1,000	1,200	140,000	15,240	10.7	129,500	8.5	12.7	107.0	40
12.	Miami Springs Senior High School, Miami Florida	R/C shelter	Above Grade	2,000	2,000	172,000	18,000	10.5	161,500	8.5	9.0	76.5	40
13.	Junior High School 55 Borough of Brooklyn N.Y.	R/C shelter	Above and Below Grade	1,900	3,200	173,000	32,000	18.5	288,000	9.0 Average	10.0	90.0	40
14.	West Islip Senior High School West Islip, N.Y.	R/C	Below Grade	*	3,319	146,500	33,194	22.4	282,000	8.5	10.0	85.0	40
15.	Miami Senior High School Miami, Arizona	Above grade - R/C roof, masonry walls, below grade - R/C	Above and Below grade	*	3,100	126,000	39,680	31.5	337,000	8.5 +	12.8	109.0	40

* Indicates that information is not available

R/C Reinforced concrete

N/A Not applicable

Note: This table contains two types of costs:
1) as given in reference 1,
2) as adjusted to Chicago, Illinois area for the year 1964 (last column).

HELTER[1]
es)

10	11	12	13		14				
					Incremental Shelter Cost				
		Incident	School and Shelter Cost					Cost per sq ft of Shelter	
Volume per Occupant	Fallout P.F.	Overpressure Resistance psi	Total dollars	Total per sq ft	Total Cost of Construction dollars	Percent Construction Cost Increase	Per sq ft of Dual-Purpose Structure	As Given[1]	As Adjusted to Chicago, Ill. Area (1964)
96.2	40	N/A	858,347	12.60	0	0	0	0	0
80.0	40	N/A	900,000	*	0	0	0	0	0
80.0	40	N/A	437,400	11.60	6,000	1.39	0.16	0.95	1.32
83.6	40	N/A	187,623	11.04	6,800	3.76	0.44	1.00	1.00
90.0	40	N/A	110,000	15.95	2,000	1.85	0.29	0.29	0.39
90.0	40	N/A	660,935	12.22	10,000	1.54	0.18	1.43	1.92
85.0	40	N/A	780,400	14.22	14,500	1.89	0.26	2.04	1.78
80.0	40	N/A	336,713	8.62	23,455	7.49	0.60	2.46	3.30
85.0	40	N/A	2,000,000	13.36	1,500	0.08	0.01	0.15	0.26
109.0	40	N/A	1,227,960	13.35	34,500	2.89	0.38	2.30	2.00
107.0	40	N/A	1,654,000	11.82	0	0	0	0	0
76.5	40	N/A	2,167,700	12.62	0	0	0	0	0
90.0	40	N/A	4,046,220	23.40	0	0	0	0	0
85.0	40	N/A	2,426,858	16.62	85,000	3.63	0.58	2.56	2.32
109.0	40	N/A	1,764,000	14.00	0	0	0	0	0

Table 2.2

SCHOOLS WITH FALLOUT SH
(Existing Structure

	1	2	3	4		5	6		7	8	9
	Name and Location	Type of Shelter Construction	Shelter Location Above or Below Grade	Capacity (Number of Persons) Based on Normal Function	Shelter	Total Area of Parent Structure sq ft	Shelter Area Gross sq ft	As percent of Total Area	Shelter Volume cu ft	Minimum Headroom ft	Shelte Area pe Occupar sq ft
1.	Lincoln Elementary School Aloa, Oklahoma	R/c Overhead slab - 17 in.	Below grade on three sides (split level)	165	256	16,500	2,565	15.0	21,800	8.5	10.0
2.	North Central School Rogers, N. Dak.	Concrete block walls, R/C Overhead slab 10 in.	Below grade	356	615	43,000	6,500	14.0	55,200	8.5	10.6
3.	Mayville High School Mayville, Wisc.	Reinforced and pre-cast concrete roof - 12 in., R/C walls - 12 in.	Split level	560	760	111,686	7,600	6.8	64,600	8.5	10.0
4.	West Dunbar Elementary School Miami, Florida	R/C	Above Grade	800	1,000	49,729	10,000	20.0	85,000	8.5	10.0
5.	Bemus Point Junior High School, Chantau-gua Co., N.Y.	R/C Overhead slab wall material, not discussed	Above and Below Grade	1,180	1,000	116,000	11,000	9.5	93,500	8.5	11.0
6.	Center Senior High School Kansas City, Mo.	R/C	Below Grade	*	685	150,065	11,116	7.3	94,500	8.5	16.3
7.	Glades Junior High School Miami, Florida	R/C	Above Grade	1,200	1,472	96,882	14,720	15.0	125,000	8.5	10.0
8.	Cascade Junior High School Longview, Wash.	R/C Overhead slab - 8 in. R/C walls -12 in.	Above grade	850	1,800	90,423	18,000	20.0	153,000	8.5	10.0
9.	Miami Coral Park Senior High School Miami, Florida	R/C roof and walls	Above Grade	1,705	1,850	132,414	19,400	14.7	165,000	8.5	10.5
10.	Miami Coral City Senior High School Miami, Florida	R/C	Above Grade	1,400	1,750	136,000	21,300	15.7	181,000	8.5	12.2
11.	William Floyd Jr-Senior High School Shirley L.I., N.Y.	R/C	Below Grade	1,550	1,761	183,082	22,566	12.4	192,000	8.5	12.8
12.	United High School Loredo, Texas	R/C Overhead slab 14 in., R/C walls thickness not given	Below Grade	540	2,000	68,000	29,000	42.7	246,000	8.5	14.5
13.	Union Park Junior High School Orange County, Fla.	R/C	Above Grade	600	988	26,425	9,880	37.4	83,800	8.5	10.0
14.	Robinswood Junior High School Orange County, Fla.	R/C	Above Grade	600	988	26,425	9,880	37.4	83,800	8.5	10.0
15.	Carver Junior High School Orange County, Fla.	R/C	Above Grade	600	988	26,425	9,880	37.4	83,800	8.5	10.0
16.	Park Junior High School Artesia, N.M.	R/C	Below Grade	1,000	2,275	95,623	34,126	35.7	292,000	8.5	15.0
17.	East Central High School Tulsa, Okla.	R/C Overhead slab - 8 in. R/C walls	Partially below Grade	*	5,469	203,798	54,689	27.0	465,000	8.5	10.0
18.	Junior High School 201 New York, New York	R/C Overhead Slab - 10 in. R/C walls	Below Grade	1,860	5,600 +	190,396	70,000	36.6	595,000	8.5	12.5
19.	Goddard Senior High School Roswell, N.M.	R/C	Below Grade	2,000	6,500	186,273	82,273	44.2	700,000	8.5	12.7

* Indicates that information is not available

R/C Reinforced concrete

N/A Not applicable

** Cost numbers in parenthesis (column 14) indicate the cost of additional equipment (ventilation, electric and plumbing). Breakdowns of this cost are not available.

Note: This table contains two types of costs:
1) as given in reference 2,
2) as adjusted to Chicago, Illinois area for the year 1964 (last column).

2

OUT SHELTER[2]

uctures)

9	10	11	12	13		14				
				School and Shelter Cost		Incremental Shelter Cost				
Shelter Area per Occupant sq ft	Volume per Occupant cu ft	Fallout P.F.	Incident Overpressure Resistance psi	Total dollars	Total per sq ft	Total Cost of Construction dollars	Percent Construction Cost Increase	Per sq ft of Dual-Purpose Structure	Cost per sq ft of Shelter: As Given[2]	Cost per sq ft of Shelter: As Adjusted to Chicago, Ill. Area (1964)
10.0	85.0	100 +	N/A	201,000	12.12	5,130	2.62	0.31	2.00	2.68
10.6	90.0	*	N/A	468,000	10.88	30,000	6.85	0.21	4.62	5.30
10.0	85.0	*	N/A	1,464,800	13.10	14,000 (4,000)**	0.96	0.13	1.84	1.84
10.0	85.0	40 - 90	N/A	542,205	10.90	15,000 (10,000)	2.85	0.30	1.50	2.61
11.0	93.5	100	N/A	1,897,551	16.36	17,500 (7,500)	0.93	0.15	1.59	1.38
16.3	138.6	40 - 500	N/A	2,156,000	14.37	0	0	0	0	0
10.0	85.0	100	N/A	1,132,300	11.69	6,680 (11,720)	0.59	0.07	0.45	0.78
10.0	85.0	100 +	N/A	1,405,588	15.54	15,000 (18,000)	1.08	0.17	0.83	0.78
10.5	88.2	100 +	N/A	1,701,517	12.85	33,000 (8,000)	1.98	0.25	1.70	2.96
12.2	103.8	100	N/A	1,638,508	12.05	7,900 (19,300)	0.48	0.06	0.37	0.64
12.8	108.8	100 +	N/A	3,719,000	20.42	5,000 (36,000)	0.13	0.03	0.22	0.19
14.5	123.2	100	N/A	704,000	10.35	20,520 (32,346)	3.00	0.30	0.71	0.95
10.0	85.0	*	N/A	434,000	16.60	15,486	3.70	0.59	1.57	2.73
10.0	85.0	*	N/A	450,000	16.60	15,486	3.60	0.59	1.57	2.73
10.0	85.0	*	N/A	432,000	16.60	15,486	3.72	0.59	1.57	2.73
15.0	127.5	600 +	N/A	1,111,147	11.61	10,000 (49,200)	0.91	0.10	0.29	0.36
10.0	85.0	1000	N/A	2,752,700	13.51	0	0	0	0	0
12.5	106.2	*	N/A	4,812,145	25.27	0	0	0	0	0
12.7	108.0	600 +	N/A	1,944,070	10.42	13,000 (117,000)	0.67	0.07	0.16	0.20

- Schools represent administrative links to other schools.
- For a portion of the school day they contain readily assembled and organized potential shelter groups.

Shelter volumes given in Table 2.1 are approximate. However, it is felt that approximations are on the conservative side, meaning that very likely somewhat more headroom is available than has been estimated. The protection factor against fallout radiation for all structures in Table 2.1 is given as 40. In Table 2.2 this number varies and in a few instances is not available.

Sleeping accommodations for sheltered personnel are not discussed. However, if a tiered bunking arrangement is used, under certain favorable conditions the capacities of these shelters may be increased. Implications of this possible increase are discussed.

There are a number of ways in which personnel space in a given shelter may be allocated, these depend to a large measure on the length of the sheltering period. In a fallout radiation environment, the sheltering period is relatively long (about two weeks). During this period, people will need to perform the essential functions of eating, sleeping and recreating to some satisfactory degree, under restricted conditions. This implies a scheduled performance of sitting, lying down, standing and walking around. Space allocation, thus, will depend on some acceptable criteria under which these functions may be performed satisfactorily. Such criteria would be based on a host of psychological as well as physiological factors affecting various groups of people. Sleeping on bare concrete may, under the circumstances, be tolerable to young and physically healthy individuals; however, the shelter group may include old, very young and perhaps ill persons who may have a difficult time withstanding such conditions. In such a case, partial bunking or mattresses may alleviate part of the problem.

Bunking may also be used to accommodate more people in a given shelter by means of efficient tiering and bunk location. Here, however, aside from problems mentioned earlier, we are faced with the additional cost of air circulation as well as bunk purchase and storage. Many of the problems briefly mentioned above have been studied,[3,4] albeit no single all-embracing solution is as yet available.

Overpressures have not been considered as part of shelter design. This does not mean that in certain cases (basement type shelters) some low level of overpressure resistance is not inherent. Some of the basement type shelters, judging by the type of materials and construction employed (column 2, Tables 2.1 and 2.2), appear to possess a potential for economic reinforcement and, thus, would gain some level of overpressure resistance. In this case, costs of uprating would be of prime interest. This topic will be treated in a little more detail in connection with the discussion of reference 10.

2.2.2 Cost

Since the object of references 1 and 2 was to present a general picture, the costs are understandably not itemized, instead lump sum totals are given. These totals are designated as "construction cost" when referring to the cost of the whole structure, and as "shelter cost" when referring to the cost of the shelter.[1] The costs of the whole structure are designated as "total cost" in some cases and as "project cost" in others.[2] Shelter costs are given under the heading of "general construction". Discussions with authors of these publications, as well as correspondence with several of the contributing architects, indicate that all of these cost numbers may be treated as "direct contract" costs. This cost ordinarily includes materials, usual installed equipment, labor, contractor's overhead, profit and contingencies. A typical breakdown of such costs is given in the following outline.

Typical Direct Contract Cost Breakdown

- Structural and Earthwork
  - Excavation, backfill and grading
  - Concrete
  - Reinforcement
  - Wire mesh
  - Forms: roof slab, beams, columns and walls
  - Damp proofing, etc.
- Architectural
  - Cinder block
  - Toilet partitions
  - Resilient tile, asphalt
  - Concrete hardener/sealer liquid
  - Insulation board
  - Painting
  - Cement enamel finish
  - Doors
  - Stairs
  - Handrail, etc.
- Mechanical
  - Filters
  - Heating coil
  - Sheet metal ductwork
  - Registers and grilles
  - Automatic temperature controls
  - Piping
  - Plumbing fixtures
  - Insulation for plumbing, etc.
- Electrical
  - Wiring
  - Switches
  - Outlets
  - Fixtures
- Contractor's Profit and Overhead Contingencies.

It must be pointed out that the outline is subject to certain variations in the included items, depending on geographic regions of origin and/or policies of originating agencies. One example of an item which may be included in some direct contract cost estimates and not in others is permanently installed equipment. Venetian blinds may be considered as permanently installed equipment in some school districts and not in others, as may school desks and other items. Definitions vary and are subject to local building codes and ordinances. Since we are dealing with school costs from different parts of the country, such variations in the data are very likely.

Total, final cost of a building may be subdivided into three general groups, i.e.,

1) Preconstruction cost.
2) Construction cost.
3) Other costs.

Only the second will be considered in this report. In general construction costs represent between 85 to 95 percent to the buyer.

Costs given in Tables 2.1 and 2.2 are listed as they appear in the publications in question, i.e., with reference to the regions in which the various structures are located. For purposes of comparison they were also adjusted by means of current cost indices[5] to apply to the Chicago, Illinois area for the year 1964. As far as these two references[1,2] are concerned, it was assumed that bids were taken in 1964. Due to lack of information, no attempt was made to adjust the data further, i.e., as urban, suburban or rural.

On the basis of adjusted data, the variation of shelter area with cost per sq ft for shelters in Tables 2.1 and 2.2 is given in Fig. 2.1. In this figure the shelters were divided into three general categories by virtue of their location relative to the ground surface: above grade, partially below grade,

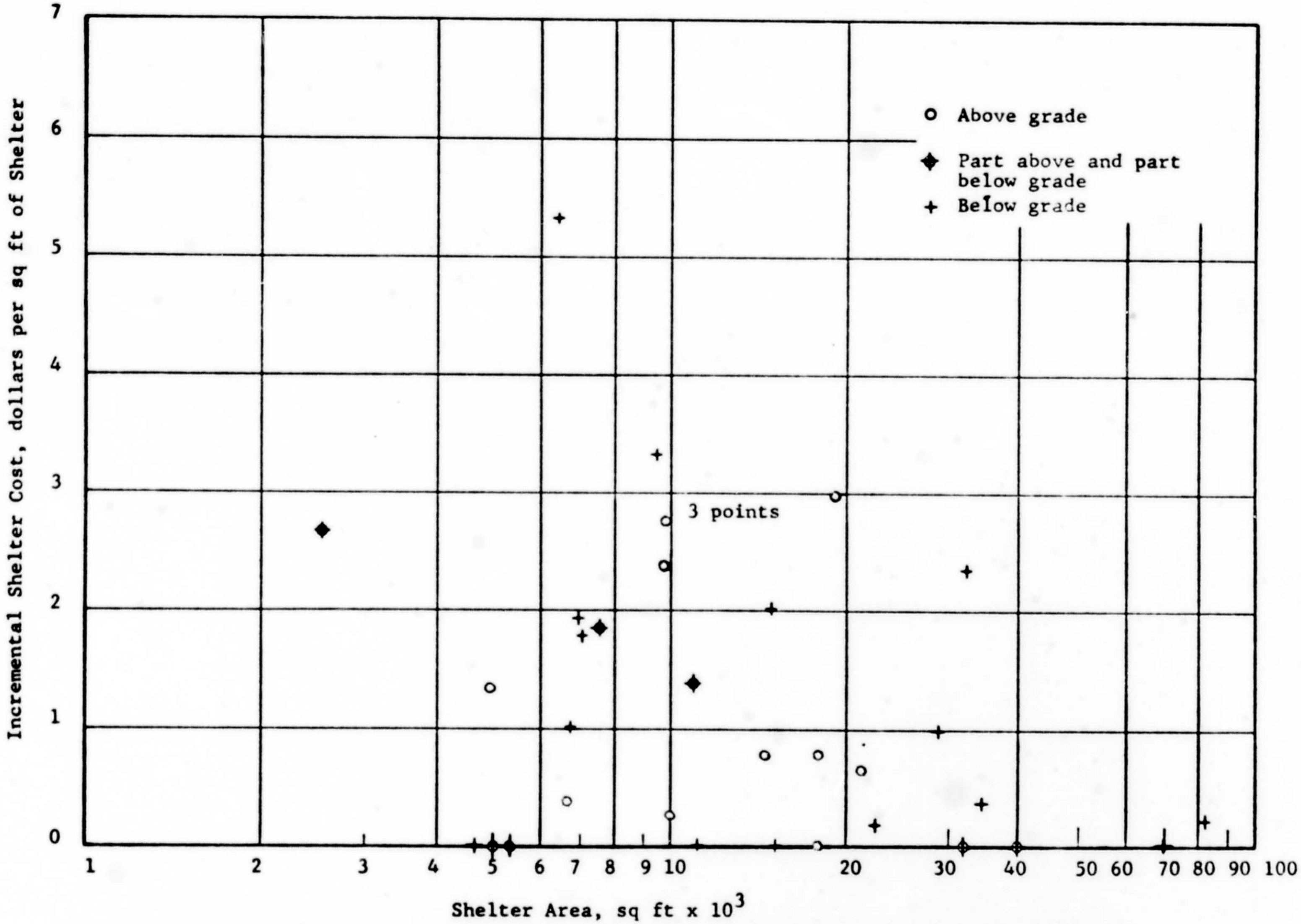

Fig. 2.1 VARIATION OF THE INCREMENTAL SHELTER COST PER SQ FT OF SHELTER AREA WITH SHELTER AREA[1,2] (Costs are Average Values for Chicago, Illinois Area for the Year 1964)

and below grade. This subdivision is arbitrary and not really well defined; it was an attempt to see if any discernible pattern was apparent in the data for structures with basements and those without. As is evident, this is not the case. It is not necessarily a reflection on the quality of the data. When comparing construction cost totals on several schools with different architectural concepts constructed in different communities at different times, we are not really comparing like items, even if the floor areas are equal. The reasons for this may be stated as follows.

The cost of a structure is strongly affected by locality; variations often are a composite of the influences of local building codes and construction labor practices as well as climate. Building costs tend to be high in cities where competition for available construction labor is keen, building codes rigid and labor unions strong. Costs tend to drop off outside the immediate influence of the city, reflecting the availability of part-time and/or nonunion labor, and more lenient building codes Such influences, however, are not regular. In certain areas of low labor cost, the productivity of such labor may be so low as to keep building costs extremely high. Transportation also may play an important part, affecting the cost and availability of construction materials.

The time of year at which bids are taken can bring about large variations in some geographic regions. Generally, cold weather causes difficult working conditions, resulting in a loss of production. This in turn leads to high bids, although occasionally a contractor is willing to take certain jobs at a low profit in order to maintain continuity over a period in which large-scale building operations are impossible By the same token, bids taken in the summer when the contractors are busy, overextended, and behind schedule tend to be much higher than during seasons of slack activity.

Certain long-range conditions can present opportunities for advantageous bid-taking although these are difficult to use to advantage. Bids taken during periods of low building activity tend to be low. One difficulty of course is that building activities tend to follow general business trends. Conditions which produce low construction costs are also likely to make investors cautious about undertaking construction programs.

Similar conflicts hold in the case of money availability and interest rates on construction. Interest is as much a real cost of a building as are materials and labor. Overall building costs can be reduced by borrowing at an opportune time. However, it is not always possible to take advantage of such variations, since conditions leading to a need for building bring with them higher interest rates and in some cases higher material costs.

Building costs are affected by other factors as well. Technical skill or lack of it in an architect or designer may in some cases seriously distort the costs of his structures. Shortcomings in drafting, detailing and specification writing may cause one building to cost considerably more than an apparently similar one. Factors influencing building costs are numerous and vary locally in the intensity of their effects. It is not possible numerically to evaluate all of these factors, especially when dealing primarily with single final cost numbers composed by different individuals. Under favorable conditions (when cost breakdowns are available) the best that can be done is to know local conditions, and to make allowances for those factors that appear most important. Factors that influence the cost of any given structure will influence to some extent the cost of a shelter within that structure.

In the light of the previous discussion it is interesting to compare costs of ordinary schools with those designed and built with fallout protection. Such a comparison is made in Fig. 2.2. In this graph, two sets of direct contract school costs are plotted. One set (schools built with fallout shelters)

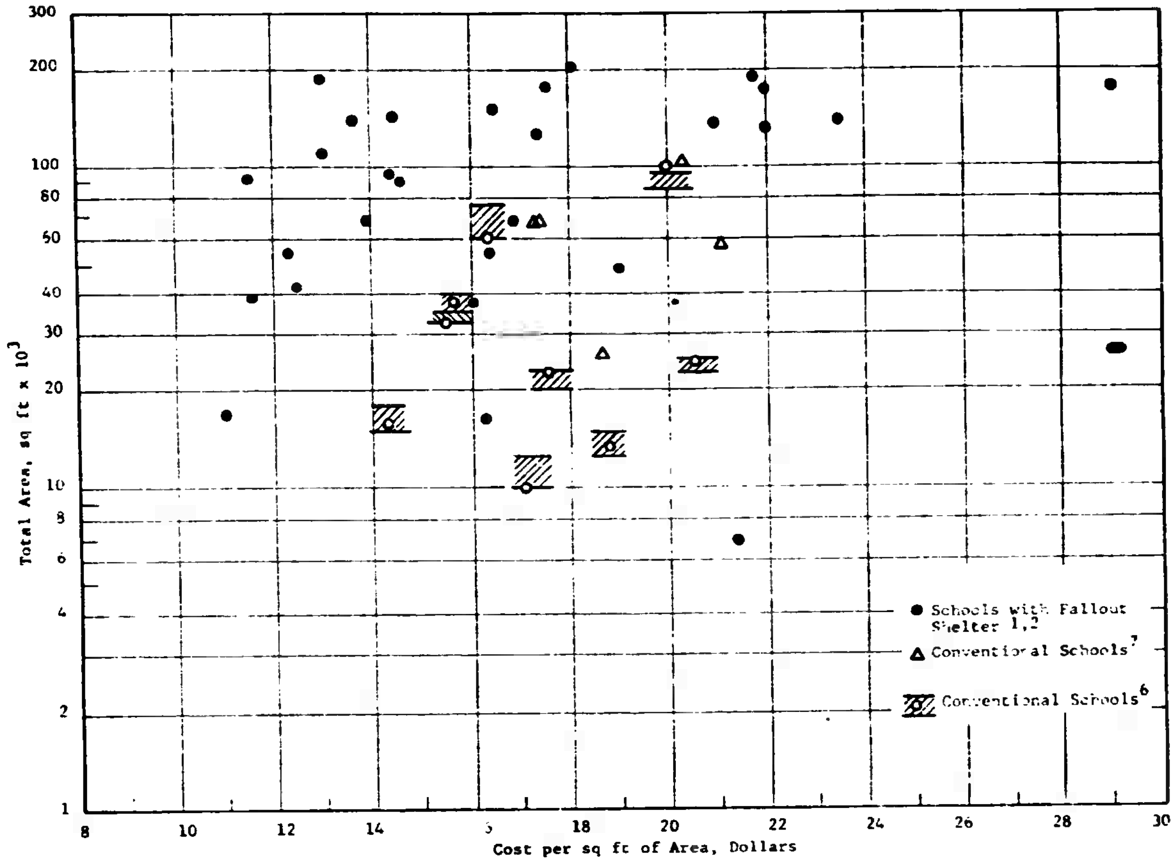

Fig. 2.2 VARIATION OF TOTAL (DIRECT CONTRACT) SCHOOL COST PER SQ FT OF AREA WITH TOTAL AREA (Costs are Average Values for the Chicago, Illinois Area for the Year 1964)

is that contained in Tables 2.1 and 2.2 and adjusted to a common base. The other has been obtained from the literature and refers to schools which have been built without fallout protection.[6,7] The data[6] has been compiled as a result of a study conducted, the objective being to prepare a building cost manual for the purpose of serving as a tool for such groups as appraisers, insurance adjustors, insurance companies, etc. Costs on different structures originating from different parts of the country were analyzed and adjusted to a common basis for purposes of comparison. Representative costs of base structures were derived, for the most part, from a number of closely comparable projects ranging from three to eight for which detailed information was available. Shaded portions which accompany these data points in Fig. 2.2 indicate ranges of cost applicability. The data[7] refers to five schools constructed recently in the Chicago area, and was obtained through the courtesy of the Chicago Board of Education. Costs plotted are final construction costs of the buildings and their normal installed equipment. They include all direct expenses for materials, labor, usual equipment and customary site preparation, as well as all extras and deletions present in the completed buildings. Also included are contractor's overhead and profit, contractor's insurance and a list of permits. In order to arrive at a common basis for comparing direct costs, the data was adjusted to correspond to average costs in the Chicago area for the year 1964. As has been mentioned earlier, only average cost indices were used for this purpose. This is due to the fact that the cost data[1,2] is to some extent incomplete and a detailed cost analysis is beyond the scope of this study. However, for the type of general cost comparison performed herein, this type of cost adjusting is sufficiently accurate. Conclusions of this comparison are discussed in the following paragraphs.

2.2.3 Discussion

It appears evident from Fig. 2.2 that both sets of data (schools built with fallout shelter and without) are very similar as to type. No discernible regular pattern is apparent in either set, even though the data[6] obtained was subject to considerable compilation and analysis. At this point, however, it should no longer be supposed that such data should follow any regular and continuous variation. The reasons for this were discussed and are summarized here.

Building costs are strongly influenced by locality. Variations to which they are subject are a composite of the local building codes, construction labor practices, climate as well as the relative affluence of individual districts. For two structures similar in all respects but built in different localities, the difference in cost, when adjusted to a common base, may be substantial. Also, although the structures whose costs are compared here are designated as schools, this does not mean that the category is specific enough for comparison purposes. Subcategories are obviously needed. Variations influencing building costs are numerous and vary locally in intensity of their effects. All of them cannot be evaluated. The best that can be done is to know what they are and make adjustments for the most important ones.

On the basis of the data shown in Fig. 2.2, it appears that there is little discernible cost difference between schools built with fallout shelter and those without. This is in part due to the fact that generally the fallout shelter cost is a small percentage of the total school cost (Fig. 2.3) and is subject to the same primary cost variations. It appears, thus, that cost influencing factors such as:

- the architectural concept,
- foundation soil conditions,
- availability of labor and materials, and
- interest rates, etc.

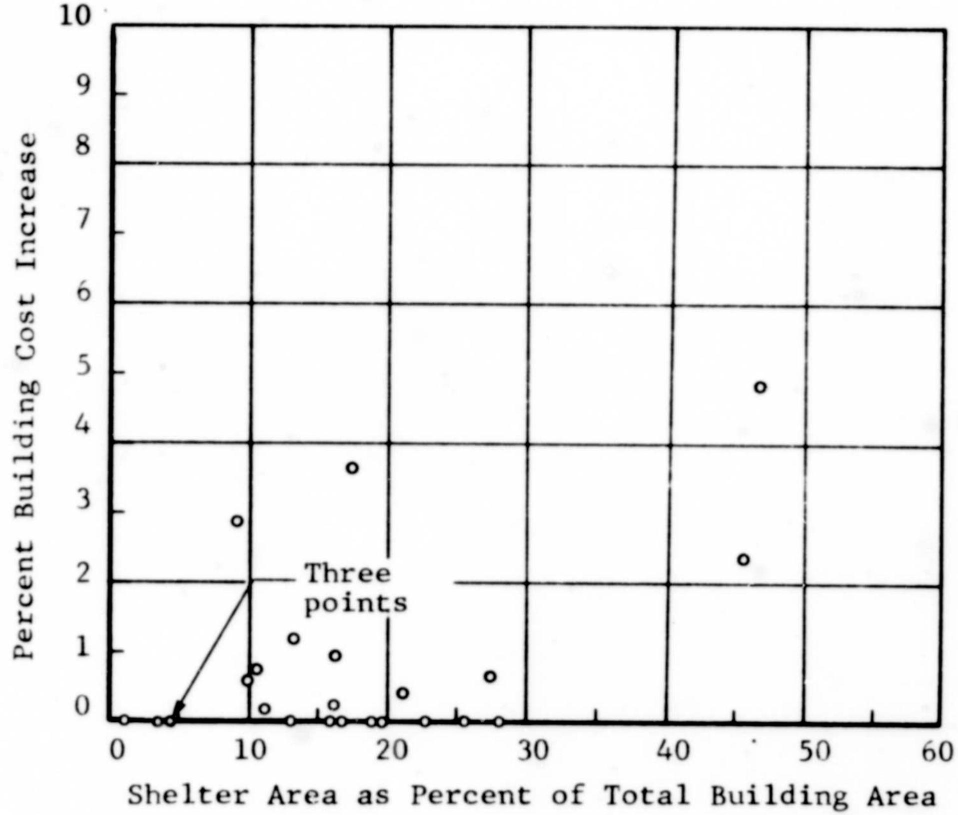

Fig. 2.3 VARIATION OF PERCENT BUILDING COST INCREASE WITH SHELTER AREA - AS PERCENT OF TOTAL AREA[2,8]

may be of an equal or greater significance to the overall building cost than the fact that a fallout shelter is included.

In the previous discussion no mention was made of the fact that structures listed in Table 2.2 have varying fallout protection factors. A fallout protection factor is another cost variation influence. However, since certain architectural concepts are more favorable in providing higher protection factors than others, and since an architect skilled in slanting techniques can do a great deal in increasing the protection factor of any particular structure, this cost influence is difficult to gauge. It seems apparent though that it is of minor influence in this case.

2.3 BUILDINGS WITH FALLOUT PROTECTION[2,8]

Structures listed and itemized in Tables 2.3 and 2.4 were obtained from references 2 and 8. With respect to their primary function, they include a service center, a church, an office building, etc., and thus represent a more diversified class of architectural concepts and structural types than schools. All of them were designed and built to include a fallout shelter. Protection factors given (column 12) vary from 40 in the lowest case to 3800 in the highest. As in the case of schools,[1,2] the costs of these structures and of their shelters, given in Tables 2.3 and 2.4, are assumed to be direct contract costs, and it is further assumed that bids were taken in 1965. An error in this assumption would result in an average cost error of about ± 2 percent per year depending on whether actual construction was earlier or later.

Some difficulty was encountered in comparing costs of school shelters in the previous section, even though schools in general belong to one class of service structures. In the present case the structures cannot even be generally classified as to utility, architectural concept or structural type. Coupled with this, is the fact that cost and constructional data are limited. For this reason, no meaningful cost comparison is possible. However, the shelter costs provided do tend to reinforce a conclusion reached in connection with school shelters in the previous section. In that section it was concluded that in general the fallout shelter influence on the total building cost is of minor significance, and may be further reduced by utilizing advantageous architectural and structural concepts and slanting techniques. To this end, shelter costs as percentages of total (direct contract) costs for structures in Tables 2.3 and 2.4 were plotted in Fig. 2.3. It is evident that, except for the number of data points, this figure is very similar to Fig. 2.4 (schools with fallout shelters) in the magnitudes of cost percentages as well as in the significant number of shelters that were achieved at no cost.

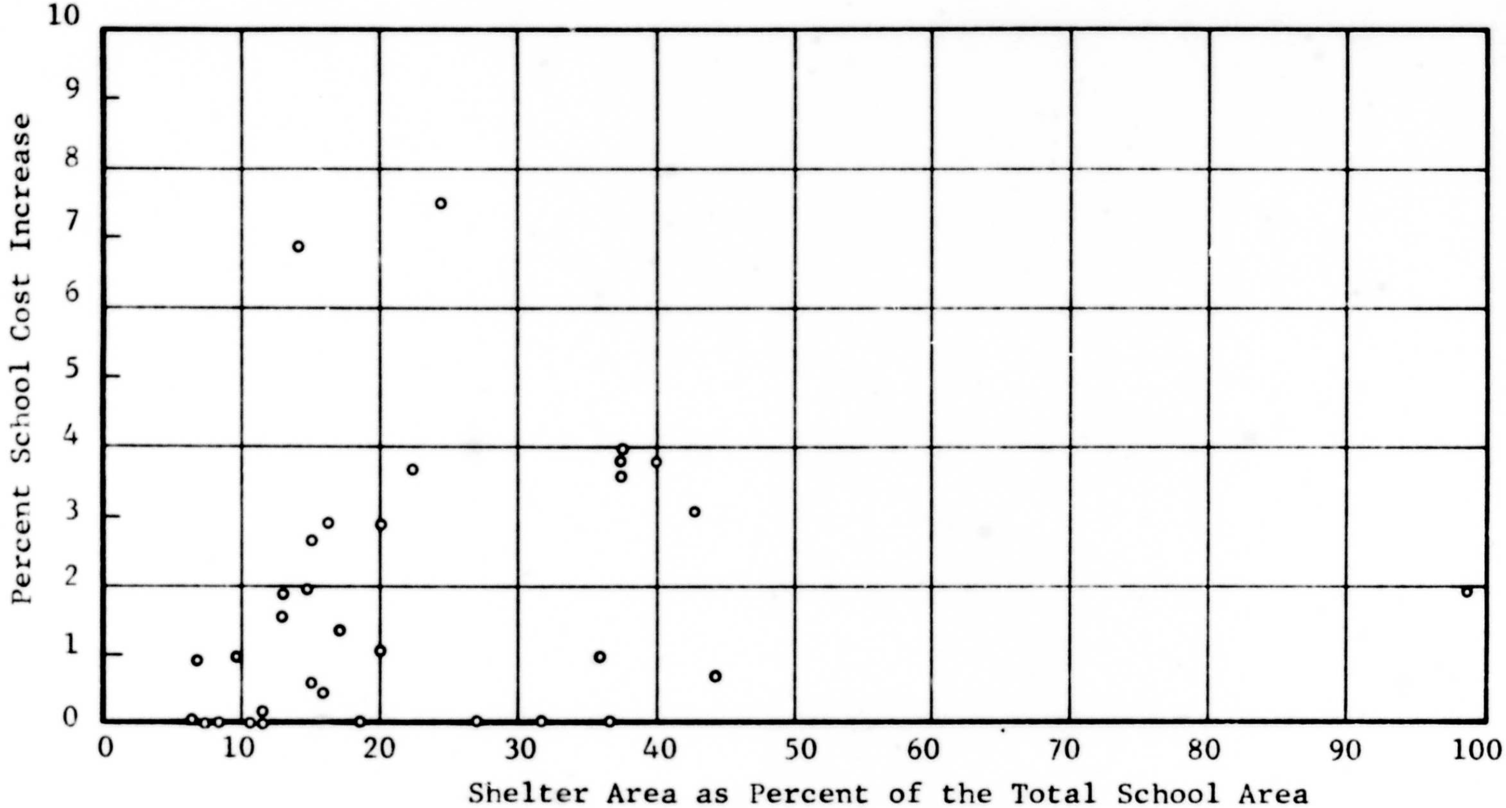

Fig. 2.4 VARIATION OF PERCENT SCHOOL COST INCREASE WITH SHELTER AREA AS PERCENT OF TOTAL AREA[1,2]

Table

BUILDINGS WITH FAL

(Existing S

1 Primary Function	2 Name and Location	3 Type of Shelter Construction	4 Shelter Location (Above or Below Grade)	5 Capacity (Number of Persons) Based on Normal Function	Shelter	6 Total Area of Parent Structure sq ft	7 Shelter Area Gross sq ft	As percent of Total Area	S V
1. Bank	City National Bank Building Los Angeles, Calif.	R/C	3 levels below grade and 2 above grade	1,000	4,777	210,000	47,770	22.8	40
2. Plant Facilities	Springfield Gas Light Company Springfield, Mass.	R/C slabs - 7 in.	Below Grade	*	(estimated) 3,000	153,700	30,000	19.5	25
3. Apartment Building	Mt. Ogden Terrace Apartments Ogden, Utah	R/C overhead slab - 12 in.	Underground Parking Garage	*	(estimated) 1,691	104,421	16,912	16.3	14
4. Office Building	New England Telephone and Telegraph Office Building Framingham, Mass.	R/C wall slabs- 12 in. and 18 in, Equivalent 12 in. of concrete overhead	Partially Below Grade	*	(estimated) 1,500	141,522	15,000	10.6	12
5. Equipment Related to the Federal Aviation Agency	Bohemia Toll Terminal Building Long Island, N.Y.	R/C and brick	Above Grade	*	(estimated) 1,169	12,813	11,691	91.4	99
6. Control Building	Administration Wing Maintenance Control Building Las Vegas, Nevada	R/C and Brick	Below Grade	*	(estimated) 621	22,080	6,210	28.1	52
7. Administration Building of Court House	Bucks County Emergency Operating Center Doylestown, Pa.	Steel Frame Brick-Sheathed	Above Grade - Ground Floor	*	600	*	6,000	*	51,
8. Fire Station	Fire Station Livermore, Calif.	Concrete Block Walls, R/C Slab 24 in.	Below Grade	*	(estimated) 304	6,523	3,043	46.7	25,
9. Church	McLean Bible Church McLean, Virginia	Precast T-beams 6 in. Concrete Block Walls - 12 in.	Above Grade Partial Core Construction	*	300	14,260	3,000	21.0	25,
10. Boy Scouts Headquarters	Council Service Center Detroit, Michigan	R/C	Below Grade	*	(estimated) 240	18,481	2,400	13.0	20,4
11. Executive Bldg. of the Central National Insurance Group	Omaha, Nebraska	R/C	Below Grade	*	(estimated) 210	6,200	2,100	33.9	17,8
12. Police Station	69th Precinct Station House Brooklyn, N.Y.	R/C	Below Grade	*	150	27,000	1,500	5.6	12,7
13. Administration Building	Administration Building for School District of the City of Pontiac Pontiac, Michigan	R/C	In the Center of the Lower-level floor area (Core shelter)	*	(estimated) 120	24,564	1,200	4.9	10,20
14. Office Building and Fire Station	Arlington County, Va. Fire Division Office Building and Fire Station No. 4	R/C	Below Grade	*	(estimated) 110	24,744	1,100	4.5	9,35

* Indicates that information is not available

R/C Reinforced concrete

N/A Not applicable

** Cost numbers in parenthesis (column 15) indicate the cost of additional equipment (ventilation, electric and plumbing). Breadkowns of this cost are not available.

Note: This table contains two types of costs:
1) as given in reference 2,
2) as adjusted to Chicago, Illinois area for the year 1964 (last column).
For further cost adjustment see reference 5 or other reliable sources.

2.3

LOUT PROTECTION[2]

tructures)

8	9	10	11	12	13	14		15				
								Incremental Shelter Cost				
						Building and Shelter Cost					Cost per sq ft of Shelter	
helter olume cu ft	Minimum Headroom ft	Shelter Area per Occupant sq ft	Volume per Occupant cu ft	Fallout P.F.	Incident Overpressure psi	Total dollars	per sq ft	Total Cost of Construction dollars	Percent Construction Cost Increase	Per sq ft of Dual-Purpose Structure	As Given[2]	As Adjusted to Chicago, Illinois Area (1964)
5,000	8.5	10	85		N/A	In excess of $4 million	19.00	0 (20,000)**	0	0	0	0
5,000	8.5	10	85	170	N/A	1,700,000	11.06	0	0	0	0	0
4,000	8.5	10	85	1,750	N/A	1,250,000	11.97	3,000	0.24	0.03	0.18	0.20
7,400	8.5	10	85	100 +	N/A	[illegible],150,000	22.26	23,000 (2,000)	0.74	0.16	1.53	1.51
,100	8.5	10	85	100	N/A	425,000	33.2	*	*	*	*	*
,900	8.5	10	85	200 +	N/A	470,000	21.29	0	0	0	0	0
,000	8.5	10	85	500	N/A	*	11.95	11,800	*	*	1.97	1.99
,800	8.5	10	85	1 000	N/A	130,000	19.93	6,000 (85,000)	4.84	0.92	1.97	2.00
,500	8.5	10	85		N/A	217,344	15.24	900	0.42	0.06	0.30	0.31
,400	8.5	10	85	135	N/A	410,095	22.10	0	0	0	0	0
,800	8.5	10	85	1,000	N/A	120,000	19.[illegible]	*	*	*	*	*
750	8.5	10	85	100	N/A	882,000	32.60	*	*	*	*	*
200	8.5	10	85	40	N/A	540,994	22.02	0	0	0	0	0
350	8.5	10	85	100 +	N/A	460,000	18.6	0	0	0	0	0

BUILDIN

1 Primary Function	2 Location and Name	3 Type of Shelter Construction	4 Shelter Location Above or Below Grade	5 Capacity: Based on Normal Function	5 Capacity: Shelter	6 Total Area of Building sq ft	7 Shelter Area: sq ft	7 Shelter Area: As percent of Total Area
1. Research Laboratory	U.S. Forest Research Laboratory Tempe, Arizona	R/C	Above grade	*	73	16,197	736	4.5
2. Credit Union	Dade County Teachers' Federal Credit Union, Coral Gables, Florida	R/C	Above grade	*	(estimated) 75	21,588	750	3.5
3. Bank	Niagara County Savings Bank, North Tonawanda, New York	R/C slab, mortar filled masonry walls	Below grade	*	(estimated) 108	8,270	1,082	13.1
4. Health Center	Tri-County Health Department Cairo, Illinois	R/C	Above grade	*	80	12,000	1,093	9.1
5. City Hall	City Hall Building Addition, Brookfield, Wisconsin	R/C	Below grade	*	140	13,317	1,485	11.2
6. Ranger Station	Kenton Ranger Station Ottawa National Forest Kenton, Michigan	Sand filled exterior walls, precast concrete roof system	Partially below grade	*	105	5,775	1,580	27.4
7. Power Plant	Wilkes Power Plant Southwestern Electric Power Company Marion County, Texas	R/C overhead slab - 4 in., brick walls - 23 in.	Above grade	*	85	*	1,625	*
8. Armory	Wyoming National Guard Armory Wheatland, Wyoming	R/C	Below grade	*	150	11,289	1,960	17.4
9. Saving & Loan Association	First Federal Savings & Loan Association Shreveport, Louisiana	R/C	Below Grade	*	(estimated) 228	11,534	2,282	19.8
10. Dormitory	McCloud Hall Girls Dormitory, York College York, Nebraska	R/C	Partially below grade	137	180	23,890	2,430	10.2
11. City Hall	Cookesville City Hall Cookesville, Tennessee	R/C	Below grade	*	(estimated) 510	32,080	5,100	15.9
12. Retirement Center	Hillside House Columbus, Ohio	R/C	Above grade	92	(estimated) 880	82,122	880	1.1
13. Gymnasium	Gymnasium Building Anne Arundel Community College Severna Park, Maryland	R/C	Partially below grade	*	(estimated) 1000	39,400	10,000	25.4
14. Public Service Building	Headquarters Building New Jersey Bell Telephone Company Camden, New Jersey	*	Partially below grade	*	(estimated) 1000	*	10,000	*
15. Home for the Aged	Somerset County Home for the Aged Somerset, Pennsylvania	R/C	Below grade	*	(estimated) 1000	61,414	10,000	16.3
16. Dormitory	Esther & Philip Klein Hall Dormitory Harcum Jr. College Bryn Mawr, Pennsylvania	R/C	Below grade		1080	64,800	10,828	16.7
17. Church	St. Jude The Apostle Church	R/C, Sand filled masonry walls with shielded windows	Below grade	820	1093	24,000	10,932	45.6
18. Library	Central Library Building Lansing, Michigan	*	Above and below grade	*	1760	50,000	17,600	35.2
19. School	Southeast Polk Senior-Junior High School Ivy, Iowa	R/C	Above grade	1200	1700	100,000	17,640	17.6
20. Library	Library Building University of California San Diego, California	R/C	Below grade	*	2400	100,000	24,786	24.8
21. Student Union Building	Student Union Building Mississippi State University	R/C	Below grade	*	(estimated) 4000	95,950	40,000	41.7

* Indicates that information is not available

R/C Reinforced concrete

N/A Not applicable

** Cost numbers in parenthesis (column 15) indicate the cost of additional equipment (ventilation, electric and plumbing). Breakdowns of this cost are not available.

Note: This table contains two types of costs:
1) as given in reference 8,
2) as adjusted to Chicago, Illinois area for the year 1964 (last column).
For further cost adjustment see reference 5 or other reliable sources.

Table 2.4

BUILDINGS WITH FALLOUT PROTECTION[8]
(Existing Structures)

5		6	7		8	9	10	11	12	13	14		
Capacity		Total Area of Building sq ft	Shelter Area		Shelter Volume cu ft	Minimum Headroom ft	Shelter Area per Occupant sq ft	Volume per Occupant cu ft	Fallout P.F.	Incident Overpressure	Construction Cost		Total Constr Dol
Based on Normal Function	Shelter		sq ft	As percent of Total Area							Total Dollars	Per sq ft	
*	73	16,197	736	4.5	5,888	8.0	10.0	80.0	*	N/A	400,710	24.74	(
*	(estimated) 75	21,588	750	3.5	6,000	8.0	10.0	80.0	*	N/A	411,038	19.04	(
*	(estimated) 108	8,270	1,082	13.1	8,656	8.0	10.0	80.0	*	N/A	172,000	20.80	2,00
*	80	12,000	1,093	9.1	8,744	8.0	13.7	109.3	100+	N/A	225,000	18.75	6,20 (2,40
*	140	13,317	1,485	11.2	11,880	8.0	10.6	84.8	*	N/A	163,804	12.30	30
*	105	5,775	1,580	27.4	12,640	8.0	15.0	120.0	*	N/A	94,706	16.40	62
*	85	*	1,625	*	13,000	8.0	19.1	152.8	100	N/A	14,100,000	*	3,86 (1,000
*	150	11,289	1,960	17.4	15,680	8.0	13.1	104.8	1000+	N/A	152,850	13.54	5,37 (3,350
*	(estimated) 228	11,534	2,282	19.8	18,256	8.0	10.0	80.0	1000	N/A	283,727	24.60	0
137	180	23,890	2,430	10.2	19,440	8.0	13.5	108.0	145	N/A	244,671	10.24	0
*	(estimated) 510	32,080	5,100	15.9	40,800	8.0	10.0	80.0	*	N/A	649,000	20.23	0
92	(estimated) 880	82,122	880	1.1	7,040	8.0	10.0	80.0	*	N/A	1,300,000	15.83	5,000
*	(estimated) 1000	39,400	10,000	25.4	80,000	8.0	10.0	80.0	*	N/A	788,000	20.00	10,250
*	(estimated) 1000	*	10,000	*	80,000	8.0	10.0	80.0	*	N/A	1,500,000	*	0
*	(estimated) 1000	61,414	10,000	16.3	80,000	8.0	10.0	80.0	*	N/A	1,060,000	17.26	8,000
	1080	64,800	10,828	16.7	292,356	27.0	10.0	270.0	1000	N/A	1,266,000	19.53	0
820	1093	24,000	10,932	45.6	87,456	8.0	10.0	80	*	N/A	350,000	14.40	0
*	1760	50,000	17,600	35.2	140,800	8.0	10.0	80	500-3800	N/A	1,694,000	27.50	0
1200	1700	100,000	17,640	17.6	141,120	8.0	10.0	80	*	N/A	1,715,941	17.16	0
*	2400	100,000	24,786	24.8	198,288	8.0	10.0	80	*	N/A	2,500,000	25.00	0
*	(estimated) 4000	95,950	40,000	41.7	320,000	8.0	10.0	80	*	N/A	1,800,000	18.76	0

te: This table contains two types of costs:
1) as given in reference 8,
2) as adjusted to Chicago, Illinois area for the year 1964 (last column).
For further cost adjustment see reference 5 or other reliable sources.

OTECTION[8]
es)

11	12	13	14		15				
			Construction Cost		Incremental Shelter Cost				
								Cost per sq ft of Shelter	
Volume per Occupant cu ft	Fallout P.F.	Incident Overpressure	Total Dollars	Per sq ft	Total Cost of Construction Dollars	Percent Construction Cost Increase	Per sq ft of Dual-Purpose Structure	As Given[8]	As Adjusted to Chicago Ill. Area (1964)
80.0	*	N/A	400,710	24.74	0	0	0	0	0
80.0	*	N/A	411,038	19.04	0	0	0	0	0
80.0	*	N/A	172,000	20.80	2,000	1.18	0.23	1.85	1.62
109.3	100+	N/A	225,000	18.75	6,200 (2,400)**	2.83 (1.1)	0.52	5.67 (2.20)	5.66
84.8	*	N/A	163,804	12.30	300	0.18	0.02	0.20	0.20
120.0	*	N/A	94,706	16.40	625	0.66	0.11	0.40	0.38
152.8	100	N/A	14,100,000	*	3,865 (1,000)	0.03	*	2.38	2.64
104.8	1000+	N/A	152,850	13.54	5,375 (3,350)	3.64 (2.2)	0.48	2.74 (1.71)	3.04
80.0	1000	N/A	283,727	24.60	0	0	0	0	0
108.0	145	N/A	244,671	10.24	0	0	0	0	0
80.0	*	N/A	649,000	20.23	0	0	0	0	0
80.0	*	N/A	1,300,000	15.83	5,000	0.33	*	0.50	0.43
80.0	*	N/A	788,000	20.00	10,250	0.98	0.17	1.03	0.98
80.0	*	N/A	1,500,000	*	0	0	0	0	0
80.0	*	N/A	1,060,000	17.26	8,000	2.34	0.33	0.73	0.78
270.0	1000	N/A	1,266,000	19.53	0	0	0	0	0
80	*	N/A	350,000	14.40	0	0	0	0	0
80	500-3800	N/A	1,694,000	27.50	0	0	0	0	0
80	*	N/A	1,715,941	17.16	0	0	0	0	0
80	*	N/A	2,500,000	25.00	0	0	0	0	0
80	*	N/A	1,800,000	16.76	0	0	0	0	0

2.4 NATIONAL SCHOOL FALLOUT SHELTER DESIGN COMPETITION STRUCTURES[9,10]

2.4.1 General Description

Data presented in Table 2.5 is based on structures illustrated in reference 9. This publication presents a series of award winning school concepts which have resulted from the National School Fallout Shelter Design Competition. Since the object was to illustrate the concepts, little data pertinent to the present study is provided These concepts, however, were the object of a study[10] conducted to determine their capabilities in a nuclear weapons environment associated with direct effects as well as fallout. It is from this publication that the majority of the data given in Table 2.5 was extracted. This latter study was concerned with the following objectives:

- Examination of the given concepts in order to determine the maximum levels of inherent protection against thermal radiation and blast induced overpressure.
- Identification of advantages and disadvantages of each such concept.
- Recommendation of economic design modifications and costs thereof.

Methods, data and assumptions employed in achieving the above objectives are briefly summarized

Since the architectural plans presented[9] are not detailed and were apparently developed using codes and construction methods typical of the various districts of origin, certain structural and constructional assumptions needed to be made. In performing structural analyses for blast, applicable current state-of-the-art procedures and data were employed. Only those structural elements were analyzed which were thought to be essential to the structure in the given weapons environment (10 MT surface burst). Such elements included:

- Roof and floor systems.
- Exterior walls, and/or columns.
- Interior partitions.
- Building frames.

For purposes of determining loading functions on exterior surfaces, the structures were considered to be closed.

As far as thermal considerations are concerned, the original architectural plans were developed in the light of fire and building codes applicable in the various regions of their origin. In order to maintain uniformity in the thermal analysis of these structures, the following assumptions were made.[10]

- The sequence of events following a nuclear attack is 1) thermal radiation; 2) blast effects, with the possibility of secondary fires; 3) radioactive fallout, and simultaneous hazard to the shelter from exposure fires. These events are sequential and separated by an interval of time.
- The major fire-fighting effort will take place between the time of the blast effects and the arrival of radioactive fallout.
- There will be no fire storm following the attack, but fires will be widespread and numerous.
- All structures conform to Section 703, Fire Resistive Construction Type B(NBFU). Non-combustible construction is acceptable, but fire resistive construction is preferred.
- The fire load (weight of combustible material per sq ft of floor area) for the fire resistive building will approximate 5 psf with an assumed heat potential of 40,000 BTU/sq ft (contents, finished flooring, interior finish and trim) and an equivalent fire rating of 30 minutes. This fire load does not hold for areas having a greater than normal fire load, or those where ignition of fires is most likely to take place.
- Practical assumptions are made in cases not covered by existing building codes (e.g., underground educational spaces).

Table 2.5

NATIONAL SCHOOL FALLOUT SHELTER DESIGN COMPETITION ST
(Conceptual Studies)

1 Structure Designation	2 Type of Shelter Construction	3 Shelter Location Above or Below Ground	4 Shelter Capacity	5 Total Area of Parent Structure sq ft	6 Shelter Area In sq ft	 As percent of Total Area	7 Fall-out P.F.
1. Grand Prize	R/C	Below Grade	2,009	43,200	20,090	46.3	100 +
2. First Prize - Region 1	R/C	Under Ground	2,000	43,000	20,000	46.6	100 +
3. Second Prize - Region 1	R/C	Above and Below Grade	2,468	44,250	24,680	55.8	100 +
4. Third Prize - Region 1	Concrete block walls - Pre-stressed concrete roof	Above grade Protected by an Earth berm	1,584	15,840	15,840	100.0	100 +
5. First Prize - Region 2	R/C and Concrete Block	Above Grade	1,693	28,336	16,930	60.0	100 +
6. Second Prize - Region 2	R/C	Above Grade	*	*	*	*	100 +
7. Third Prize - Region 2	Circular School Heavy Concrete Roof	Above Grade	1,457	29,030	14,570	50.2	100 +
8. Certificate of Merit Region 2 - Split Level	R/C	Partially Above and Below Sloping Grade	*	*	*	*	100 +
9. First Prize - Region 3	R/C	Above Grade	2,597	32,820	25,970	79.0	100 +
10. Second Prize - Region 3	Native Stone and Mortar	Depressed Area	*	*	*	*	100 +
11. Third Prize - Region 3	R/C. brick	Above Grade	*	*	*	*	100 +
12. Certificate of Merit Region 3	*	Above Grade	*	*	*	*	100 +
13. First Prize - Region 4	R/C	Above Grade	2,380	32,720	23,800	72.8	100 +
14. Second Prize - Region 4	R/C	Above Grade	*	*	*	*	100 +
15. Third Prize - Region 4	*	Above Grade	2,028	44,890	20,280	45.2	100 +
16. Certificate of Merit Region 4	Concrete	Above Grade Surrounded by Earth Berm	*	*	*	*	100 +
17. First Prize - Region 5	R/C Core Type	Partially Below Grade	*	*	*	*	100 +
18. Second Prize - Region 5	R/C and Concrete Block	Above Grade	1,920	60,440	19,200	31.8	100 +
19. Third Prize - Region 5	R/C and Concrete Block	Above Grade	1,953	41,470	19,530	47.0	100 +
20. Certificate of Merit Region 5	R/C	Below Grade	*	*	*	*	100 +
21. Certificate of Merit Region 5		Above Grade	4,304	43,040	43,040	100.0	100 +
22. First Prize - Region 6	Multilevel Building Reinforced Concrete	Below Grade	*	*	*	*	100 +
23. Second Prize - Region 6	Folded plate roof R/C walls	Above Grade	1,178	33,500	11,780	35.2	100 +
24. Third Prize - Region 6	Folded plate roof Concrete Block Walls	Above Grade (core type)	1,117	32,240	11,170	36.4	100 +
25. Second Prize - Region 7	T-beam roof, grouted brick walls	Above Grade	1,388	26,500	13,880	52.4	100 +
26. Third Prize - Region 7	Circular Structure R/C slabs	Above Grade	*	*	*	*	100 +

* Indicates that information is not available

R/C Reinforced concrete

** "Upgrading" as used herein refers to modification of an earlier c

Note: Costs appearing in this table are as given in reference 10
see reference 5 or other reliable sources.

Table 2.5

OOL FALLOUT SHELTER DESIGN COMPETITION STRUCTURES[9,10]
(Conceptual Studies)

3	4	5	6		7	8		9		
			Shelter Area			Incident Overpressure Resistance psi		Cost of Upgrading **		
ter Location Above elow Ground	Shelter Capacity	Total Area of Parent Structure sq ft	In sq ft	As percent of Total Area	Fall-out P.F.	As Designated	As Upgraded	Total dollars	Cost per sq ft of Parent Structure	Cost per sq ft of Shelter
ow Grade	2,009	43,200	20,090	46.3	100 +	1	5	35,000	.81	1.74
der Ground	2,000	43,000	20,000	46.6	100 +	2	6	14,000	.32	.70
ove and Below Grade	2,468	44,250	24,680	55.8	100 +	2	8	19,000	.43	.77
ove grade otected by an rth berm	1,584	15,840	15,840	100.0	100 +	1	6	15,000	.95	.95
ove Grade	1,693	28,336	16,930	60.0	100 +	2	10	10,000	.35	.59
ove Grade	*	*	*	*	100 +	*	*	*	*	*
ove Grade	1,457	29,030	14,570	50.2	100 +	1	9	24,000	.83	1.65
rtially Above d Below Sloping ade	*	*	*	*	100 +	*	7	*	*	*
ove Grade	2,597	32,820	25,970	79.0	100 +	1	5	12,000	.36	.46
pressed Area	*	*	*	*	100 +	2	10	0	0	0
ove Grade	*	*	*	*	100 +	2	10	0	0	0
ove Grade	*	*	*	*	100 +	*	*	*	*	*
ove Grade	2,380	32,720	23,800	72.8	100 +	5	10	11,000	.34	.46
ove Grade	*	*	*	*	100 +	*	*	*	*	*
ove Grade	2,028	44,890	20,280	45.2	100 +	1	10	13,000	.29	.65
ove Grade rrounded by rth Berm	*	*	*	*	100 +	1	9	*	*	*
rtially low Grade	*	*	*	*	100 +	5	9	0	0	0
ove Grade	1,920	60,440	19,200	31.8	100 +	1	10	44,000	.73	2.29
ove Grade	1,953	41,470	19,530	47.0	100 +	1	8	19,000	.46	.97
low Grade	*	*	*	*	100 +	2	10	*	*	*
ove Grade	4,304	43,040	43,040	100.0	100 +	2	10	35,000	.81	.81
low Grade	*	*	*	*	100 +	*	*	*	*	*
ove Grade	1,178	33,500	11,780	35.2	100 +	1	10	8,000	.24	.68
ove Grade ore type)	1,117	32,240	11,170	36.4	100 +	1	6	18,000	.56	1.61
ove Grade	1,388	26,500	13,880	52.4	100 +	3	8	23,000	.87	1.66
ove Grade	*	*	*	*	100 +	10	10	0	0	0

** "Upgrading" as used herein refers to modification of an earlier concept which exists only on paper.

Note: Costs appearing in this table are as given in reference 10. For cost adjustment see reference 5 or other reliable sources.

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- With the exception of windowless and underground buildings, smoke venting will be provided primarily by doors and windows. In the event of a nuclear attack, fallout shelters would be threatened by 1) fires resulting from the nuclear blast; 2) fires resulting from exposure to flames in the surrounding area; 3) fires initiating within the shelter, as a result of either blast damage or accidental ignition.

Primary references consulted included the following:

"National Building Code" New York: The National Board of Fire Underwriters, 1955.

"Fire Effects of Bombing Attacks" TM-9-2, 1st Ed. Rev., Washington: Department of Defense, Office of Civil Defense, August, 1952.

"Fire Safety to Life, Classification Guide for Fallout Shelters" OCD-PS-64-40 (unpublished report by the Factory Mutual Research Corporation, Norwood, Mass.).

On the basis of architectural data, assumptions aforementioned and references consulted, the concepts were evaluated with respect to the assumed thermal environment. Recommendations for upgrading were subsequently made for those concepts for which sufficient information was available. Thermal analyses and resulting recommendations were of a qualitative nature.

As far as nuclear radiation hazards are concerned, due to low overpressure levels considered in the analysis (0 to 10 psi for a 10 MT surface burst), levels of initial radiation are insignificant. With respect to fallout radiation, the original structures were designed to provide a protection factor in excess of 100. It was estimated that the recommended changes would increase these factors by about 5 percent.

In terms of blast protection, this group of structures belongs to that category of dual-purpose shelters for which, due to low levels of overpressure, blast closures are not considered.

2.4.2 <u>Discussion</u>

Costs given in Table 2.5 are for upgrading the concepts in question to the particular overpressure levels indicated. They are thus over and above the initial cost which would include specified levels of fallout protection (P.F. 100+). Initial costs of these concepts are not available. The term "upgrading" as used here, refers to revising a concept which exists only on paper. This is not the same thing as upgrading an existing structure which would be a great deal more costly. The given costs are based on recommended changes and include both structural and thermal considerations. The extent of these considerations was discussed in the previous section. The costs are based on labor and materials in the New Orleans area and include contractor's overhead, profit and insurance. Thus, as to type, they correspond to those discussed and used in the preceding sections of this report.

The school concepts discussed in this section are unique architectural types. It appears that in developing them, a great deal of effort was expanded in utilizing various slanting methods to advantage. They are good examples of the numerous techniques that can be applied to the terrain as well as to the structure in achieving a desirable level of fallout protection. It is thus the more regrettable that costs on them are not available. Such costs would be very desirable for comparison with those of ordinary schools as well as those of references 1 and 2. The fact that the inherent level of blast protection is on the average about 2 psi is not surprising, since an extreme use of slanting techniques for fallout does not necessarily result in stronger structures or more massive structural members.

It is not entirely clear however what this rated (inherent) overpressure resistance (2 psi, etc.) means in terms of percent survivors, and whether the "upgraded" resistance of these concepts has the same or a different meaning with respect to shelteree survivability. A classification is necessary for a correct evaluation of cost effectiveness. It is also not clear how much thought was given to foundations and foundation soil conditions in upgrading these concepts. This may be a significant cost influence.

The influence of low overpressure shelters on the total cost of parent structures is of interest and can be determined approximately if it is assumed that the given upgrading costs (Table 2.5) are on the average applicable, in the initial construction stage, to schools discussed earlier.[1,2] The average upgrading cost to the direct effects environment of 10 psi (average for Table 2.3) is $0.99 per sq ft of shelter area or $0.52 per sq ft of total school area. The average cost of fallout shelters[1,2] is $1.28 per sq ft of shelter area or $0.65 per sq ft of total school area. This last number corresponds to 1.63 percent of total school cost. If the resistance of this latter group of shelters is increased to 10 psi, the average cost increases to $1.17 per sq ft of total area, or 2.9 percent of total (direct contract) cost. This last number may now be compared to other cost estimate constituents. Consider the average percent breakdown of direct contract cost for schools[6] given as follows.

Item	Costs Percent
Structural, Earthwork and Architectural	76*
Mechanical	
Heating and Ventilating	10.7
Plumbing	6.1
Electrical	7.2

* Contractor's overhead, profit and insurance are included in the above percentages.

Although detailed information is not available, it may be safely assumed that the average percent breakdown of direct contract costs for schools[1,2] is magnitude-wise similar to the one given above.

It was concluded earlier that generally the fallout shelter cost influence on the total cost is of "minor" significance. In the light of the discussion it appears that if a low level (8 to 10 psi) of blast protection is provided, this conclusion is not seriously affected. Thus in the light of available data, it may be concluded that significant increases in levels of protection can be obtained by means of relatively minor changes in conventional (fallout protection type) concepts at moderately low additional costs. This is significant if it is considered that the area between 2 psi and 10 psi overpressure contours is in excess of 270 sq miles for a 10 MT surface burst. The probability of survival in this area is quite high without recourse to special mechanical life support measures. Such contours for a large city (Chicago) are shown in Fig. 2.5. It will be noted that the area between the contours covers a relatively large portion of the city. While multiple weapon considerations strongly affect this argument, it would appear that a strong and continuing interest in the low pressure region is always justified.

Presuming structure survival from 10 to 2 psi, people can be affected by thermal radiation, debris within the building, glass fragments, and displacement by blast winds. Assuming sufficient warning is given, personnel can avoid window areas, which would minimize thermal radiation and glass fragments; the displacement effects can be minimized by having personnel lie on the floor, reducing exposure to blast winds and likewise the force affecting displacement. Again with sufficient warning, potential debris within the building (ash trays, lamps, books, pictures, etc.) could be removed and stored where it would have the least chance of being accelerated by blast winds.

The above discussion, however, needs to be considered in the light of the following observations. In upgrading this set of concepts it was assumed that there will be no large scale fires following the attack. This assumption may well apply in

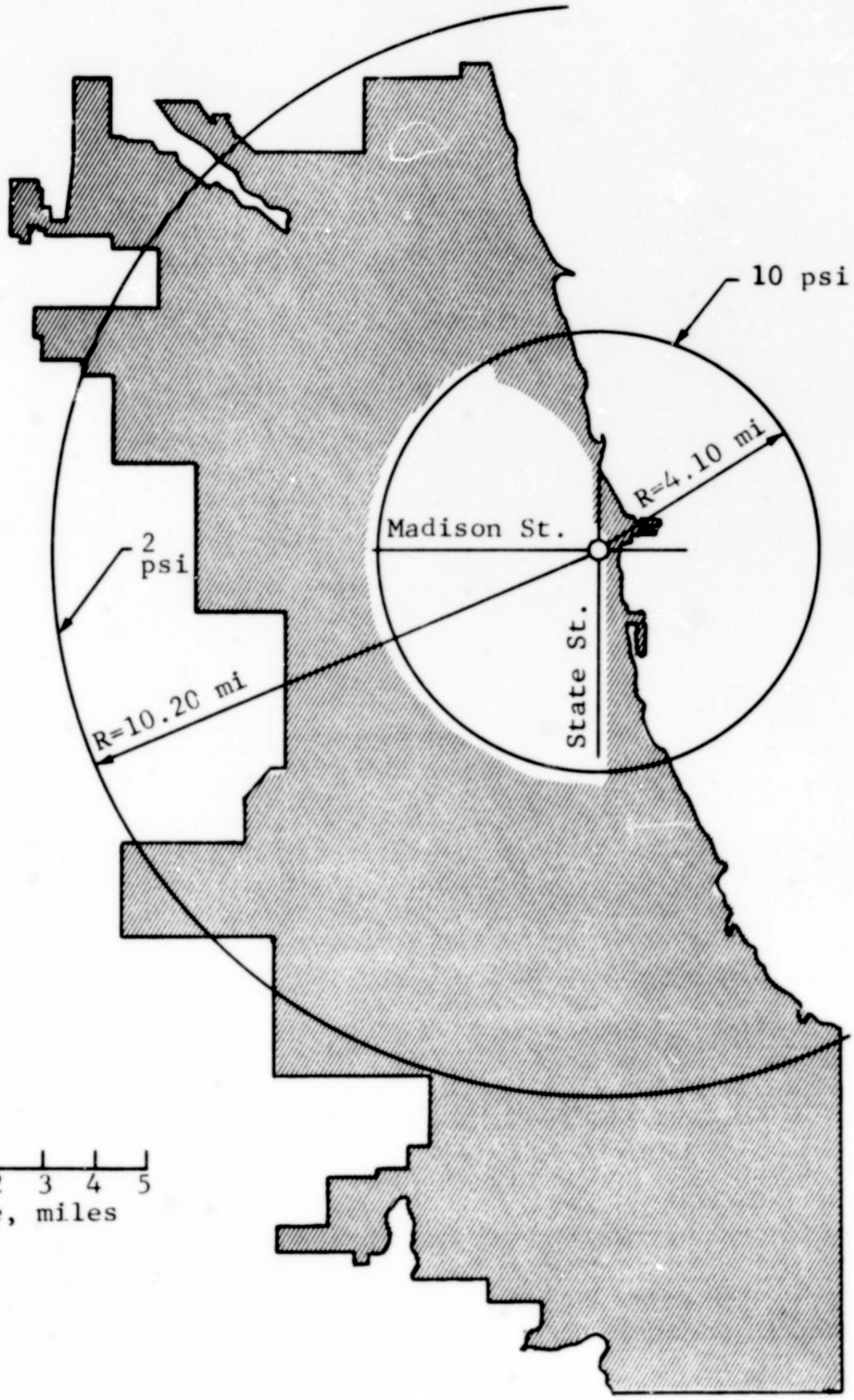

Fig. 2.5 INCIDENT OVERPRESSURE CONTOURS FOR A 10 MT SURFACE BURST

certain regions; however for such structures located in a large and crowded city, this is no longer realistic. Consideration should be given for devising means for increasing the survivability of shelter occupants under such conditions. At this time it would be difficult to estimate what the additional cost would be. Also, as has been mentioned earlier, due to low overpressures (10 psi or less), blast closures were not considered in the design of these shelters. The definition of low overpressure would depend in part on the physical well being of the group assigned to a particular shelter. Thus in some cases blast closures at this level of overpressure would need to be considered in order to increase the survivability of occupants. Some obvious cases where this would apply are hospital and homes of the aged shelters.

2.5 COMMUNITY FALLOUT SHELTERS FOR THE COUNTY OF LOS ANGELES[11]

2.5.1 General Description

In order to investigate the feasibility of protecting the citizens of Los Angeles County against nuclear fallout, a study of five prototype fallout shelters was performed.[11] These shelters are of the single-purpose types and are proposed to be located under schools and playgrounds. The sites serve a maximum radius of 1/2 mile, or 15 min. walking distance. An exception was made in areas of sparse population, where the use of cars and parking appears to be necessary. Five specific sites were selected in order to develop a standard shelter design under varying site conditions and to determine the effects these conditions would have on construction cost.

Two basic shelter units (Fig. 2.6) were developed (long and short). Each is a box-type permanent reinforced concrete structure having an 8 ft 6 in. ceiling height. The roof was designed to carry a 24 in. earth cover plus a 100 lb per sq ft live load. Two-way slabs (without beams) were specified. A "long unit" is 220 ft long and has a capacity for approximately 1200 persons. It was especially designed for use under football fields, the required entrances at either end being far enough apart to span the field and side line areas. The "short unit" is more suited for use under relatively small and crowded sites. This unit is 100 ft long and has a capacity for approximately 600 persons. Both units are 60 ft wide and have identical cross sections. Each of these units was further developed as a two level structure. Approximately 10 sq ft of floor space was provided for each occupant. This includes the areas taken up by toilets and access tunnels, but not stairways and equipment rooms.

Entrance to the shelters is by means of stairways at each end. These are housed within circular structures with reinforced concrete roofs and earth filled masonry or concrete

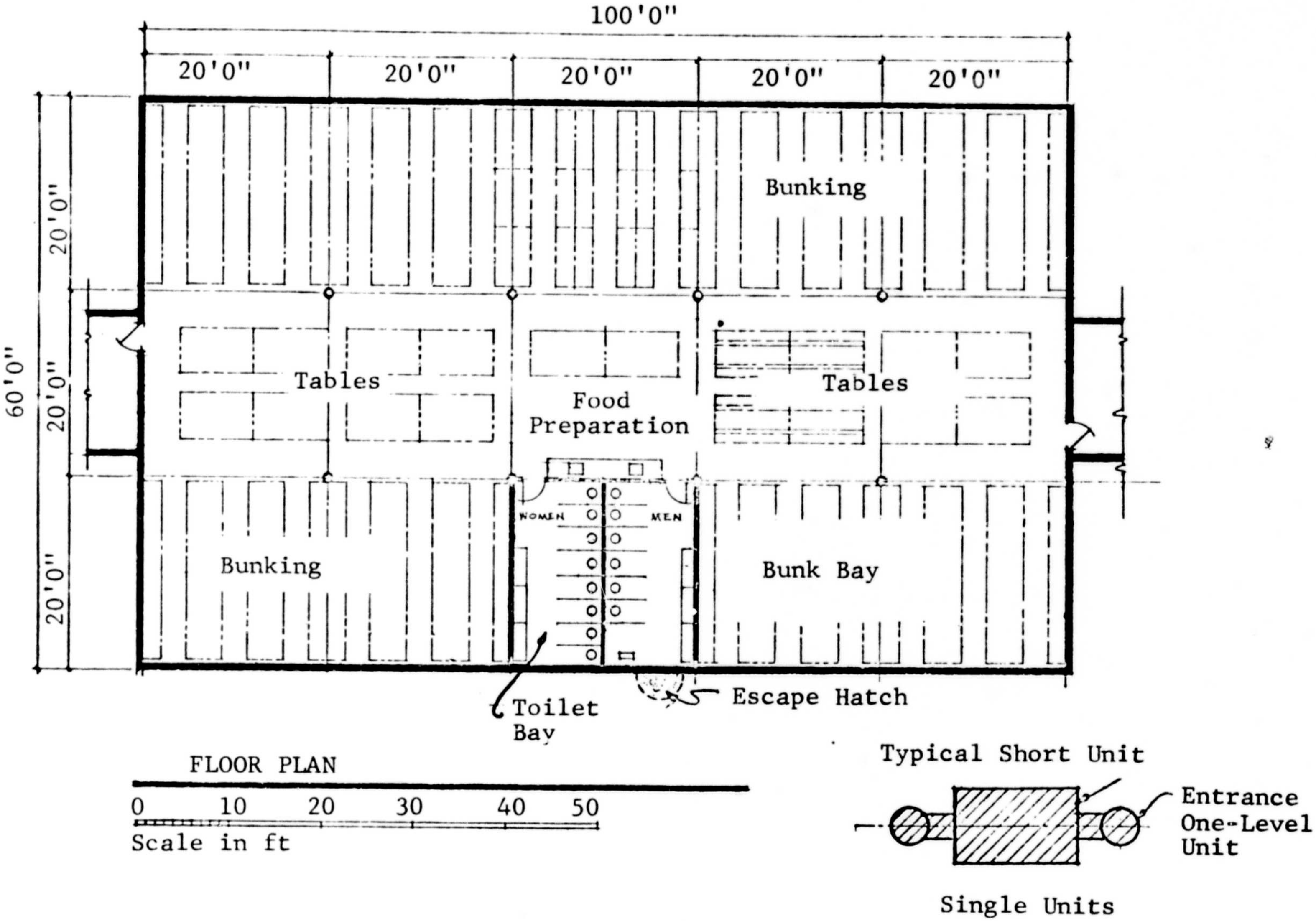

Fig. 2.6 TYPICAL "SHORT" SHELTER UNIT, COMMUNITY FALLOUT SHELTERS FOR THE COUNTY OF LOS ANGELES[11]

block walls. Blast doors are provided. The entrance structures, in addition to stairways, also house ventilation fans, two-way radios, periscopes, air supply and exhaust vents. The space under stairways is used for emergency electric generators. In addition to the entrances at either end, each shelter has an escape hatch at its center to be used in case of emergency.

The shelters have a protection factor of 1000 against fallout and have the capacity to resist blast overpressure of approximately 5 psi when analyzed in accordance with the concept of limit design.

The basic shelters are sized to accommodate three 76 in. bunks end to end between columns. The bunks are 76 in. by 24 in. and are placed four high except along the walls where they are three high to allow for exhaust ducts. Each of the five shelters was composed of such basic units as described and designed to accommodate the residents living in its vicinity. The number of persons in the areas considered varies from 2400 to 4800. The proposed shelters are briefly described below.

Hollywood High School

Hollywood High School is a typical, crowded high school in an older area. The required shelter capacity is 4800. The shelter site is occupied by a football field and other sports and recreational facilities. The shelter consists of two two-level long units. Tunnels leading to the shelter area are shielded and can be used for extra shelter space.

Southwest Sportsman's Park

The park site is in an area of average population density. The required minimum shelter capacity is 2400. The shelter site is unused but may be developed as a recreational or parking facility. The shelter consists of two one-level long units.

Damen Jr. High School

This typical jr. high school is in a residential area of average population density. The required shelter capacity is 2400. The proposed shelter consists of two two-story short units.

Birney Elementary School

Birney Elementary School is typical of the newer schools in the Long Beach District. The required shelter capacity of 3600 is provided for by means of three one-level short units.

Antelope Valley Jr. College

This college site is in a semirural area having approximately 2400 persons within a driving distance of two miles. The proposed shelter consists of one two-level long unit with extended entrance tunnels to conform to the surface parking pattern.

The essential characteristics of these shelters are summarized in Table 2.6. Contract, equipment and site restoration costs are given. These costs are for materials, labor and equipment for the year 1961 in the Los Angeles area. It is assumed that contractors overhead, profit and insurance have been included. Items included in the cost numbers are outlined below.

- Earthwork and Structure (Contract)

  Site clearance, excavation, backfill, compaction and grading.

  Reinforced concrete and masonry work.

  Dampproofing, waterproofing, expansion joints.

  Miscellaneous metals, doors and frames, hardware, screens, closures, handrails, etc.

- Plumbing

  Water supply and distribution systems

  Liquid waste disposal system

  Fuel storage and piping system

Table 2.6

COMMUNITY FALLOUT SHELTERS FOR THE COUNTY
(Feasibility Study)

	1	2	3	4	5	6	7	8
Structure Designation	Capacity Number of Persons	Gross Area sq ft	Total Volume cu ft	Minimum Headroom ft	Shelter Area per Occupant sq ft	Shelter Volume per Occupant cu ft	Fallout P.F.	Maximum Dose of Radiat rad
1. Hollywood High School Hollywood, Calif.	[illegible]	62,400	530,000	8.5	10	85	1000	N/A
2. Southwest Sportsman's Park Los Angeles, Calif.	2,752	27,520	234,000	8.5	10	85	[illegible]	N/A
3. Dana Jr. High School Arcadia, Calif.	2.509	25,092	213,000	8.5	10	85	1000	N/A
4. Birney Elementary School Long Beach, Calif.	4,103	41,028	348,000	8.5	10	85	1000	N/A
5. Antelope Valley Jr. College Lancaster, Calif.	3,038	30,384	258,000	8.5	10	85	1000	N/A

Note: For further cost adjustment see reference 5 or other reliable sources.

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7	8	9	10	11	12	13	14	15
allout P.F.	Maximum Inside Dose of Initial Radiation rad	Incident Overpressure Resistance psi	Contract Cost dollars (Los Angeles Area - 1961)	Contract Cost per sq ft (Los Angeles Area - 1961)	Equipment Cost dollars (Los Angeles Area - 1961)	Equipment Cost per sq ft (Los Angeles Area - 1961)	Cost of Site Restoration dollars	Contract Cost Chicago, Ill. Area (1964)
1000	N/A	5	443,077	7.11	240,218	3.[illegible]	28,990	7.13
1000	N/A	5	243,770	8.85	109,514	3.98	16,400	8.87
1000	N/A	5	195,306	7.77	112,596	4.50	9,300	7.78
1000	N/A	5	357,807	8.70	163,367	3.98	26,605	8.72
1000	N/A	5	215,548	7.10	104,360	3.45	12,100	7.12

- Electrical
  - Normal electric service system
  - Telephone service system

<u>Equipment (not in contract)</u>

- General
  - Bunks
  - Tables and benches
  - Periscopes
  - Sinks
  - Washstands
  - Toilets
  - Toilet partitions
- Plumbing
  - Heavy duty sump pump (3/4 H.P., 115 volt single phase motor and accessories)
- Ventilation
  - Supply and exhaust blowers and motors
  - Ducts, grilles and dampers
  - Filters
  - Cooling towers, motors, pumps, coils and piping
- Electrical
  - Engine-generator sets
  - Lighting fixtures
  - Radios and antennas
  - Radiation detectors
  - Intercom system
  - Clocks

2.5.2 Discussion

Shelters discussed in this section were treated as single-purpose types. However, they are of interest herein for the following reasons. These structures, should they become acceptable, would be located next to schools and park playgrounds. Thus located, they become amenable to dual-use. These are efficiently laid out and structurally well proportioned concepts which closely resemble conventional construction. With minor modifications, they could easily serve as expanded school facilities and indoor playground recreation areas. Individual units are also amenable to prefabrication, thus some level of cost reduction may be possible.

Also, it is concluded by the authors[11] that such shelters, if located in parks and school grounds, could provide fallout protection for practically all of the citizens of Los Angeles County within 15 min of their homes. If these shelters are viewed as dual-use structures, the above statement is significant. The construction cost increases for providing fallout shelters in conventional schools or conventional buildings, at least for the data available,[1,2,8] does not appear to exceed 8 percent (Fig. 2.3 and 2.4). If the "Los Angeles shelter concepts" are viewed as dual-use, and if it is assumed on the strength of previous data, that the incremental cost increase for providing a fallout shelter is 8 percent, then the average incremental shelter (contract) cost (Table 2.6) becomes \$ 0.68 per sq ft of area (for the year 1964). This is not greatly different from previous data, if it is considered that the concepts in question have an inherent level of blast protection of 5 psi. Also, if it is possible to upgrade these concepts (in the preconstruction stage) as cheaply as is stated (in reference 10) then they certainly appear to have a definite economic potential in regions of low overpressure. It would be interesting to examine this potential by taking contractor bids on these concepts in several large cities located in different parts of the country.

Since such a task is beyond the scope of this study, the costs (column 11, Table 2.6) were historically and geographically adjusted using average indices[5] to apply to several large cities and are given in the table below.

AVERAGE (1965) CONTRACT SHELTER COSTS FOR SEVERAL LARGE CITIES[11]
(Dollars per Sq Ft of Shelter Area)

Shelter Designation*	Los Angeles	Chicago	New Orleans	New York	Washington D.C.
1	7.81	7.26	6.32	8.11	6.80
2	9.72	9.04	7.87	10.10	8.45
3	8.54	7.94	6.91	8.87	7.42
4	9.56	8.89	7.74	9.93	8.32
5	7.80	7.26	6.32	8.10	6.78

*See Table 2.6

This table only serves to illustrate possible cost variations and the fact that the economy of a given shelter system is strongly influenced by local conditions.

As far as resistance to large scale fires is concerned, this was not explicitly considered. However, since these structures are to be located under playgrounds and football fields, and not under actual buildings, this is a distinct advantage in overcoming such hazards.

2.6 DUAL-PURPOSE FALLOUT AND BLAST RESISTANT SCHOOLS AND COMMUNITY SHELTERS[12,13,14,15,16]

2.6.1 General Description

Three types of dual-purpose school shelters are discussed in this section, namely:

- above grade with fallout protection,
- below grade with fallout protection,
- below grade with blast protection.

With one exception, all studies discussed herein are of the cost and conceptual type. The one exception is an existing elementary school in use at this time. Major school facilities considered in the conceptual studies include conventional type classrooms, toilet facilities, equipment, storage and general activity rooms. Such facilities as cafeterias, auditoriums, gymnasiums and laboratories are not considered. Capacities of these structures are based on approximately 10 sq ft per occupant. These concepts are adaptable to existing structures as well as to new construction.

2.6.2 Above Grade Schools with Fallout Protection for 300, 550 and 1100 Persons[12]

Three school type dual-use shelters with capacities of 300, 550 and 1100 persons were considered. They are windowless, strictly above grade reinforced concrete structures intended to provide protection against fallout radiation caused by the detonation of megaton range nuclear weapons.

Structural design conforms to the (1956) ACI Building Code, including the appendix on ultimate strength design. It is based upon a minimum concrete strength of 3000 psi for the roof system and columns and 2500 psi elsewhere. The reinforcement conforms to ASTM A432 which has a minimum yield point of 60,000 psi.

The roof system consists of a one-way (12 in.) slab spanning between the exterior walls and longitudinal corridor beams. The thicknesses of the roof and 16 in. reinforced concrete walls are governed primarily by radiation requirements. The concepts are assumed to be adequate to provide protection against blast overpressures on the order of 1.5 psi, and have a protection factor against fallout radiation of 100. It should be evident that in terms of survivability the 1.5 psi overpressure resistance given here has a different meaning from the 2 psi resistance discussed in connection with references 9 and 10.

2.6.3 Below Grade Schools with Fallout Protection for 350, 550 and 1100 Persons[13]

Three school type dual-use shelters with capacities of 350, 550 and 1100 persons were considered in this study. They are basement type reinforced concrete structures intended to provide protection against fallout effects produced by megaton range nuclear weapons.

As in the previous case, the structural design conforms to the (1956) ACI Building Code and the material properties of reinforced concrete and steel are the same. The roof system consists of a 10 in. one-way slab spanning between the exterior walls and longitudinal corridor beams. The thickness of the slab is governed primarily by fallout radiation requirements. The concepts are assumed to be adequate to provide protection against blast overpressures on the order of 2.5 psi, and have a protection factor against fallout radiation of 100.

2.6.4 Below Grade Fallout and Blast Resistant Schools for 350, 550 and 1100 Persons[14]

This study considers three basement type blast resistant dual-purpose shelters with capacities of 350, 550 and 1100 persons, for each of the three overpressure levels, 5, 25 and 50 psi. The structural design of these concepts is based on ultimate strength theory for concrete and, in most cases, is controlled by blast loading. The strength under normal loading conditions meets the requirements of the 1956 ACI Building Code.

The basement ceiling system of the 5 psi structure consists of one-way slab spanning between the exterior walls and longitudinal corridor beams. For 25 and 50 psi designs, the basement ceiling spans two ways between transverse and longitudinal reinforced concrete tilt up walls. The 10 in. slab for the 5 psi structure is governed by fallout radiation requirements and affords a minimum protection factor of 100. This factor may be somewhat greater depending on the type of construction of the upper level school and the relative locations of the interior partitions. The 21 and 30 in. roof slab thicknesses of the 25 and 50 psi basement schools are based upon structural requirements and afford the required radiation protection to reduce the initial radiation on the ground surface to a tolerable level of 20 rads or less within the shelter.

The interior partitions of the 5 psi shelter are of cinder block construction, while the interior partitions of the 25 and 50 psi shelters are reinforced concrete tilt-up bearing walls. In the 25 and 50 psi schools, reinforced concrete partitions were selected to serve as bearing walls and to provide lateral resistance against ground shock.

The thicknesses of the main structural members at the various pressure levels are as follows:

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

* Footing

The designs are based upon a minimum concrete strength of 3000 psi for the roof system and columns and 2500 psi elsewhere for the 5 psi basement school, while concrete strength for the 25 and 50 psi shelter was assumed as 3000 psi throughout. Reinforcement conforms to ASTM A432. Live load on the basement roof was taken as 75 psf for classrooms and 100 psf for corridors. Dead load and live load from the upper level roof slab was assumed as 10 psf and 40 psf, respectively. Debris loading was assumed as negligible in comparison with blast load. Allowable soil bearing capacity was taken as 4 tons per sq ft. The equivalent static blast load on the basement roof was assumed equal to the peak incident overpressure at all three pressure levels based on allowable maximum deformations several times the peak elastic value.

2.6.5 Costs

Detailed cost estimates are provided for each structure considered. These are direct contract costs and, in addition to materials and labor, include 25 percent for contractor's profit and overhead contingencies. It is assumed that they are based on average suburban values for the year 1962.[13,14] The cost estimates were compiled with the following assumptions in mind.

- Normal power is available in the case of fallout shelters and not available in the case of blast shelters.
- Normal foundation conditions (not rock) exist.
- The ground water table is below foundations.
- Provision for air conditioning, which may be required in certain zones, is not included in the cost estimates.
- Normal utility lines (water, power, sewerage) are assumed to be available immediately adjacent to the construction prior to an attack.

Final costs as well as other shelter characteristics are given in Table 2.7.

Table 2.7*

DUAL-PURPOSE FALLOUT AND BLAST RESISTANT
(Conceptual Studies)

1	2	3	4	5	6	7
Structure Designation	Capacity Number of Persons	Gross Area sq ft	Total Volume cu ft	Minimum Headroom ft	Shelter Area per Occupant sq ft	Shelter Vol per Occupa cu ft
1. Above grade schools with fallout shelter (reference 12)	300	3,600	32,400	9	10	90
	550	6,180	55,620	9	10	90
	1,100	12,260	110,340	9	10	90
2. Below grade schools with fallout shelter (reference 13)	350	4,140	37,260	9	10	90
	550	6,440	57,960	9	10	90
	1,100	12,260	110,340	9	10	90
3. Below grade blast resistant schools (reference 14)	350	4,140	37,260	9	10	90
	350	4,140	37,260	9	10	90
	350	4,140	37,260	9	10	90
	550	6,440	57,960	9	10	90
	550	6,440	57,960	9	10	90
	550	6,440	57,960	9	10	90
	1,100	12,260	110,340	9	10	90
	1,100	12,260	110,340	9	10	90
	1,100	12,260	110,340	9	10	90
4. Abo School a below ground school and community shelter for 2400 persons. Artesia, New Mexico (reference 15)	2,400	33,767	314,033	9.3	10.05	93.77

N/A Not applicable

* Structures 1, 2 and 3 are conceptual studies while structure 4 is an existing school

** Costs given are based on average suburban values for 1962 and are subject to local variations. They include 25 percent for contractor's profit and overhead contingencies in the case of (1,2 and 3) and 25 percent in the case of (4). For purposes of adjusting costs refer to reference 5.

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AST RESISTANT SCHOOLS[12,13,14,15]
dies)

Area ...pant ...	7 Shelter Volume per Occupant cu ft	8 Fallout P.F.	9 Maximum Inside Dose of Initial Radiation rad	10 Incident Overpressure Resistance psi	11 Contract** Cost dollars	12 Cost per sq ft	13 Percent Unit Cost Increase over that for Fallout Protection Alone
				Fallout			
	90	100	N/A	1.5	74,260	20.60	
	90	100	N/A	1.5	110,050	17.80	
	90	100	N/A	1.5	198,880	16.20	
				Fallout			
	90	100	N/A	2.5	63,640	15.40	
	90	100	N/A	2.5	90,480	14.00	
	90	100	N/A	2.5	163,795	13.40	
	90	100	20	5	72,600	17.40	13.0
	90	100	20	25	87,560	21.20	37.6
	90	100	20	50	110,780	26.80	74.0
	90	100	20	5	100,700	15.60	11.4
	90	100	20	25	121,040	18.80	34.3
	90	100	20	50	154,440	24.00	71.4
	90	100	20	5	177,180	14.50	6.7
	90	100	20	25	212,750	17.40	29.8
	90	100	20	50	271.410	22.10	65.0
	93.77	1000	N/A	5	459,980.0	13.61	

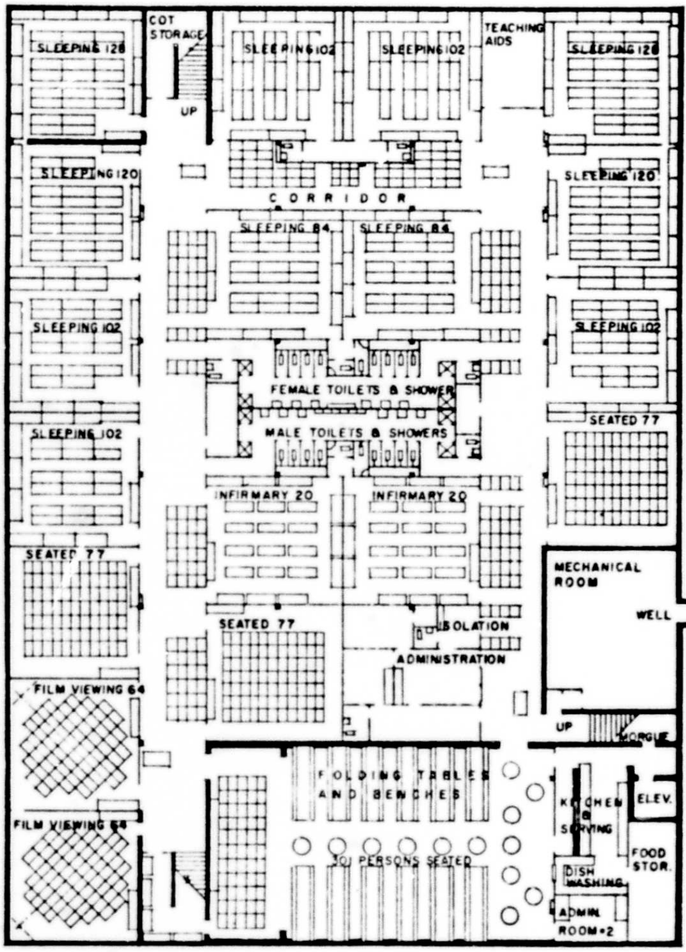
2.7 A BELOW GROUND SCHOOL AND COMMUNITY SHELTER FOR 2400 PERSONS, ARTESIA, NEW MEXICO[15]

2.7.1 General Description

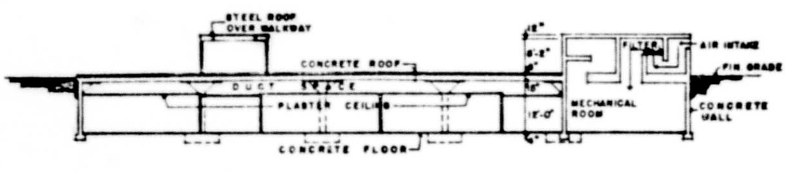
This is an existing basement type reinforced concrete structure designed as an educational facility with features for protection from fallout gamma radiation caused by the detonation of megaton range nuclear weapons. It has a capacity of 540 pupils when functioning as a school, and about 2400 persons when functioning as a shelter. In addition to fallout protection (protection factor of over 1000), it can withstand an overpressure of about 5 psi. The school is shown in Fig. 2.7 and is very similar to those described in references 13 and 14.

The structure is recessed into the earth with the roof slab (15 in., two-way) exposed so that the school function can make use of it for recreational purposes. The supporting columns are spaced at 28 ft 10 in. intervals. This dimension is a function of the classroom size. The design is based on a minimum concrete strength of 3000 psi and 50,000 psi yield point reinforcing steel. The design conforms to the ACI Building Code including criteria for ultimate design. The exterior auxiliary doors and filters can withstand and function after being subjected to 5 psi incident overpressure. The school has a gross floor area of 33,767 sq ft.

The contract cost of the school (25.6 percent for contractors profit and overhead contingencies) was $459,980 or $13.61 per sq ft of gross area. It is assumed herein that bids were taken in 1961. The difference in cost between school only and school and fallout shelter is given as $126,619, or $3.76 per sq ft. This corresponds to a cost increase of 27.6 percent and is significantly greater than corresponding values given earlier (Tables 2.1 and 2.2).



a) Underground Plan, Showing Furniture Arrangement for Survival Condition



b) Cross Section Elevation

Fig. 2.7 ABO ELEMENTARY SCHOOL AND COMMUNITY SHELTER[15]

2.7.2 Discussion

In designing the "school and shelter" structures described only the very basic educational and service facilities were considered. These included:

- classrooms,
- basic wiring and plumbing,
- toilet facilities and
- storage space.

Gymnasiums, auditoriums, and kitchens or cafeterias were not included. It was assumed that recreational activities would take place outdoors. Considered as educational facilities then, these structures may be classified as supplementary classroom space for existing large schools, or as complete self-contained schools serving small rural communities. Viewed in this light costs (Table 2.7) should generally be comparable to those given for conventional schools in Tables 2.1 and 2.2 and Fig. 2.2. An approximate comparison indicates that as school costs go, those given in Table 2.7 are not greatly different. This may be rather significant if it is considered that the concepts in question were designed with a substantial level of blast resistance (1.5 to 50 psi) in addition to fallout protection. As far as incremental costs are concerned, this is known only in the case of Abo school, for which the incremental cost increase due to providing fallout protection is 27.6 percent. In the case of conventional schools[1,2] the corresponding cost increase does not exceed 8 percent, and in the majority of the cases tabulated, is less than 4 percent (Fig. 2.4). In comparison the Abo school shelter appears expensive, however, we are not really comparing like shelters. In the case of conventional schools, the shelters are located either in basements or in centrally located areas when basements are not available. In either case, the shelter walls or roof are not directly exposed to radiation.

Addition l mass is provided by multiple floors and walls. In the case of Abo school, the roof slab is directly exposed to radiation and the entire structure has 5 psi overpressure resistance in addition to fallout protection. The fallout protection factor in this case is also much larger than that of conventional schools.[1,2] The type of architectural concept considered as well as the degree of protection provided should account for the larger additional cost.

Size may be a significant cost influence as far as unit costs are concerned. It will be noted that in terms of size, the "school shelter structures" under discussion are on the lower end of the scale when compared to those given in Tables 2.1 and 2.2. Unit cost may be decreased by seeking an optimum shelter size (see Fig. 2.8).

Variation of shelter cost with overpressure is given in Fig. 2.9 and 2.10. It is interesting to note that blast protection (blast doors included) in the neighborhood of 5 psi can be obtained at a cost about 5 percent higher than that expended for fallout protection alone. Considering that this would decrease with increasing floor area, this number is generally comparable to shelter costs discussed in connection with reference 10. Cost of additional blast protection, however, increases substantially and is well over 60 percent at 50 psi overpressure. It appears that in order to reduce this unit cost, one influencing factor would be an increased shelter size or the addition of conventional superstructures.

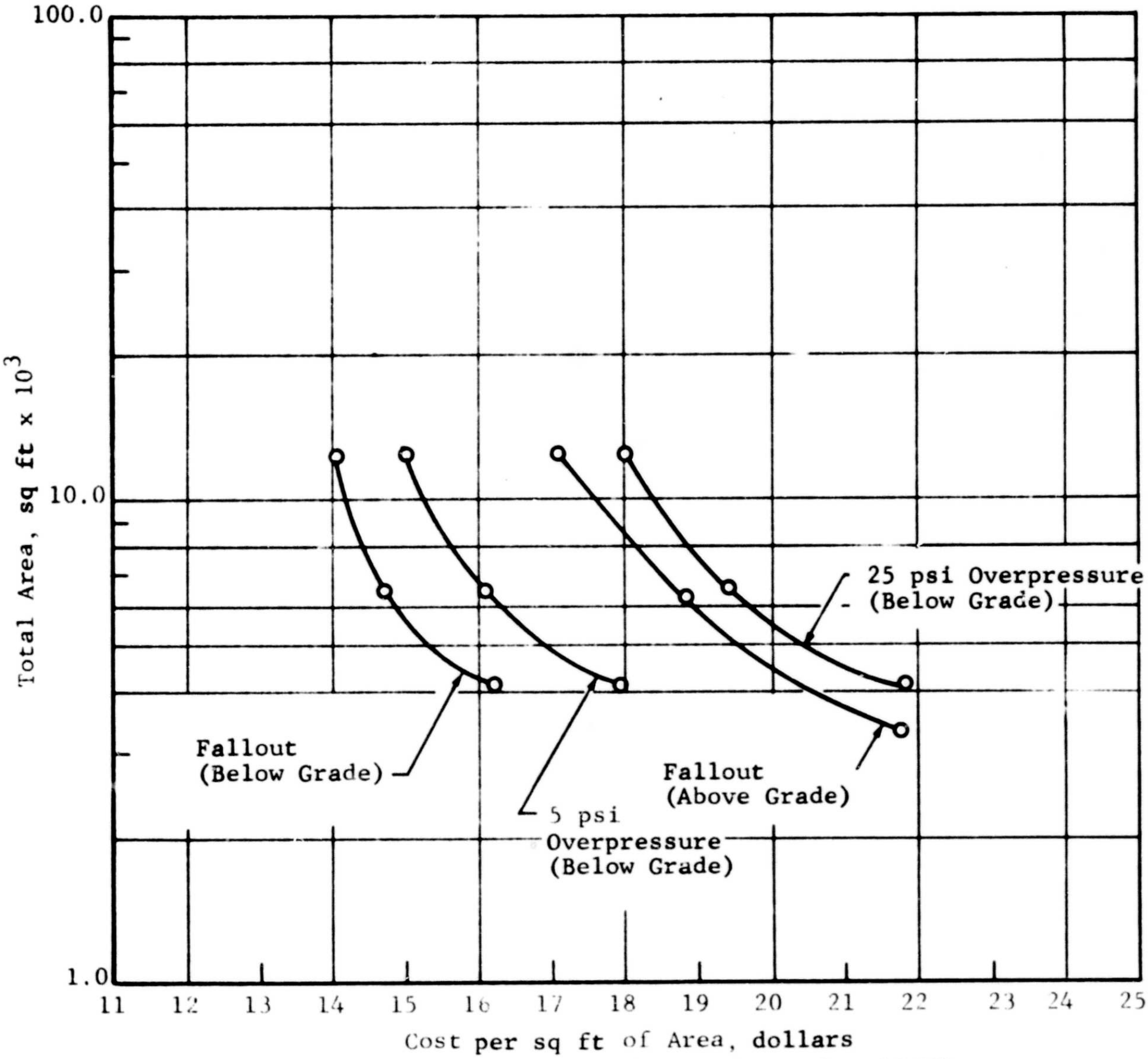


Fig. 2.8 VARIATION OF TOTAL CONTRACT COST WITH TOTAL AREA (Dual-Purpose Schools)[12,13,14]

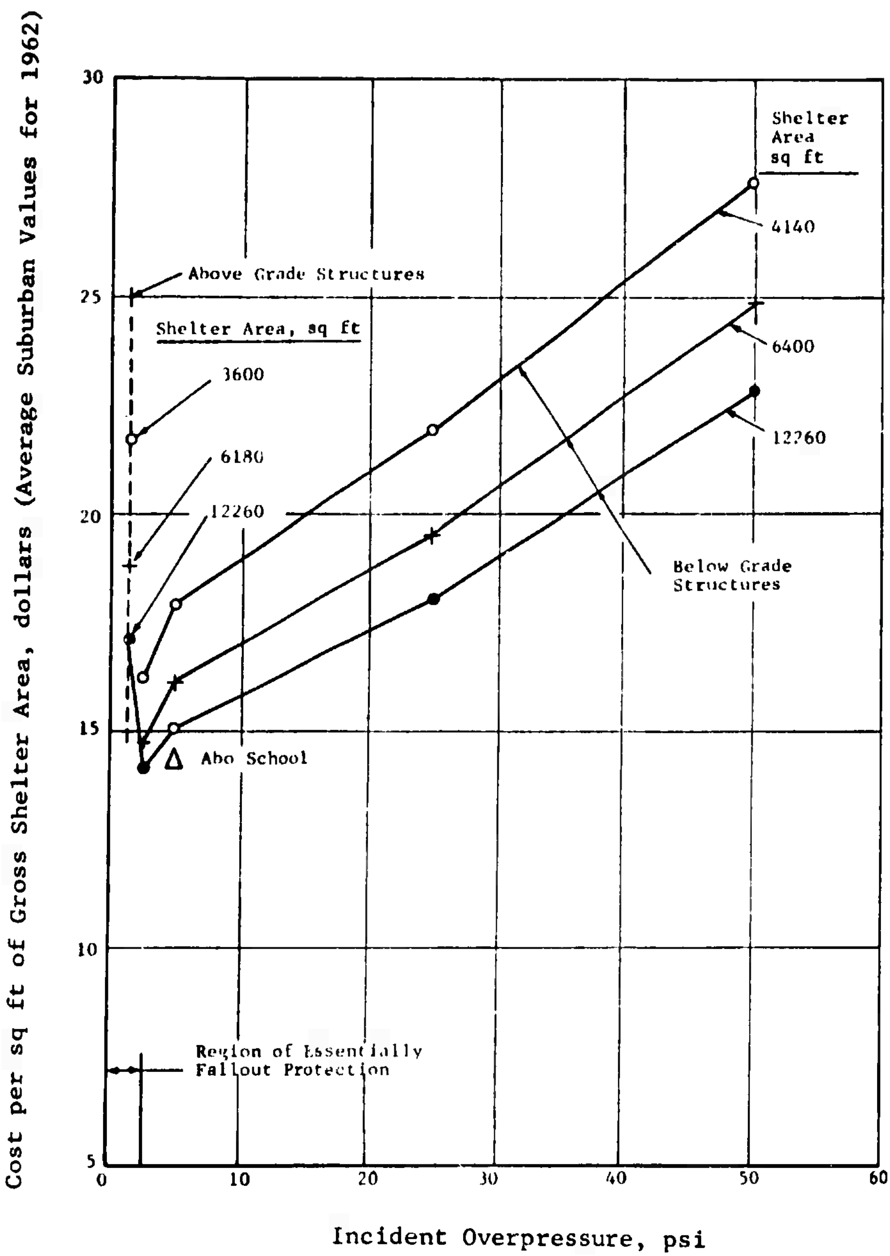


Fig. 2.9 VARIATION OF SHELTER COST WITH OVERPRESSURE (Dual-Purpose Schools)[12,13,14,15]

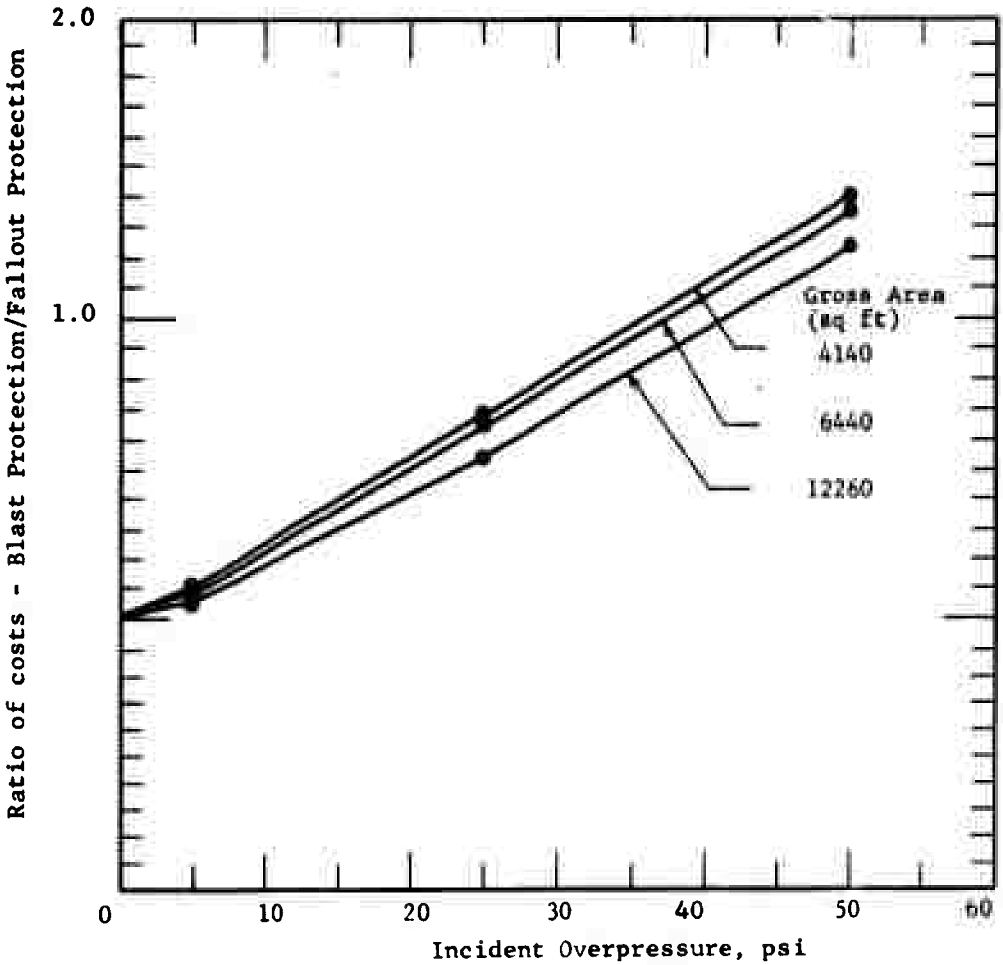


Fig. 2.10 VARIATION OF SHELTER COST INCREASE WITH OVERPRESSURE[12,13,14]
(See Table 2.7)

2.8 PROTECTIVE SHELTERS IN CHURCHES[17]

Cost data presented in this section was obtained from reference 17. This publication is a professional guide which deals in a general manner with the subject of incorporating fallout radiation shelters into churches. In addition to a discussion concerned with the justification of adapting such structures to dual-use and the technical means of doing so, five design examples are presented. Expected additional costs for including shelters are also given. However, since the examples are meant only to provide guidance in this area of design, much of the cost information pertinent to the study at hand is not included. It is felt that for reasons given below, these structures are worthy of consideration as dual-purpose shelters.

At least one church is found in every community and is frequently located at its geographic center. Often a church is the most solidly constructed building in the community. In many cases church schools are located in close proximity to them. Often food preparation facilities and first aid equipment exist on the premises.

In the past, during natural disasters such as earthquakes, flood, tornadoes, etc., churches have served as shelters for displaced persons, as field hospitals, food and medical supplies distribution centers, etc. It is reasonable to expect that similar leadership will be exerted by them in the event of an emergency arising from a nuclear weapons attack. Five design examples are briefly described here. The examples are general and costs are given without reference to year or specific locality. A comparison of costs is presented in Table 2.8. Even though the costs are incomplete and shelter descriptions general they are valuable for two reasons, 1) they represent an additional dual-purpose concept and 2) they describe some of the means of making this economically feasible.

Table 2.8

PROTECTIVE SHELTERS IN CHURCHES[17] (Feasibility Studies)

1	2	3	4	5	6	7	8	9	10	11	12
Structure Designation	Capacity* Number of Persons	Cross Area** sq ft	Approximate Total Volume cu ft	Minimum Headroom ft	Minimum Shelter Area per Occupant sq ft	Shelter Volume per Occupant cu ft	Fallout P.F.	Maximum Inside Dose of Initial Radiation rad	Incident Overpressure Resistance psi	Contract Cost Increase dollars	Cost per sq ft Increase
I	1,000	15,150	136,300	9	10	90	100	N/A	N/A	56,000	3.70
II (Initial)	200	3,320	29,900	9	10	90	100	N/A	N/A	8,000	2.41
(Final)	1,000	18,820	169,300	9	10	90	100	N/A	N/A	13,500	0.72
III	700	14,650	131,800	9	10	90	100	N/A	N/A	29,000	1.98
IV	720	11,220	101,000	9	10	90	100	N/A	N/A	0	0
V	600	8,500	76,500	9	10	90	100	N/A	N/A	15,900	1.87

N/A Not applicable

* Congregation seating capacity and sheltering capacity

** Gross area of parent structure which acts as shelter in times of emergency

Note: Costs given are average values for central United States and are as given in reference 17. It is assumed that they are based on the year 1962.

2.8.1 <u>Design Example No. I, Above Ground Shelter in Church</u>

This example considers an above ground church having a congregation seating capacity of 1000. The church has a gross area of about 15,150 sq ft. Due to increased thicknesses of various structural members, the church as a shelter has a fallout radiation protection factor of over 100. Chemical and biological filters are included in the air-conditioning system. Emergency generators are provided. The additional construction cost of such a shelter in the central United States is estimated at $56,000.

2.8.2 <u>Design Example No. II, Above Ground Shelter in a Growing Plan</u>

Many churches must be planned to grow with their congregations. The planning must conform to existing needs and means, yet provide flexibility for future additions. This example indicates ways that shelter can be included in this planning.

In its initial phase the building is suited to a congregation of up to 200 persons. The central multiuse and chapel space will seat 135 in assembly or 100 at tables for eating. Movable partitions permit the three classrooms to become a single large space capable of seating an additional 60. For the first few days of the emergency period following an attack, all sleeping, eating and other activities would be confined to the multipurpose space. After the radiation hazard decreases it will be possible to make some use of the classrooms to relieve overcrowding. Toilet rooms and kitchen will be adequate for emergency use. The mechanical space below these areas is large enough to accommodate future additions to the heating system as well as chemical and biological filters, cooling coils to condition the air supply, a diesel generator, a well pump and a hydro-pneumatic tank where conditions are such as to require their use. A thick concrete folded plate roof provides overhead protection for the shelter area.

The second phase of construction adds at one side of the original structure a church capable of seating a congregation of 330, and two large classrooms under a mezzanine at the rear which can be opened to the church to provide additional seating. Two additional classrooms and administrative offices are added at the opposite side of the original structure. While no new shelter space is added at this time, the existing shelter is now completely surrounded and has an improved protection factor. It now becomes the fellowship hall of the enlarged building.

The third phase adds more classrooms and a library-lounge space. The latter is designed to furnish additional shelter and has a thick concrete folded plate roof similar to that of the fellowship hall. The two shelters are connected by the area under the mezzanine at the rear of the church.

The final phase adds a fellowship hall at the rear of the church large enough for team games or to seat 400. The new construction gives additional protection to the shelter area under the church mezzanine. It is estimated that the increase in construction cost to provide the first unit of shelter would amount to $8000. The increase in cost of the final building to provide all of the shelter would amount to $13,500.

2.8.3 Design Example No. III, Semiunderground Shelter in an Initial Unit

Many new congregations start their church building with a fellowship hall, which is usually less expensive to build than a church and more flexible to use. In this example, the hall is large enough to use as a gymnasium and can serve as a temporary church for a congregation of 700. The floor is below ground level and as a result, the surrounding earth helps to protect the shelter area. Shielding overhead is provided by a thick concrete folded plate roof. The only windows are small triangular openings with fixed glass directly under the roof gables. Exits are protected by deep areaways.

A circular above ground classroom wing is connected to the fellowship hall by a service area containing toilet rooms, kitchen, storage areas and mechanical space, all partially below ground level. The central portion of the classroom wing is protected by the surrounding rooms and another thick concrete folded-plate roof. This part of the shelter contains a library-lounge area and administrative offices. Classroom windows are kept to a minimum in the expectation that some use can be made of the classrooms to relieve overcrowding after the first few days in the shelter.

Mechanical systems and equipment are similar to those of the previous design examples. The toilets provided for the normal use of the building will be adequate for all but the most crowded conditions. It is estimated that the increase in construction cost to provide shelter would amount to $29,000.

2.8.4 Design Example No. IV, Below Ground Shelter in a Church Addition

In this example, a building containing a fellowship hall, classrooms and a church for a congregation of 720 is planned as an addition to an existing structure containing classrooms and a small chapel. The shelter area includes the classrooms and fellowship hall, which are below ground level and beneath the church. The shelter is protected by the surrounding earth and by the overhead mass of the church floor and roof. Since the classrooms have no conventional exterior windows, visual interest is directed inward to the large open central area of the fellowship hall. Ample lighting and colors, textures and plant material contribute to the attractiveness of the area. Small windows at the ceiling line of the classrooms maintain a degree of orientation with the outside and improve the psychological climate of these rooms.

Under conditions of emergency occupancy, the classrooms would be used as segregated sleeping areas; the choir room, as an infirmary; and the central area, as space for dining and general activity. Chemical toilets or disposable units would be required to supplement the facilities provided for normal use.

The roof above the church is a thin concrete shell structure supported on concrete rigid frames. Exterior glass is minimal and it is probable that some use can be made of the church to relieve overcrowding after the first few days. The floor of the church is a heavy concrete slab of uniform thickness. Since the normal construction provides adequate protection for the shelter area, providing shelter under the same conditions as in the previous examples would involve no increase in construction cost.

2.8.5 Design Example No. V, Shelter in an Existing Building

In this example of an existing building on a city lot, the fellowship hall in the basement is remodeled to make a shelter for 600 persons. The steel beams supporting the church floor above the shelter are strengthened by adding steel angles in order to support the extra weight of 8 in. of solid concrete overhead shielding in the form of precast panels. The bottom surface of the panels is finished to form a new ceiling and new surface-mounted lighting fixtures are installed. Although relatively small amounts of radiation would enter through the deep areaways at the basement windows, they are easily and effectively blocked by stacking masonry units or sandbags on boards laid across at the top.

The fellowship hall is already air-conditioned, and no changes are required in the ventilation system other than the addition of filters in the fresh air intake and minor modifications to the ductwork. The building is also equipped with emergency lighting but does not have adequate capacity to operate the ventilating equipment. Because it appears probable, in this instance, that normal electrical service to the building would be interrupted for the duration of the emergency, additional generator capacity and fuel supply must be provided.

Emergency water supply is from a well and hydro-pneumatic tank. It is separated from the public water supply system in such a way that a connecting piece can be inserted to introduce well water to the system after the public supply has been cut off. Costs of remodeling, including emergency power and a well, are estimated at $15,900.

2.9 AUSTERE COMMUNITY FALLOUT SHELTER

Data contained in this section was obtained from reference 18. This reference describes a low-cost rectangular, above ground dual-purpose protective shell with immediate utility as a fallout shelter. The basic configuration is sufficiently flexible to be customized for purposes such as light storage warehouse, assembly plant, etc. A prototype of such a structure with P.F. of 100 is described below.

- Use was made of 20 ft bay modules, the prototype structure is three-bays wide and four-bays long (60 x 80 ft inside dimensions). This will provide shelter space for about 500 persons.
- Filled cavity walls, 24 in. thick, provide required wall mass for fallout shielding and permit block lay-up without cutting or waste.
- Open-web steel joists and steel girders on Lally columns support corrugaged sheet metal decking, which, in turn, is covered by 1 ft of select fill and a 3 in. layer of reinforced concrete.
- Minimum electrical and ventilation equipment was provided.

Construction costs of the basic protective shell, including 5 percent for contractors' contingencies, but excluding engineering fees, are $39,700 or $7.88 per sq ft. The clear floor area is 4800 sq ft. Assuming that this structure is used as a warehouse, the credit for such utility may be taken as approximately $4.25 per sq ft. The net construction cost of the shelter becomes $3.63 per sq ft. This structure was scheduled for completion in June 1965, it is assumed thus that the costs are for midyear 1964, in the area of Washington, D.C.

2.10 DUAL-PURPOSE SUBURBAN COMMUNITY CENTERS[19,20]

2.10.1 General Description

As in the case of reference 13, shelters discussed herein are basement type reinforced concrete structural concepts designed to provide protection against associated effects of megaton range nuclear weapons. These structures were designed to serve as community shelters during normal occupancy and as protective shelters in times of emergency. Possible uses of such community centers are as recreation halls, religious facilities, etc.

Three designs with capacities of 100, 500 and 1000 persons were considered. Each was designed and costed for four nuclear weapons environments characterized by fallout radiation and 5, 25 and 50 psi blast induced overpressures. All designs considered, conform to the ACI Building Code including the provisions on ultimate strength design. They were based upon a minimum concrete strength of 3000 psi for the roof system and columns, and 2500 psi elsewhere in the case of the fallout and 5 psi designs. In the case of 25 and 50 psi shelters, 3000 psi concrete was specified to be used throughout. Reinforcement in each case conforms to ASTM A432.

In the case of the design treating fallout radiation alone, the basement ceiling system consists of a two-way (10 in.) flat slab spanning between exterior walls and interior columns. The thickness of the slab is governed primarily by fallout radiation requirements. Thicknesses of various structural members in shelter concepts where blast protection was considered are given. The ceiling height in all cases is 9 ft and is based on normal occupancy considerations. Cubage thus supplied exceeds 65 cu ft per person.

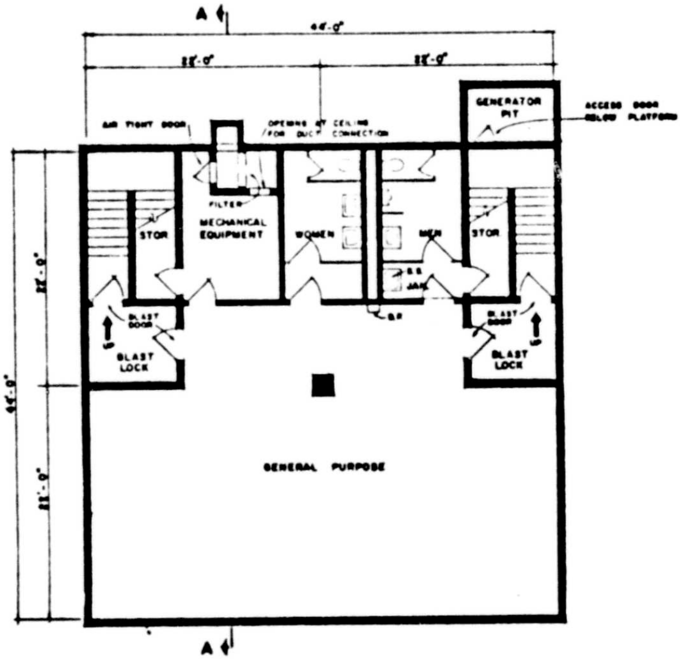
Member	Thickness at Indicated Pressure Level		
	5 psi	25 psi	50 psi
Roof, Slab	12"	21"	36"
Drop Panels	-	6"	9"*
Columns	12"x12"	2'-0"x2'-0"	2'-6"x2'-6"
Exterior Walls	8"	8"	8"
Exterior Wall Footings (Width)	1'-8"	1'-10"	3'-10"
Interior Wall Footings (Width)	1'-6"	1'-6"	1'-6"
Column Footings	6'-6"x6'-6"	12'-6"x12'-6"	18'-0"x18'-0"

Note: 6 in. for 100 person shelter and 9 in. for 500 and 1000 person shelters.

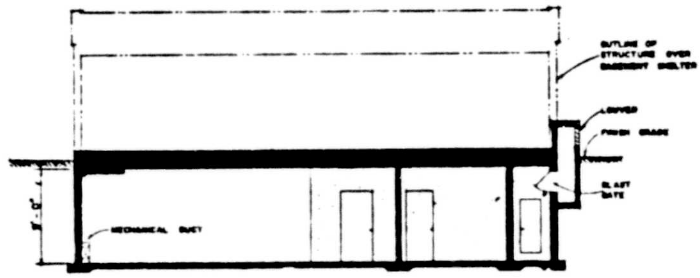
Even though not specifically provided for, fallout shelters discussed herein are assumed to possess a blast overpressure resistance of 1.5 psi. It again should be evident that in terms of survivability the 1.5 psi overpressure resistance given here has a different meaning from the 2 psi resistance discussed in connection with references 9 and 10 . All shelters considered have a protection factor against fallout radiation of 100. Blast shelters have the capacity to reduce initial radiation on the inside to 20 rads. A typical basement layout is given in Fig. 2.11.

The mechanical ventilating system is based on a single zone supply air system for open areas. The supply air quantity is based on an air delivery of 15 cfm per person, of which 10 cfm is fresh, and the balance is recirculated air. It is assumed that a structure above the shelter will be heated. Heat for tempering incoming air to the basement during normal use in winter is assumed to be supplied by a plant servicing both levels. The cost of such a plant is not included in the cost estimates.

As far as electrical considerations are concerned, normal power may or may not be available during an emergency in the case of fallout shelters. Both cases are discussed. However,



Lower Level Plan



Section A-A

Fig. 2.11 COMMUNITY SHELTER FOR 100 PERSONS (25 and 50 psi) cost estimates are based on normal conditions. In the case of blast shelters normal power is assumed to not exist. Cost estimates, in addition to wiring, switching and outlets, also include a diesel engine driven generator.

Cost estimates provided may be classified as direct contract costs. They are based on average suburban unit prices for the year 1963. In addition to items discussed, they are based on the following assumptions.

- Normal foundation conditions (not rock) exist.
- The ground water table is below the basement floor slab.
- Provision for air conditioning, which may be required in certain zones, is not included in costs.
- Normal utilities (water, power, sewerage) are available immediately adjacent to the construction.

Costs and other shelter characteristics are summarized in Table 2.9. In this table the costs are final contract costs and include 25 percent for contractor's overhead contingencies and profit.

Table 2.9

DUAL-PURPOSE SUBURBAN COMMUNITY CENTERS
(Conceptual Studies)

1 Shelter Capacity Number of Persons	2 Gross Area sq ft	3 Total Volume cu ft	4 Minimum Headroom ft	5 Shelter Area per Occupant sq ft	6 Shelter Volume per Occupant cu ft	7 Fallout P.F.	8 Maximum Inside Dose of Initial Radiation rad	9 Incident Overpressure Resistance psi	10 Contract* Cost dollars	11 Contract Cost per sq ft	12 Percent Unit Cost Increase over that for Fallout 1.5 psi
100	1,940	17,460	9	10	90	100	N/A	1.5 (Fallout)	34,600	17.80	--
100	1,940	17,460	9	10	90	100	20	5.0	42,100	21.70	21.90
100	1,940	17,460	9	10	90	100	20	25.0	56,180	29.10	64.00
100	1,940	17,460	9	10	90	100	20	50.0	68,240	35.20	98.70
500	5,630	50,670	9	10	90	100	N/A	1.5 (Fallout)	83,000	14.70	--
500	5,630	50,670	9	10	90	100	20	5.0	95,640	17.00	15.90
500	5,630	50,670	9	10	90	100	20	25.0	121,440	21.60	47.00
500	5,630	50,670	9	10	90	100	20	50.0	151,840	27.00	84.70
1,000	10,810	97,290	9	10	90	100	N/A	1.5 (Fallout)	150,900	14.00	--
1,000	10,810	97,290	9	10	90	100	20	5.0	170,600	15.80	13.20
1,000	10,810	97,290	9	10	90	100	20	25.0	218,600	20.20	44.30
1,000	10,810	97,290	9	10	90	100	20	50.0	274,900	25.40	82.00

* Cost given are based on average suburban values for 1963 and include 25 percent for contractor's profit and overhead contingencies. For purposes of cost adjustment see reference 5 or other reliable sources.

2.10.2 Discussion

If a sheltering capability is to be included in the design of a given dual-purpose structure, the additional cost may be determined by first designing and costing the building subject to its primary function and local building codes, and subsequently revising the design in order to provide the required shelter space of desired hardness. The difference in cost between the two designs would be what is ordinarily considered as incremental or shelter cost.

Subject to the primary function, both the original and the modified designs would most likely have the same number of square feet of floor space; however they would not necessarily be architecturally or structurally similar. The type of shelter (blast, fallout, hardness level, size, etc.), and the fact that it is included in a conventional building may have a significant influence on the architectural concept and the load transmitting system of the superstructure. This is true to a considerably lesser extent for those buildings in which only the basement portion is hardened to serve as a shelter.

The classes of existing architectural and structural concepts even for as specific a group of buildings as schools are for all practical purposes very large. Any logical classification as to type (a formidable task in itself) followed by a comparative cost and design analysis described above may not produce any definitive and widely applicable criteria on the economics of dual-purpose shelters. Such an analysis is formidable, laborious and further compounded by the fact that building costs are strongly influenced by variations which are a composite of local building codes, construction labor practices and also the climate.

Although above grade architectural concepts vary considerably their basements are in most cases surprisingly similar. Basements by their very nature are considerably better suited for sheltering purposes than are corresponding superstructures.

Generally, much beyond an overpressure level of 10 psi, hardening of superstructures becomes increasingly expensive. There are, of course, exceptional cases where the architectural concept is especially advantageous and amenable to slanting techniques. However, such cases become increasingly rare with increasing levels of overpressure and associated nuclear weapons effects, and thus tend to tax to a considerable extent the skill and ingenuity of the designer.

If it is accepted that for nuclear weapons environments in excess of 10 psi overpressure and associated effects, basements of conventional buildings are the only logical shelter candidates, then there exists a fairly reliable means for determining their incremental shelter cost and consequently the extent of their capabilities. Specifically, the previous refers to new construction and considers the class of those conventional buildings in which basements would be included subject to their primary function.

In the light of the previous statement, consider the design of a conventional building with a basement and assume that its "general contract" cost estimate has been broken down under two main sub-headings:

- cost of superstructure,
- cost of basement.

The basement design can be modified to suit the requirements of a given nuclear weapons environment without affecting the architectural concept, support system or the cost of the superstructure. The difference in cost between conventional and modified basements without reference to the cost of the superstructure is certainly a good approximation to the incremental (shelter) cost.

Thus, it appears that in order to determine the extent of the potential of this class of dual-purpose candidate structures, it is only necessary to investigate the capabilities of a set of basements. To this end a catalog of a series of basements designed and costed for various nuclear weapons environments, soil and foundation conditions would serve as a powerful tool.

Specific structures briefly described earlier in this section were designated as dual-purpose suburban community centers. Judging by their elevation views and floor plans (Fig. 2.11) these structures are simply basements which are amenable to a variety of purposes. One such purpose may be some type of community center of which there are many. They may also be basements of churches, stores, offices, municipal buildings, etc. In the light of previous discussion, these basement designs are ideally suited to be included in the basement shelter evaluation catalog described earlier. Even though costs of corresponding basements designed for conventional loadings are not available at this time, incremental costs between fallout and blast shelters of the same size and similar construction are useful.

It is often desirable to know not only the incremental shelter cost but its influence on the cost of the whole structure as well. This may be easily determined by the method described above. However it is interesting to note that in some cases this may be obtained directly from knowledge of the incremental shelter cost.

The approach discussed is primarily suited to new construction and is thus limited. Great numbers of potential dual-use shelters exist at this time with capabilities that it would be desirable to investigate. To accomplish this task, it is necessary first to determine the inherent strength of such candidate structures and then to isolate effective and economic means of reinforcing them for various nuclear weapons environments. If it is again accepted that basements are the logically dominant shelter candidates, then the first part of the task may be effectively accomplished with the aid of a catalog consisting of basements designed and costed for conventional loading and evaluated for various nuclear weapons environments. The second part of the task, i.e., reinforcing and costing for various weapons environments, is also formidable; however, here again a similar approach will prove effective. To this end it is necessary to assemble a catalog of economic structural, fire and radiation reinforcement (upgrading) techniques and their costs. A catalog of such techniques may also be very useful in a post attack environment. A draft report, "Modification of Existing Buildings as Community Shelters" has treated this subject to a considerable extent.

2.11 PARKING GARAGE AND COMMUNITY SHELTERS FOR 5000 PERSONS[21,22,23]

2.11.1 General Description

Parking garages described in this section are one story below grade reinforced concrete structural concepts designed to provide parking space as well as protection against the effects of megaton range nuclear weapons (1 to 20 MT). Separate designs consider fallout radiation as well as direct effects. Direct effects designs include 5, 25 and 50 psi incident overpressure levels. The structures are based on multiples of a 29 x 27 ft bay, proportioned to dimensions of an average city block, with parking facilities for 150 cars during normal operations and shelter space for 5000 persons during times of emergency. A typical floor plan of one such garage is shown in Fig. 2.12. Characteristic locations for structures of this type are:

- below a city park,
- below a street, or
- below a street level parking area.

The shelters were designed to provide a protection factor against fallout radiation in excess of 100 and will limit the initial radiation dosage within the shelter to 20 rads. The structural design conforms to the ACI Building Code and is based on a minimum concrete strength of 3000 psi for the roof system, columns and column footings and 2500 psi elsewhere. Reinforcement conforms to ASTM A432 which has a minimum yield point of 60,000 psi. Bearing capacity of the soil was taken as 4 tons per sq ft.

Two general garage concepts were considered and are designated as "Structure I" and "Structure II". Structure I was designed to be located below a parking lot and thus has a roof system able to serve as a deck. Structure II was designed to be located below a city park. The roof system of Structure I in the case of "fallout only" design consists of a 10 in. flat slab spanning between the exterior walls and interior columns, while a 12 in. slab with 3 in. thick drop panels is used for the roof system of Structure II. Clear ceiling heights are 8 ft.

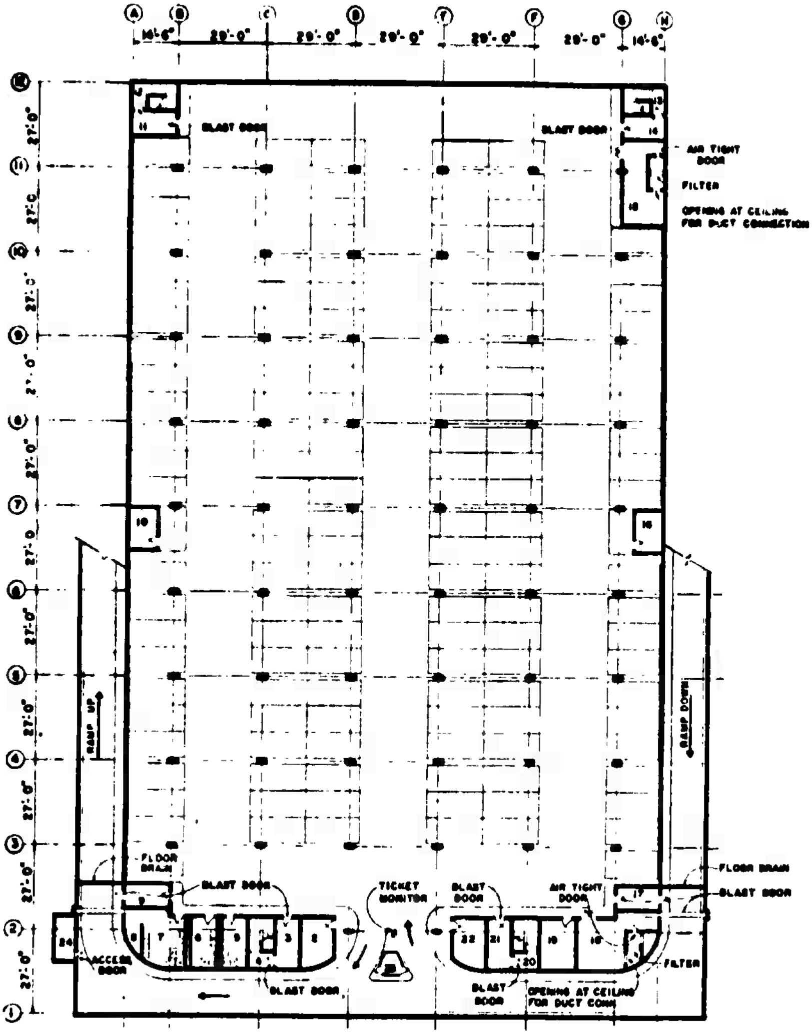


Fig. 2.12 PARKING GARAGE SHELTER FOR 5000 PERSONS (Lower Level Plan)

Although no specific provision was made for blast protection, it is estimated that both structures are adequate for a blast overpressure in the range of 1.5 to 2.5 psi. In the case of blast resistant designs, the shelter (garage) roof systems consist of two-way flat slabs spanning between exterior walls and interior columns. The slab thicknesses for 5, 25 and 50 psi structures are 12, 21 and 36 in. respectively. The ceiling height for the 5 psi shelter is 8 ft and 9 ft 2 in. for the 25 and 50 psi shelters.

The main blast doors at the ramp entrances of the 25 and 50 psi shelters consist of structural steel I-beams with steel cover plates. The hollow interior of these doors is filled with concrete. The doors are rolled open and closed electrically and mechanically. Blast seals are provided around the door periphery. The doors of the 5 psi shelters consist of standard overhead rolling doors reinforced to resist this blast overpressure. These doors are manually operated. The structures are fireproof and all partitions and finishes are fire retardant.

Shelter costs and other data are given in Table 2.10. These are direct contract costs and include 25 percent for contractor's overhead and profit contingencies. It is assumed that they are based on average urban prices for the year 1963. The estimates were based on the following general assumptions.

- Normal power available during emergency in the case of fallout shelters and not available in the case of blast shelters.
- Normal foundation conditions (not rock).
- Ground water table below basement floor slab.
- Normal utilites (water, power, sewerage) are assumed to be available immediately adjacent to the construction prior to an attack.

2.11.2 Di[illegible]

"Underground parking garage" is a name ordinarily given to a large basement structure specifically adapted to parking of conventional size civilian motor vehicles. Primary characteristics of such adaptations are:

- ramps and doors suitable for vehicular traffic,
- interior column spacing commensurate to efficient vehicle movement and economy of space.

In all other respects these concepts (Fig.2.1)are very similar to those discussed in the previous section[19] [illegible] the general category of basement structures.

Underground parking garages are ordinarily constructed at those locations at which sufficient parking space cannot otherwise be obtained. This implies congested urban zones. Such parking garages may be portions of

- department stores,
- multistory apartment buildings,
- large multistory parking garages, etc.

In congested urban areas, more than elsewhere, the possibility of large scale fires following a nuclear weapons attack is real. The problem of survivability of structures (shelters) subjected to blast loading has been treated in fair detail for most structures considered in this report. However, survivability of shelter occupants subjected to mass fires external to shelters has received correspondingly little attention. This is also true of shelters presented in this section. Habitability in such an environment requires some means of insulation and possibly internal cooling for some duration of time. Multistory underground parking garages possess the capability of alleviating this problem to some extent by letting the upper levels provide some of the insulation for the lower ones, however, this would mean a corresponding reduction in shelter capacity. Parking garages discussed herein are single level and their given costs do not include consideration of this type of protection.

Table 2.10

DUAL-PURPOSE PARKING GARAGE ANI
(Conceptual Stuc

1 Shelter Capacity Number of Persons	2 Gross Area sq ft	3 Total Volume cu ft	4 Minimum Headroom ft	5 Shelter Area per Occupant sq ft	6 Shelter Volume per Occupant cu ft	7 Fallout P.F.	8 Maximum Inside Dose of Initi Radiation rad
5000	51,670	413,360	8	10	80	100	N/A
5000	51,670	413,360	8	10	80	100	20
5000	51,670	473,814	9.17	10	91.7	100	20
5000	51,670	473,814	9.17	10	91.7	100	20

N/A Not applicable

* Structure I is a below grade parking garage designed with a roof slab capable of serving as a deck of a parking lot.

** Structure II is a below grade parking garage designed to be located below a city park (supports 3 ft 6 in.,of soil over the roof).

*** Cost given are based on average urban values for the year 1963 and include 25 percent for contractor's profit and overhead contingencies. For purposes of adjusting costs see reference 5 or other reliable sources.

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um e Initial tion d	9 Incident Overpressure Resistance psi	10 Structure I*			11 Structure II**		
		*** Contract Cost dollars	Contract Cost per sq ft	Percent Unit Cost Increase over that for Fallout	Contract Cost dollars	Contract Cost per sq ft	Percent Unit Cost Increase over that for Fallout Protection Alone
	1.5-2.5	570,000	11.00	--	670,000	12.95	--
	5	592,060	11.50	4.54	676,860	13.10	1.16
	25	826,350	16.00	45.40	865,430	16.80	29.70
	50	1,114,640	21.60	96.30	1,148,380	22.20	71.40

For purposes of comparing costs of the concepts in question with those of conventional parking garages and emphasizing the potential sheltering utility of such structures, two existing parking garages were selected and are briefly described below.

Grant Park Garages "North" and "South"[19] are below grade multilevel reinforced concrete structures of flat slab and column construction. They are located next to each other partially below Michigan Avenue and partially below the adjoining Grant Park which is in the immediate vicinity of the Chicago Loop. This area has peak day time and night time populations of approximately 256,000 and 4000 persons respectively. Both garages are under the jurisdiction of the Chicago Park District.

Grant Park Garage North was constructed by the city of Chicago in 1953 to meet the rising need for parking space in the Chicago Loop area. It is a two-level structure with a capacity for 2100 vehicles and a corresponding floor area of 775,260 sq ft. Its direct contract bid cost for the year 1953 was $5,941,588. This corresponds to $7.65 per sq ft of floor area. Within a relatively short time, the parking facilities in the Loop area again proved inadequate and Grant Park Garage South was constructed in 1963 immediately adjacent to the then existing North parking garage. This is a three-level underground structure with a capacity to accommodate 1500 cars and a corresponding floor area of 537,516 sq ft. Its direct contract cost for the year 1963 was $6,769,530 which corresponds to $12.59 per sq ft of floor area. It is to be deduced that the difference in cost of $7.65 as opposed to $12.59 per sq ft is due primarily to the difference in time of construction.

Both structures have approximately an 8 ft ceiling height on each level. In both cases, exit and entrance ramps feed directly into the street, one of Chicago's major transportation arteries, under which they are constructed. It is interesting to note that these two structures have the floor area capacity (had they been designed with some nuclear weapons environment in mind) to accommodate (shelter) approximately one half of the day time Loop area population, assuming 10 sq ft of floor area per shelteree. This, of course, does not take into account other available potential shelter space.

Costs of these two existing structures are compared to those of the previous parking garage-shelter concepts in Fig. 2.13, for the year 1963. In a gross sense, the costs compare favorably in the fallout effects region. This seems to indicate that the costs of the two existing parking garages would not have been significantly increased if fallout protection or some low level of overpressure resistance had been considered in their design. The comparison becomes more favorable if it is considered that parking garage-shelter conceptual studies have floor areas which are significantly smaller than those of the two existing garages. These smaller garage concepts, however, may have a wider application in which case their costs are meaningful.

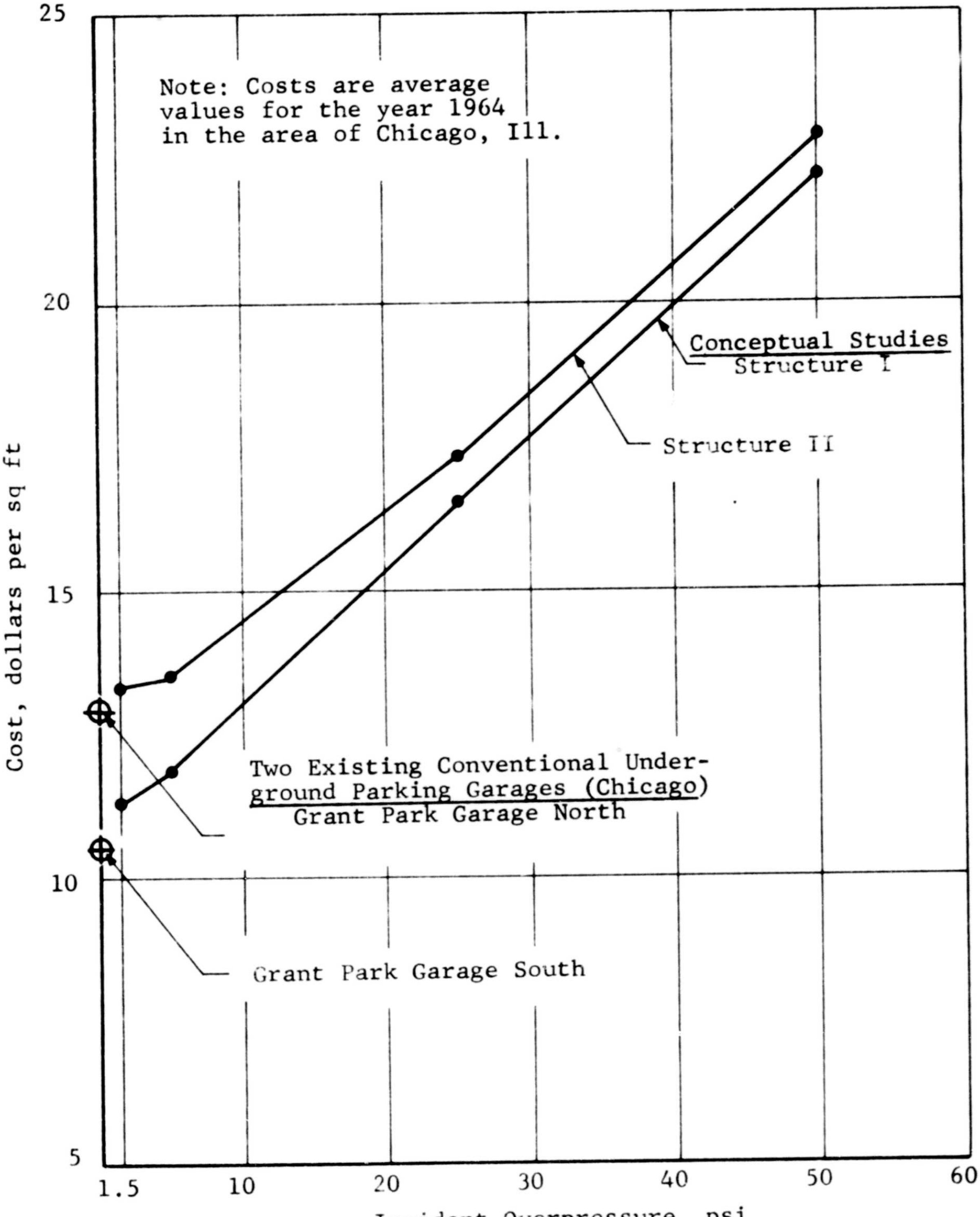


Fig. 2.13 VARIATION OF UNIT COST WITH OVERPRESSURE (Underground Parking Garages)

2.12 BLAST RESISTANT DESIGN OF SEVERAL BUILDING TYPES

2.12.1 General Description

Data on structures discussed herein was obtained from the results of a study[24] conducted to determine the

- practicability of design for atomic blast resistance,
- estimated construction cost for a range of blast pressure loadings and a comparison of costs with conventional construction, and
- estimated additional cost of providing personnel shelter areas.

Blast resistant designs and construction cost estimates were prepared for the following building types and peak incident blast overpressures.

Conventional

- Administration Building, Two-Story for 10, 20 and 30 psi.
- Communications Building for 10, 20 and 30 psi.
- Warehouse for 10, 20 and 30 psi.

Unconventional (General Purpose)

- Concrete Igloo for 25, 50, 100 and 200 psi.
- Earth Covered, Concrete Rectangular, 40 x 80 ft, for 25, 50, 100 and 200 psi.
- Earth Covered, Concrete Double Barrel Arch, 40 x 80 ft usable floor area, for 50 psi.
- Earth Covered, Concrete Dome, 25 ft diameter for 50, 100 and 200 psi.
- Buried, Concrete Rectangular, 40 x 80 ft, for 50, 100 and 200 psi.
- Buried, Concrete Double Barrel Arch, 40 x 80 ft usable floor area, for 50 psi.
- Buried, Concrete Dome, 25 ft diameter, for 50, 100 and 200 psi.
- Buried, Concrete Igloo, 26 ft 10 in. x 60 ft 8 in. for 50, 100 and 200 psi.

Blast loadings on these structures were based on peak incident overpressures given before. Calculations relative to these loadings were based on the preliminary draft of the Corps of Engineers' Manual EM1110-345-413, "Design of Structures to Resist the Effects of Atomic Weapons".

Roofs and exposed floor slabs, walls, columns, footings and above ground earth covered arches were designed for plastic deformation under the design blast load. Above ground earth covered domes, buried arches, buried domes, blast doors and escape hatch doors were designed for maximum elastic deformation under design blast load. Blast loading on buried structures was taken as that at the ground surface.

The designs were based on the following set of material and foundation properties:

- Reinforcing bars: Intermediate grade in accordance with ASTM Specification Designation A305-56T and with Federal Specification QQ-B-71a. Yield point stress, 47,500 psi, increased approximately 10 percent to account for rapid rates of strain for most cases.
- Structural steel: ASTM Specification Designation A7-56T and Federal Specification QQ-5-741. Yield stress, 38,000 psi (corresponding to standard ASTM rate of loading) increased approximately 12.5 percent to account for rapid rates of strain for most cases.
- Concrete: f_c' increased 30 percent to account for rapid rates of strain for most cases.
- Foundation bearing pressure: 4 tons/sq ft, rated capacity; 8 tons/sq ft, ultimate capacity.

Computations relative to the radiation levels were based upon "Capabilities of Atomic Weapons", Department of Defense Manual TM 23-200, June 1955 (Secret).

Features or items not considered in the overall designs are listed below

- Mechanical equipment including:

  Blast valves
  Chemical filters
  Cooling water facilities (cooling towers, spray ponds or wells)
- Electrical equipment
- Decontamination facilities
- Button-up provisions
- Standby equipment
- Duration of shelter occupancy

In the design of the exposed abovegrade structures, the thicknesses of walls and roofs were determined subject to blast resistance requirements only; thus, in some cases, these will not provide adequate shielding against fallout radiation The publication in question considers both conventional and unconventional architectural concepts; however, since primary interest in the case of dual-use shelters is directed toward the conventional type, only these are described and discussed in the following paragraphs

2.12.1.1 Two-Story Administration Building

The design of the administration building shown in Fig. 2.1ℓ was based on the Wing Headquarters Building, Westover Air Force Base, Chicipee Falls, Massachusetts. The existing building dimensions (exterior) of the main wing are 208 ft 6 in. x 65 ft 6 in. Those of the smaller wing are 95 x 49 ft. Exterior walls are constructed of 12 in. concrete block. Roof and floor systems are of wood and are supported on wooden joists which frame into steel girders. The ground floor slab is reinforced concrete on grade There is a basement under the smaller wing containing the boiler rooms, storage space and other miscellaneous areas.

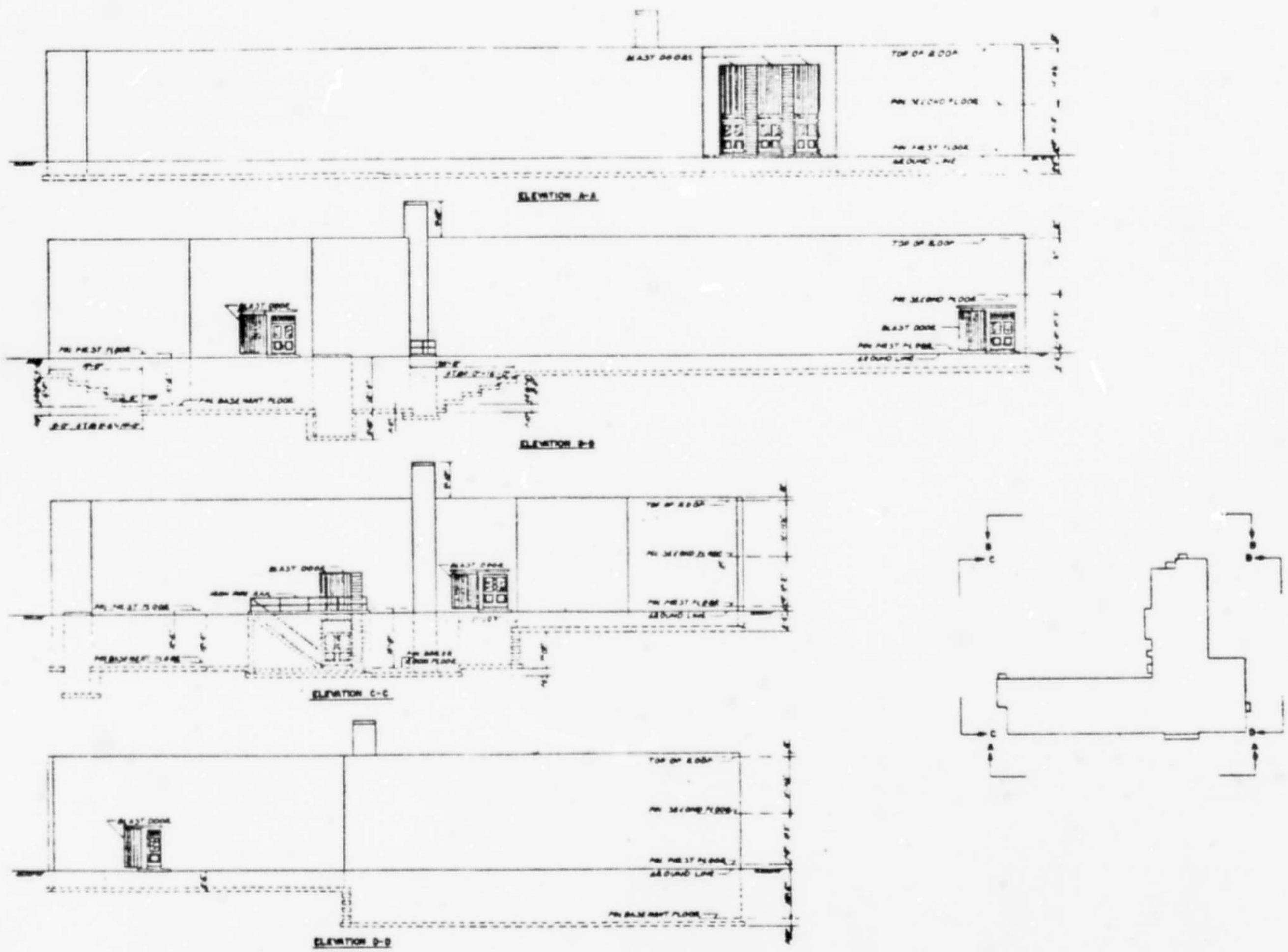


Fig. 2.14 ADMINISTRATION BUILDING (20 psi Blast Resistant)

The proposed blast resistant administration building is a reinforced concrete, windowless structure with both utility and blast doors at all exterior openings. The clear dimensions have been maintained essentially the same as those of the existing building described. The roof and floor systems are of beam and slab construction. Exterior wall panels are one-way slabs spanning vertically between floor levels. Roof and floor slabs were designed as deep beams to carry wall panel blast loads. The walls are utilized to act as shear walls as well. A buried personnel shelter, for blast and radiation protection, with a capacity for approximately 170 persons (based upon 10 sq ft of floor area per occupant) is provided adjacent to the basement area.

2.12.1.2 Communications Building

The design of the single story Communications Building shown in Fig. 2.15 was adapted from drawings of the Base Communication Center, McGuire Air Force Base, Wrightstown, New Jersey. The interior dimensions of the main wing of the existing building are 177 ft 6 in. x 25 ft 4 in. The smaller wing of the building contains a garage (20 ft 0 in. x 22 ft 0 in.), heat exchange room (14 ft x 22 ft), and motor generator room (9 ft 10 in. x 16 ft 0 in.). The walls are concrete block bearing walls. The roof system consists of a 2-1/2 in. reinforced concrete slab resting on bar joists. The reinforced concrete floor slab rests upon a 6 in. cinder fill.

The proposed blast resistant Communications Building is a reinforced concrete windowless structure with both utility and blast doors at all of its openings. The clear dimensions were maintained essentially the same as those of the existing structure described. The roof of the main wing is of continuous beam slab and column construction. The roof of the small wing is a two-way slab. The garage is not blast resistant. Wall panels of the main wing were designed to act as one-way slabs and shear walls and are supported at the roof and floor slab.

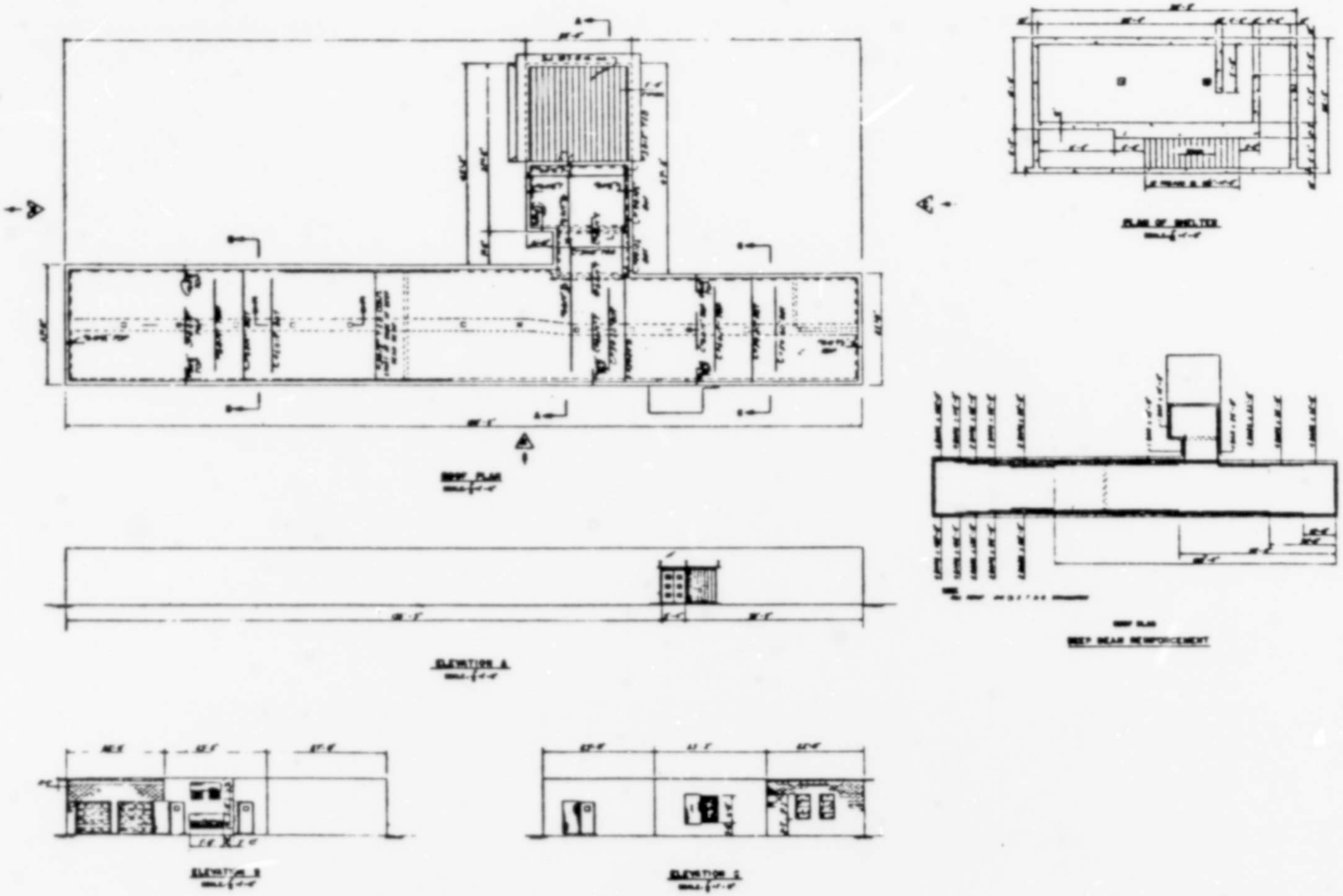


Fig. 2.15 COMMUNICATION BUILDING (10 psi Blast Resistant)

A buried personnel shelter for blast and radiation protection with a capacity for about 30 persons is provided below the switchboard room.

2.12.1.3 Base Supply Warehouse

Designs of this structure, illustrated in Fig. 2.16, were based upon drawings of the Base Supply Warehouse, Keesler Air Force Base, Mississippi. The interior dimensions of the existing structure are 62 ft 4 in. x 237 ft 4 in. The walls are of concrete block. Roof joists span 21 ft between longitudinal reinforced concrete beams supported by reinforced concrete columns spaced at 14 ft intervals. The roof system may be either precast concrete joists or bar joists. The floor slab rests on fill and is 4 ft above grade. The existing building is divided into two areas by a 12 in. thick fire wall.

The proposed blast resistant warehouse is a windowless reinforced concrete structure with both utility and blast doors for all of its openings. The clear dimensions are essentially the same as those of the existing warehouse described. The roof is of beam and slab construction. The roof beams are restrained at the walls by pilasters of the same cross-sectional dimensions as the beams. Wall panels were designed as two-way slabs supported at the pilasters, floor and roof slabs. Walls are utilized as shear walls. A buried personnel shelter for blast and radiation protection with a capacity of approximately 10 persons is provided below the floor slab adjacent to the office area.

With each of these structures, the thicknesses of various structural members comprising them are controlled by radiation requirements. Roof, walls, columns and footings were designed for plastic deformation, while the blast doors were designed for maximum elastic deformation.

Unit prices used for the structural estimates were derived from national average costs using the National Construction Estimator (1957 through 1958 Edition) as a guide. Costs of

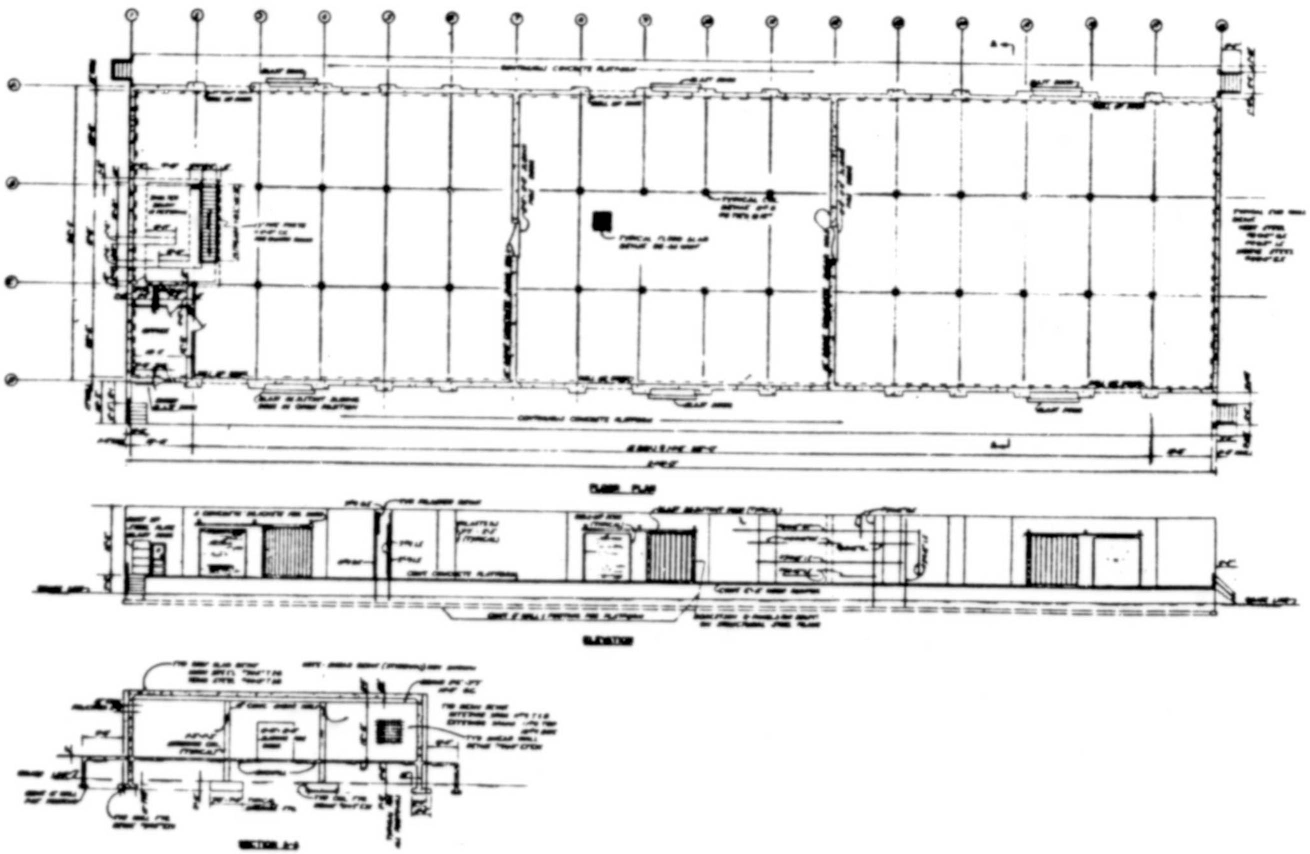


Fig. 2.16 WAREHOUSE (20 psi Blast Resistant)

conventional as well as blast resistant structures, and their shelters are given in Table 2.11. These represent the sum of 1) structural and earthwork and 2) architectural costs for labor and materials. Twenty-five percent for profit and overhead contingencies was included. Not included are costs for mechanical and electrical equipment and corresponding labor. Thus in accordance with the direct contract cost definition given earlier, these represent only a portion (about 70 percent) of total direct contract cost.

Since these structures do not fall in the general class of dual-use shelters, only their relative costs are of interest herein. For this reason, the costs given in Table 2.11 were not reduced to a common base for comparison with other blast resistant structures discussed in this report. Variation of cost with overpressure is given in Fig. 2.17.

2.12.2 Discussion

In the blast and associated nuclear weapons environment studies dealing with dual-use shelters discussed in the earlier sections of this report, the primary objective was: people survivability. With this objective in mind, each case was approached by considering a shelter of some favorable configuration, materials, method of construction and location (relative to the ground surface within the confines of the parent structure) capable of providing resistance against some given nuclear weapons attack environment, as well as protection and habitability in the corresponding immediate post-attack environment. No attention was directed to the survival of the whole of the parent structure.

In the study discussed in this section, the approach taken with respect to three structures described earlier (administrative building, communications building, and warehouse) was different. Consideration was given to the practicability of survival of the whole of these structures (parent structure included), as well as that of the operating personnel.

Table 2.11

BLAST RESISTANT DESIGN OF SEVERAL BUI

1 Primary Function	2 Name and Location	3 Type of Construction	4 Capacity, Main Structure and Adjoining Shelter	5 Area of Structure sq ft	6 Area of Shelter sq ft	7 Volume, Main Structure cu ft	8 Volume, Shelter cu ft	9 Minimum Headroom, Main Structure ft	10 Minimum Headroom, Shelter ft	11 Shelter A Per Occu sq ft
1. Administration Building	Wing Headquarters Building, Westover Air Force Base, Chicopee, Mass.	Concrete block walls, wooden roof and floor system, partial basement	3,480	34,800	N/A	702,960	N/A	First floor(9.9) Second floor(10.3)	N/A	10
2. Administration Building (10 psi blast resistant)	Conceptual study	R/C beam and slab roof system, one-way slab wall panels, blast doors	3,650	34,800	1,700	702,960	*	First floor(9.9) Second floor(10.3)	*	10
3. Administration Building (20 psi blast resistant)	Conceptual study	Same as 10 psi structure	3,650	34,800	1,700	702,960	*	First floor(9.9) Second floor(10.3)	*	10
4. Administration Building (30 psi blast resistant)	Conceptual study	Same as 10 psi structure	3,650	34,800	1,700	702,960	*	First floor(9.9) Second floor(10.3)	*	10
5. Communications Building	Base Communication Center, McGuire Air Force Base, Wrightstown, N.J.	Concrete block walls, R/C roof slab on bar joists	535	5,350	N/A	56,175	N/A	10.5	N/A	10
6. Communications Building (10 psi blast resistant)	Conceptual study	R/C beam and slab roof system, one-way slab wall panels, blast doors	565	5,350	300	56,175	*	10.5	*	10
7. Communications Building (20 psi blast resistant)	Conceptual study	Same as 10 psi structure	565	5,350	300	56,175	*	10.5	*	10
8. Communications Building (30 psi blast resistant)	Conceptual study	Same as 10 psi structure	565	5,350	300	56,175	*	10.5	*	10
9. Warehouse	Base Supply Warehouse, Keesler Air Force Base, Miss.	Concrete block walls, bar joist roof system	1,479	14,790	N/A	192,270	N/A	13.0	N/A	10
10. Warehouse (10 psi blast resistant)	Conceptual study	R/C beam and slab roof system, two-way slab walls, blast doors	1,489	14,790	100	192,270	*	13.0	*	10
11. Warehouse (20 psi blast resistant)	Conceptual study	Same as 10 psi structure	1,489	14,790	100	192,270	*	13.0	*	10
12. Warehouse (30 psi blast resistant)	Conceptual study	Same as 10 psi structure	1,489	14,790	100	192,270	*	13.0	*	10

* Indicates that information is not available

R/C Reinforced concrete

N/A Not applicable

** The study in question (reference 24) was concerned with blast resistance alone. Radiation protection for personnel within the main structures was not considered. The assumption being that personnel would be housed within adjoining shelters during times of emergency.

Note: Costs given are national average costs. They were derived using the "National Construction Estimator", 1957-58 edition as a guide. This reference should be consulted for cost adjustments.

.11

SEVERAL BUILDING TYPES[24]

10	11	12	13		14		15		16		17			18
Minimum Headroom, Shelter ft	Shelter Area Per Occupant sq ft	Volume Per Occupant cu ft	Fallout P.F.		Inside Dose of Initial Radiation		Incident Overpressure		Cost		Cost per sq ft			Additional Cost of Blast Resistance per sq ft of Area, Main Structure
			Main Structure	Shelter	Main Structure rad	Shelter rad	Main Structure psi	Shelter psi	Main Structure dollars	Shelter dollars	Main Structure	Shelter	Total	
N/A	10	First floor(99) Second floor(103)	N/A	N/A	N/A	N/A	N/A	N/A	317 '35	N/A	9.12	N/A	9.12	-
*	10	First floor(99) Second floor(103)	Not specifically considered **	*	Not specifically considered	*	10	10	372,410	23,124	10.70	13.60	10.84	1.58
*	10	First floor(99) Second floor(103)	Not specifically	*	Not specifically	*	20	20	456,983	24,230	13.13	14.25	13.18	4.01
*	10	First floor(99) Second floor(103)	Not specifically considered	*	Not specifically considered	*	30	30	565,428	27,630	16.25	16.25	16.25	7.13
N/A	10	105	N/A	N/A	N/A	N/A	N/A	N/A	66,828	N/A	12.49	N/A	12.49	-
*	10	105	Not specifically considered	*	Not specifically considered	*	10	10	82,416	9,389	15.40	31.30	16.25	2.91
*	10	105	Not specifically considered	*	Not specifically considered	*	20	20	100,593	10,086	18.80	33.62	19.59	6.31
*	10	105	Not specifically considered	*	Not specifically considered	*	30	30	120,155	11,838	22.46	39.46	23.36	9.97
N/A	10	130	N/A	N/A	N/A	N/A	N/A	N/A	106,865	N/A	7.23	N/A	7.23	-
*	10	130	Not specifically considered	*	Not specifically considered	*	10	10	157,507	7,634	11.17	76.34	11.09	3.94
*	10	130	Not specifically considered	*	Not specifically considered	*	20	20	204,017	9,403	14.43	94.03	14.33	7.20
*	10	130	Not specifically considered	*	Not specifically considered	*	30	30	272,471	13,594	19.34	135.94	19.21	12 11

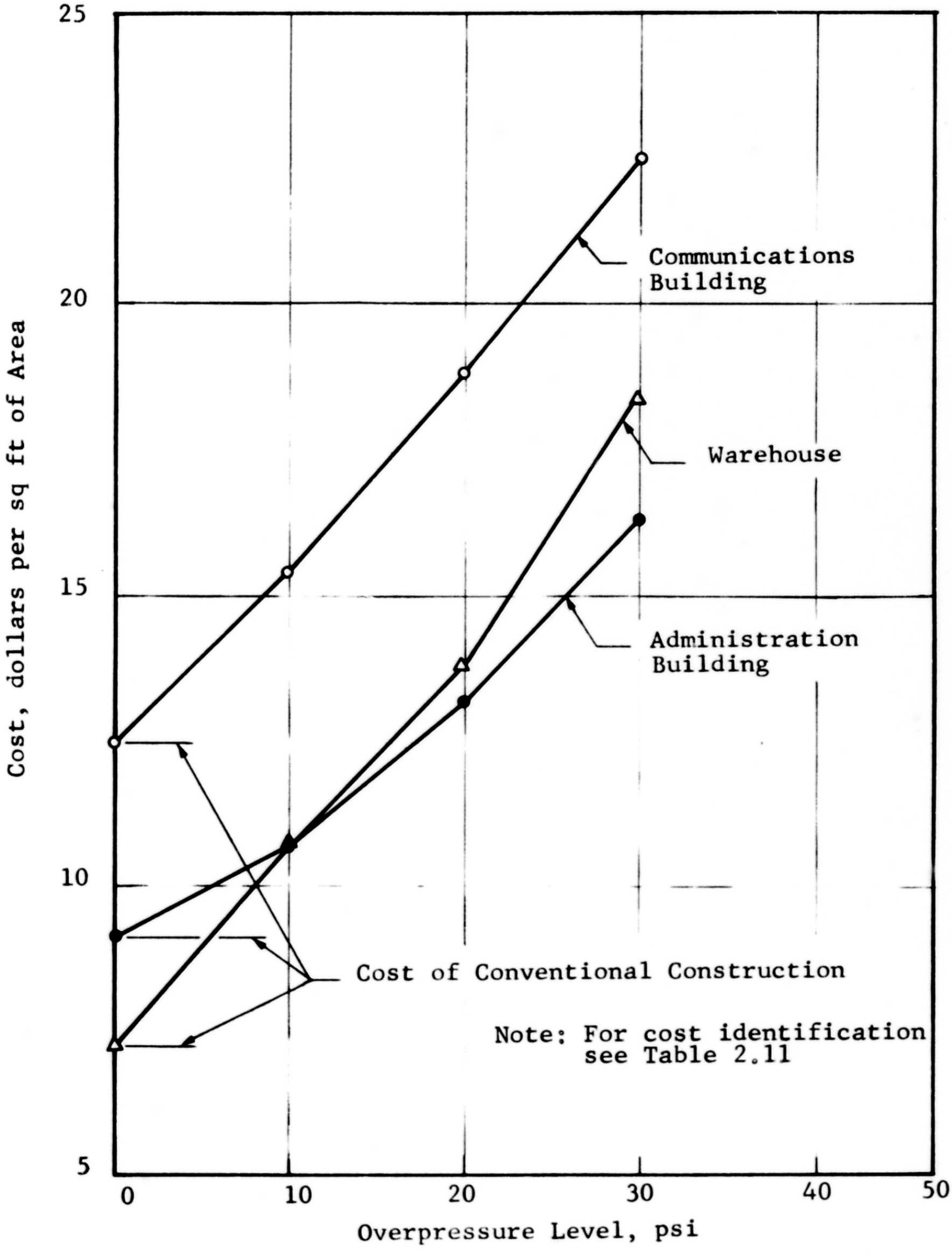


Fig. 2.17 VARIATION OF STRUCTURAL COST WITH OVERPRESSURE FOR THREE TYPES OF CONVENTIONAL STRUCTURES [24] (Mechanical and Electrical Costs not Included)

For the three categories of buildings defined by utilitarian function, existing representative structures were selected. These were then redesigned, keeping essentially the same clear inside dimensions, for three levels of blast induced overpressure (10, 20 and 30 psi). It was assumed that operating personnel would not remain on the main premises during an attack or immediate post-attack period and for this reason no specific consideration was given to initial radiation, fallout radiation and local or mass fires. This is not meant to imply that some undetermined level of such protection does not exist.

As far as safety of operating personnel is concerned, personnel shelters, considering initial and fallout radiation in addition to blast overpressure, were provided in the designs in proximity to each structure. These shelters belong to the "single purpose" category.

Although these structures do not belong to the general category of dual-purpose shelters, they are of interest since the practicability of hardening conventional above grade structures is considered. The personnel shelters were designed with a single purpose in mind; however, there does not appear to be any reason to suppose that they are not suitable for some dual-use function. With this in mind, personnel shelter costs are also of interest. Variation of percent shelter cost increase, over that of the main conventional structures, with overpressure for each of the three structures is given in Fig. 2.18. Similar data are also given in Table 2.12. It is interesting to note that especially in the case of the Administration Building, the shelter cost remains essentially constant with overpressure above 10 psi. In regard to the other two structures, this variation is still relatively small when compared to similar plots such as Fig. 2.3, 2.4, and 2.10. The relative magnitudes of shelter cost increase are also worth comparing. Such variations are highly desirable.

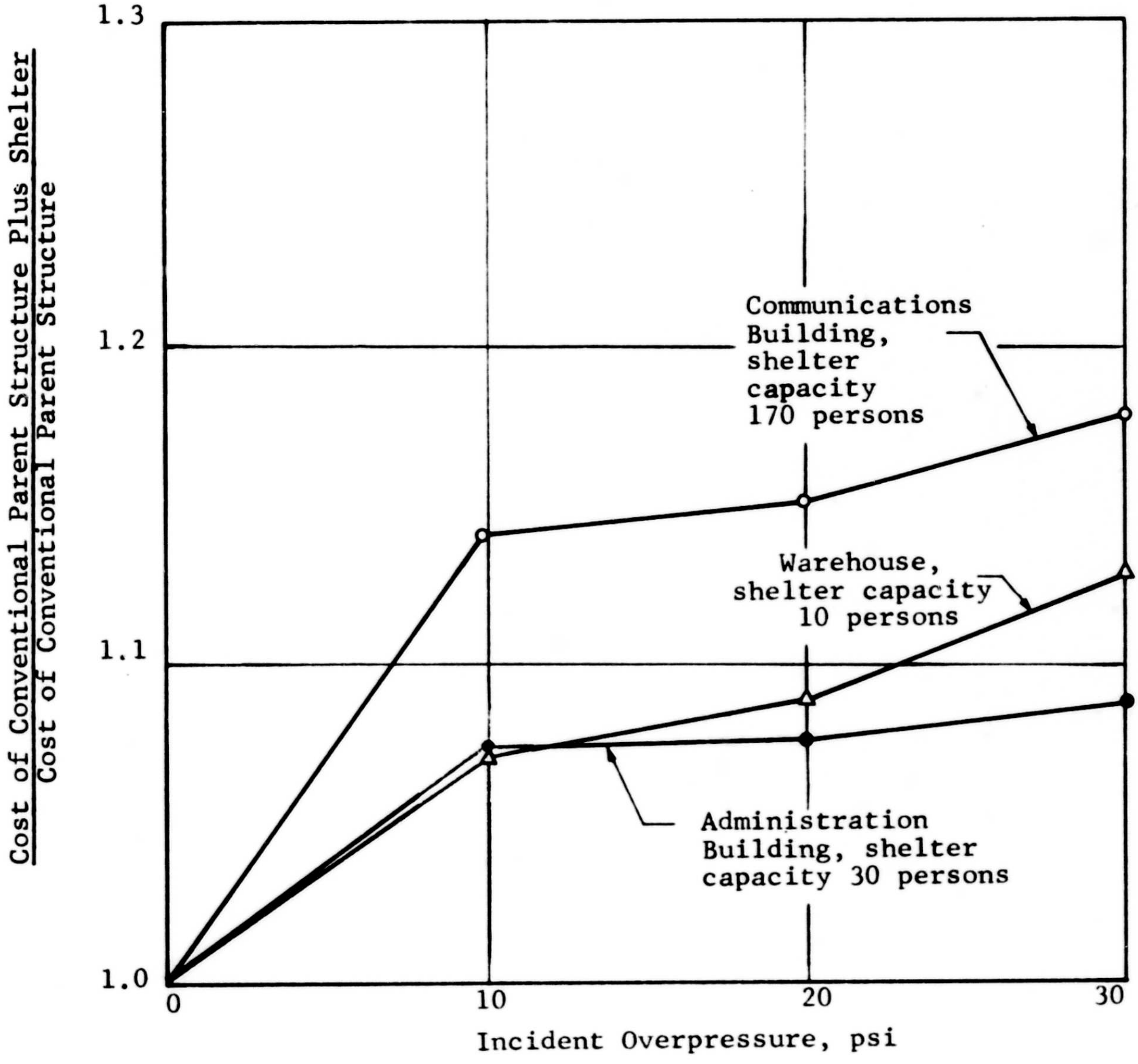


Fig. 2.18 VARIATION OF BUILDING COST INCREASE WITH OVERPRESSURE [24]

Table 2.12

PERCENT INCREASE IN THE COST OF HARDENING[24]

	Cost Increase over Conventional Construction due to Hardening of the Parent Structure for Blast only, percent	Number of Shelteree Spaces Added (at 10 sq ft per person)	Cost Increase over Conventional Construction due to Inclusion of a Personnel Protective Shelter (Blast and Initial Radiation), percent	Number of Shelteree Spaces Added (at 10 sq ft per person)
Administration Building (10 psi blast protection)	17	3480	7.3	170
Administration Building (20 psi blast protection)	44	3480	7.6	170
Administration Building (30 psi blast protection)	78	3480	8.7	170
Communication Building (10 psi blast protection)	23	535	14.1	30
Communication Building (20 psi blast protection)	51	535	15.1	30
Communication Building (30 psi blast protection)	80	535	17.7	30
Warehouse (10 psi blast protection)	47	1479	7.1	10
Warehouse (20 psi blast protection)	91	1479	8.8	10
Warehouse (30 psi blast protection)	155	1479	12.7	10

In designing a personnel shelter, the goal should be a structural configuration which is initially economic and adaptable to higher overpressure levels and associated effects with little added cost. Personnel shelter configurations discussed in this section appear to approach these conditions. Unfortunately, the reference in question does not describe the shelters in any desirable detail. A shelter plan and its elevation for the Communications Building are given in Fig. 2.15. This, however, was apparently reduced from a large drawing and has lost a great deal of its detail. Shelter descriptions for the other two structures were not provided.

As for the problem of providing blast resistance to above grade structures the story appears to be entirely different (Fig. 2.19, Table 2.12). The act of providing a 30 psi blast and radiation resistant below grade personnel shelter within a conventional warehouse increases the original cost about 13 percent (Fig. 2.18), however rendering the complete above grade warehouse 30 psi blast resistant but without radiation protection (initial or fallout), increases the original cost by a factor of 2.55 (Fig. 2.19). Practicability of providing blast protection for any structure depends in part on its function. It is evident that a warehouse with few internal walls, large ceiling heights and long support spans (Fig. 2.16) is not as amenable to blast protection as a Communication Building (Fig. 2.15). However, even in the case of the Communication Building, the cost of blast protection is substantial (Fig. 2.19). These structures were not meant to be personnel shelters, and if viewed as hardened personnel shelters, initial and fallout radiation protection, as well as habitability equipment and supplies, would need to be provided and cost further increased. It appears that these three structures do not possess characteristics conducive to economic dual-use shelter adaptation.

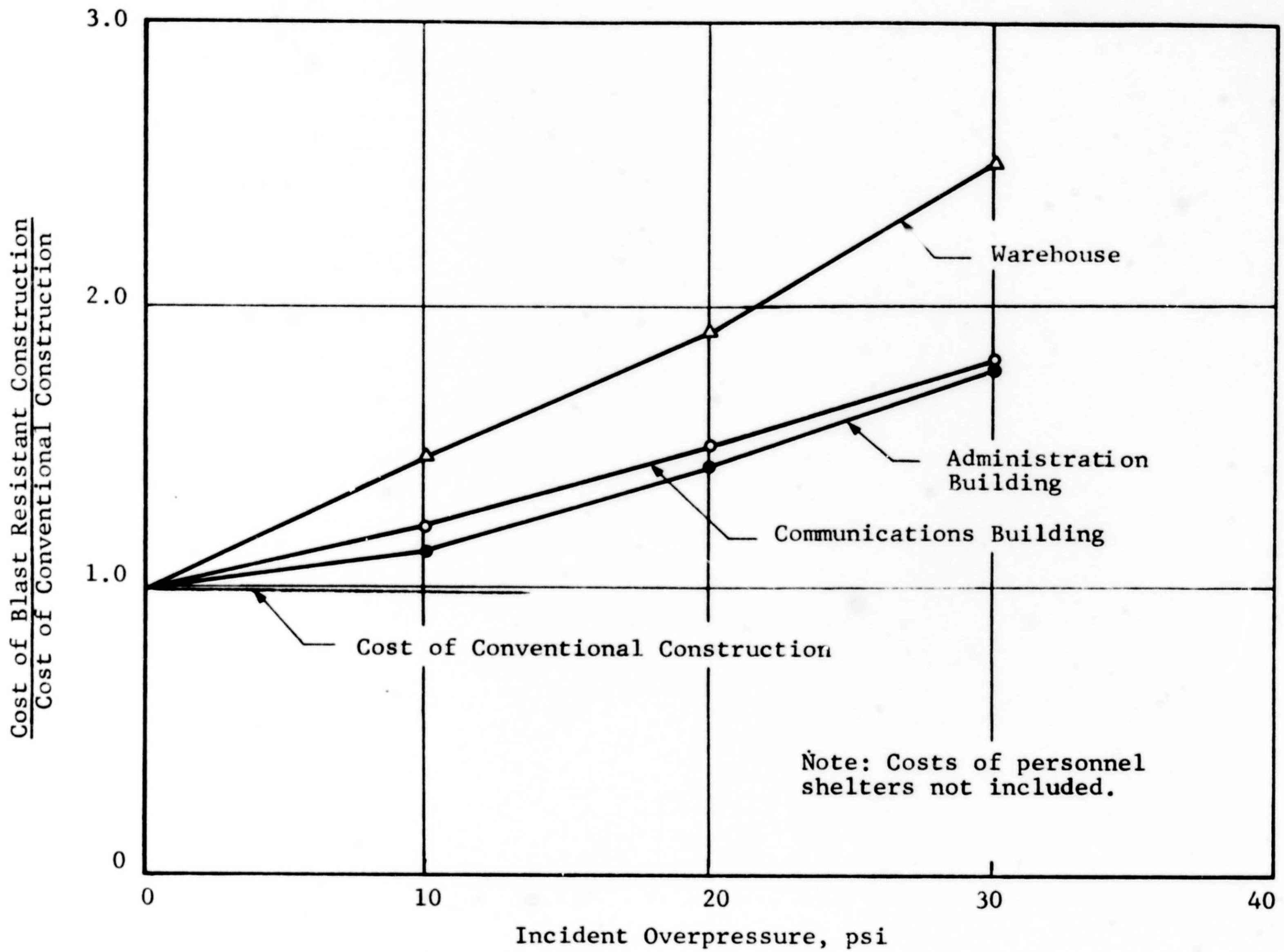


Fig. 2.19 VARIATION OF COST INCREASE WITH OVERPRESSURE

2.13 FEASIBILITY OF SHELTER INCORPORATION IN SPECIFIC GROUND FLOOR AREAS (Study Performed for Norfolk, Virginia Redevelopment and Housing Authority)[25]

2.13.1 Introduction

This section describes a study concerned with the feasibility of incorporating blast and fallout resistant shelters in above grade portions of conventional structures. Five existing structures recently constructed (1958-62) in the downtown area of Norfolk, Virginia were considered. In this area, the water table is very close to the ground surface and basements are only rarely constructed. Thus, if dual-use shelters are to be provided, they would need to be located for the most part in ground floor portions of conventional structures. The problem posed by the study is very real since ground water problems exist in many densely populated regions of the country, and efficient means of mass sheltering in such regions are yet to be studied. The study in question bypasses the ground water problem by seeking above grade shelters. It considers nuclear weapons environments ranging from fallout radiation alone to 30 psi blast overpressure and subsequent fallout radiation. Shelters are designed without blast doors, and the possibility of large scale fires resulting from primary and secondary sources is not considered. Despite this, the study is instructive in seeking solutions to a real situation. It is described and discussed in the following paragraphs.

2.13.2 Tidewater Park Elementary School

This school is a one-story above grade structure located adjacent to the Downtown Norfolk Redevelopment Project. It has sixteen classrooms, covers a gross area of 35,000 sq ft and has a normal operating capacity for 6000 persons including students, teachers, administrative and service personnel.

The roof system of the conventional (nonreinforced) structure consists of tar and gravel laid over planking and supported on light steel "bulb tees" which in turn are supported on precast concrete joists. The walls are of the load-bearing type and of masonry construction. The floor consists of a 6 in. reinforced concrete slab over 6 in. of compacted sand. The structure has a pile foundation with a single row of piles under each bearing wall. The floor plan of the building is shown in Fig. 2.20 in which the proposed shelter portion is shaded. This portion has a net floor area of 6510 sq ft and was designed as an ordinary fallout shelter (fallout radiation only) as well as a 30 psi fallout shelter. In each case, the shelter portion was designed as a continuous reinforced concrete structure internally braced by partitions which act as shear walls. Additional piles were provided in the case of the 30 psi shelter. Dimensions of pertinent structural members for both shelters are given below.

	Conventional Fallout Shelter	30 psi Fallout Shelter
Roof Thickness, in.	18	22
Wall Thickness, in.	22	22
Partition Thickness, in.	8	8

Costs and other pertinent data on this concept are given in Table 2.13.

Table 2.13

FEASIBILITY OF SHELTER INCORPORATION I
(Conceptual Study Performed for Norfolk, Virginia

1 Structure Designation	2 Type of Shelter Construction	3 Shelter Location Above or Below Grade	4 Capacity, Number of Persons: Based on Normal Occupancy	4 Capacity, Number of Persons: Based on Shelter Occupancy	5 Total Area sq ft	6 Shelter Area: Net sq ft	6 Shelter Area: As Percent of Total Area	7 Shelter Volume cu ft	8 Minimum Headroom ft	9 Shelter Are per Occupan sq ft
1. Tidewater Park Elementary School (30 psi fallout Shelter)	R/C (Rectangular, Continuous)	Above Grade	600	600	34,900	6550	18.8	65,500	10	10.9
2. Tidewater Park Elementary School (Fallout Shelter Only)	R/C (Rectangular, Continuous)	Above Grade	600	600	34,900	6550	18.8	65,300	10	10.9
3. Horst Advertising Building (30 psi Fallout Shelter)	R/C (Rectangular, Continuous)	Above Grade	80	100	23,000	1100	4.8	8,800	8	11
4. Horst Advertising Building (Fallout Shelte- Only)	R/C (Rectangular, Continuous)	Above Grade	80	100	23,000	1100	4.8	8,800	8	11
5. Plaza One Building (Main Shelter)	R/C (Rectangular, Continuous)	Above Grade	400	400	104,000	3750	3.6	30,000	8	9.4
6. Plaza One Building (Central Stair-well Shelter)	R/C	Above Grade	N/A	N/A	N/A	7200	*	*	N/A	N/A
7. Rennert Building	R/C (Rectangular, Continuous)	Above Grade	960	1307	426,190	13,075	3.1	204,000	Lower Level-8 Upp. Level-7	10
8. Public Safety Building										
a.) Jail	R/C (Rectangular, Continuous)	Above Grade	*	1130		11,300	85.6	108,000	9.6	10
b.) Linle Building			*	414		11,300	85.6	108,000	9.6	10
c.) Courts Building					175,000 (Total)	4,140	88.6	28,900	7.0	10
			*	2560		75,600	93.3	323,000	12.6	10

* Indicates that information is not available

N/A Not applicable

** See stairwell shelter data, page 120.

Note: For identification of costs given in this table refer to Section 2.13.9, page 130.

le 2.13

ATION IN SPECIFIC GROUND FLOOR AREAS[25]
irginia Redevelopment and Housing Authority)

	9	10	11	12	13		14			
					Building Cost		Shelter Cost			
	Shelter Area per Occupant sq ft	Volume per Occupant cu ft	Fallout P.F.	Incident Overpressure psi	Total dollars	per sq ft	Total dollars	Per sq ft of Parent Structure	Per sq ft of Shelter	Percent of Total Parent Structure
	10.9	109	200	30	520,000	14 9	64,000	1.83	9.8	12.3
	10.9	109	400	N/A	520,000	14.9	37,000	1.06	5.6	7.1
	11	88	350-450	30	200,000	8.7	19,800	0.86	18.0	10.0
	11	88	350-450	N/A	200,000	8.7	10,300	0.45	8.9	5.1
	9.4		400	30	2,000,000	19.2	50,000	0.48	13.3	2.5
	N/A	N/A	1000	30	N/A	*	(Case 1)** 250,000-300,000 (Case 2) 400,000-500,000	*	(Case 1) 125.0 (Case 2) 205.0	*
evel-8 evel-7	10	Lower Level-80 Upper Level-70	Upper Level-500-850 Lower Level-285-390	30	6,000,000	14.1	93,000	0.22	7.1	1.6
	10	96	475	30						
	10	96	475	30						
	10	70	500	30			90,000			
	10	126	715	30	4,250,000 (Total)	24.3	35,000	2.09	8.9	8.6
							240,000			

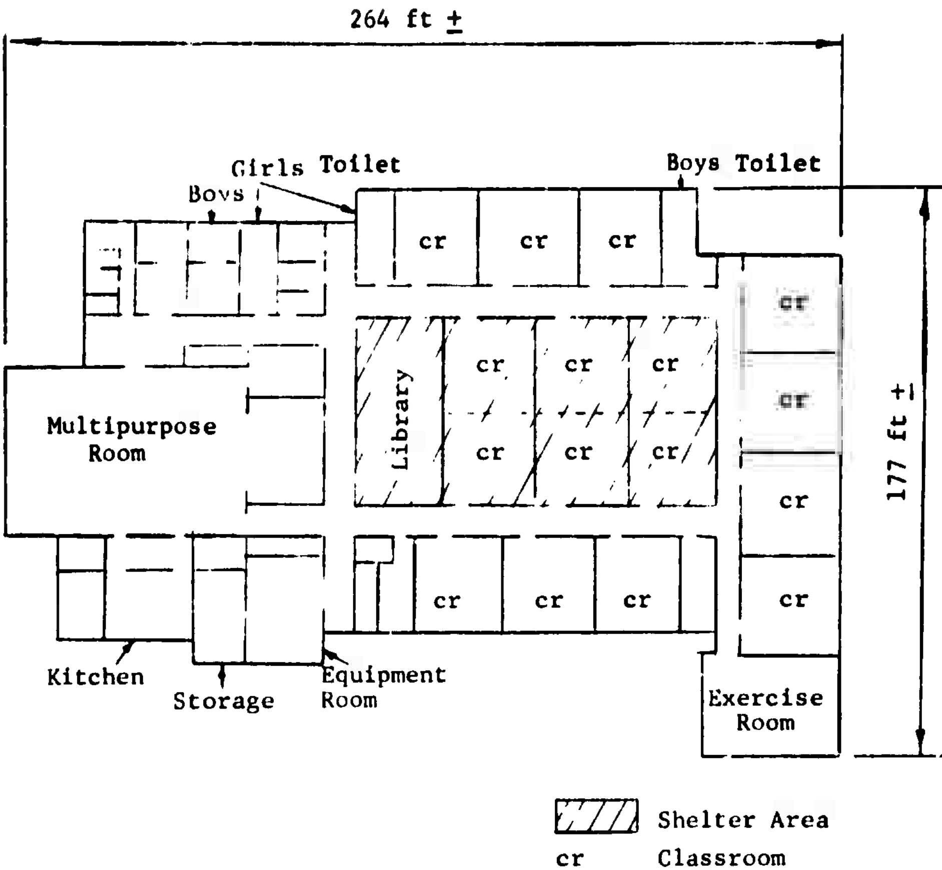


Fig. 2.20 TIDEWATER PARK ELEMENTARY SCHOOL, BUILDING PLAN

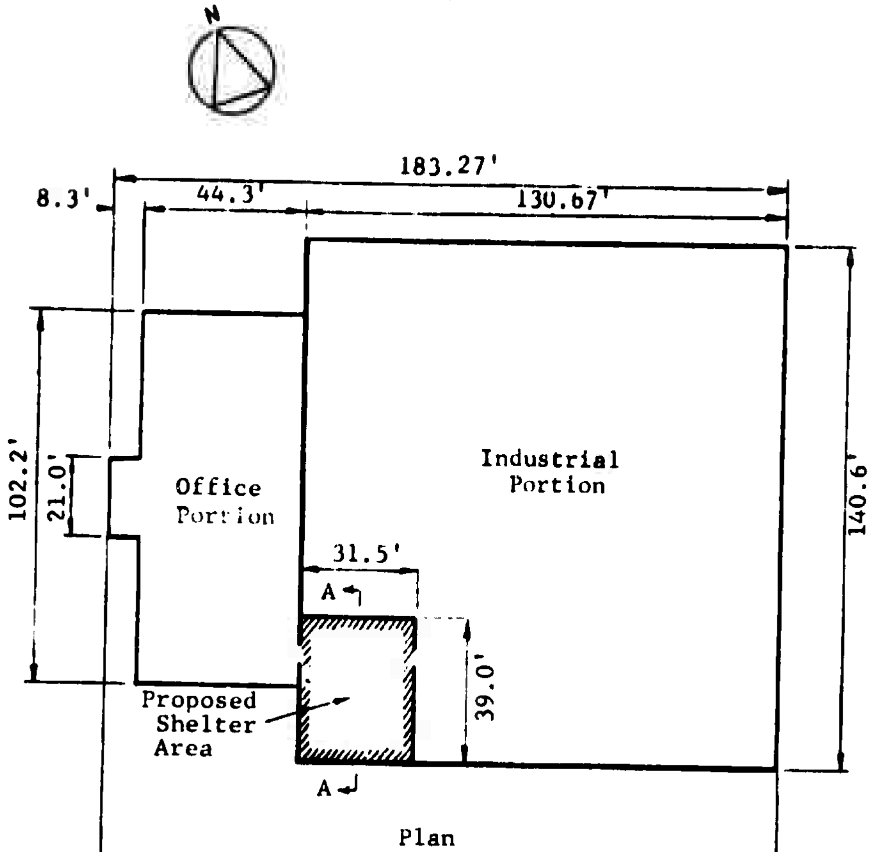
2.13.3 Horst Advertising Building

This is a one-story above grade structure with a gross floor area of approximately 23,000 sq ft, of which about 4500 sq ft is office space, while the remaining 18,500 sq ft is devoted to industrial functions. Exterior walls of the office portion are of glass and brick whereas the walls of the industrial portion are of windowless masonry construction. Ceiling heights in the office and industrial portions are approximately 10 and 14 ft respectively. The structure rests on spread footings about 3 ft below grade. The estimated normal operating staff is between 50 and 60 persons with a maximum of 80 persons. The shelter portion of the structure was studied in the light of 100 person capacity. The building plan including the location of the proposed shelter portion is shown in Fig. 2.2_ and cross sections through the shelter portion . Fig. 2.22.

For both the conventional as well as the 30 psi shelter study the shelter portion was designed as a continuous rectangular reinforced concrete structure internally interconnected by means of shear partitions. Thicknesses of pertinent structural members for both shelters are given below.

	Conventional Fallout Shelter	30 psi Fallout Shelter
Roof Thickness, in.	18	18
Wall Thickness, in.	22	22
Floor Thickness, in.	18	18
Partition Thickness, in.	8	8

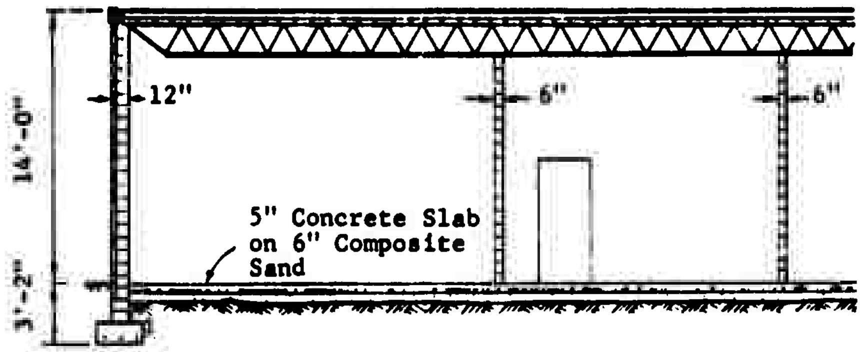
For costs and other pertinent data on this structure see Table 2.13.



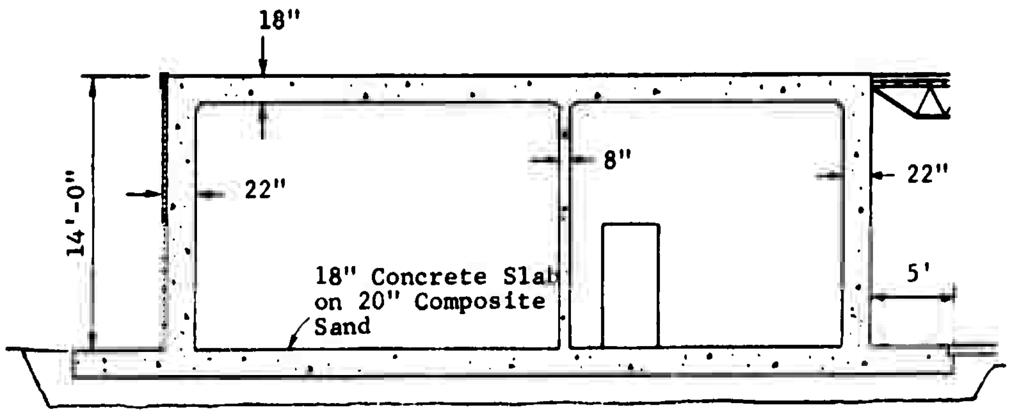
Scale, 1 in.= 40 ft

South Elevation

Fig. 2.21 HORST ADVERTISING BUILDING,
PLAN AND ELEVATION



Section A-A, Proposed Conventional Construction



Section A'-A", Proposed as a 30 psi Fallout Shelter

Note: For locations of sections
see Fig. 2.21.

Fig. 2.22 SECTION THROUGH SHELTER PORTION OF HORST ADVERTISING BUILDING (As Built and As Shelter)

2.13.4 Plaza One Building

This is an eleven-story above grade structure located within the Downtown Norfolk Redevelopment Project. It is primarily an office building with the ground floor used for retail shops. It is of reinforced concrete construction with square columns and two-way slab floors. The first floor slab is on grade and the entire structure rests on a pile foundation. The ceiling height of the first floor is 12 ft, while that of the remaining floors is 8 ft 6-1/2 in. The structure has a gross floor area of 104,000 sq ft of which 20,000 sq ft are on the ground floor and the remainder distributed equally among the ten remaining floors. The net usable area in the entire structure is approximately 80,000 sq ft. In addition there is an 11,000 sq ft terrace at the second floor level over the portion of the structure not covered by the office tower.

Normal occupancy of the building is estimated at 400 persons of which 140 are expected to be on the ground floor with the remaining 260 distributed in some fashion among the remaining floors. The shop at the west end of the ground floor (Fig. 2.23) was investigated for sheltering purposes. It has a floor area of 4340 sq ft. As part of conventional (nonreinforced) construction, its exterior walls are part solid masonry and part display windows.

The shelter was designed as a continuous reinforced concrete structure internally braced by means of five shear partitions. The roof is a one-way slab supported by three reinforced concrete beams, walls and shear panels. Foundation capacity was increased by providing additional piles. A cross section through the proposed shelter protion of the structure is given in Fig. 2.24. Thicknesses of pertinent structural members are tabulated on page 120.

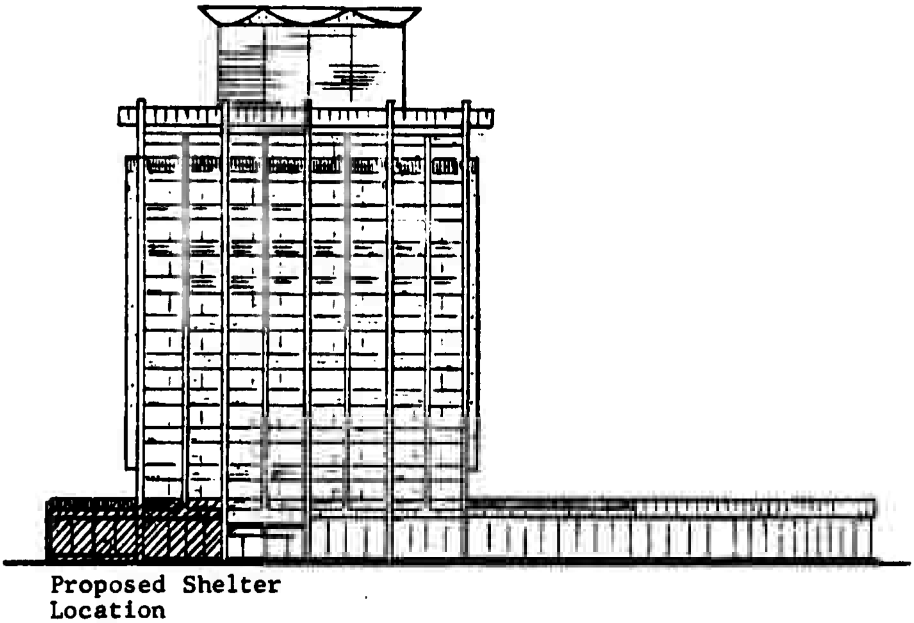


Fig. 2.23 ELEVATION OF PLAZA ONE BUILDING

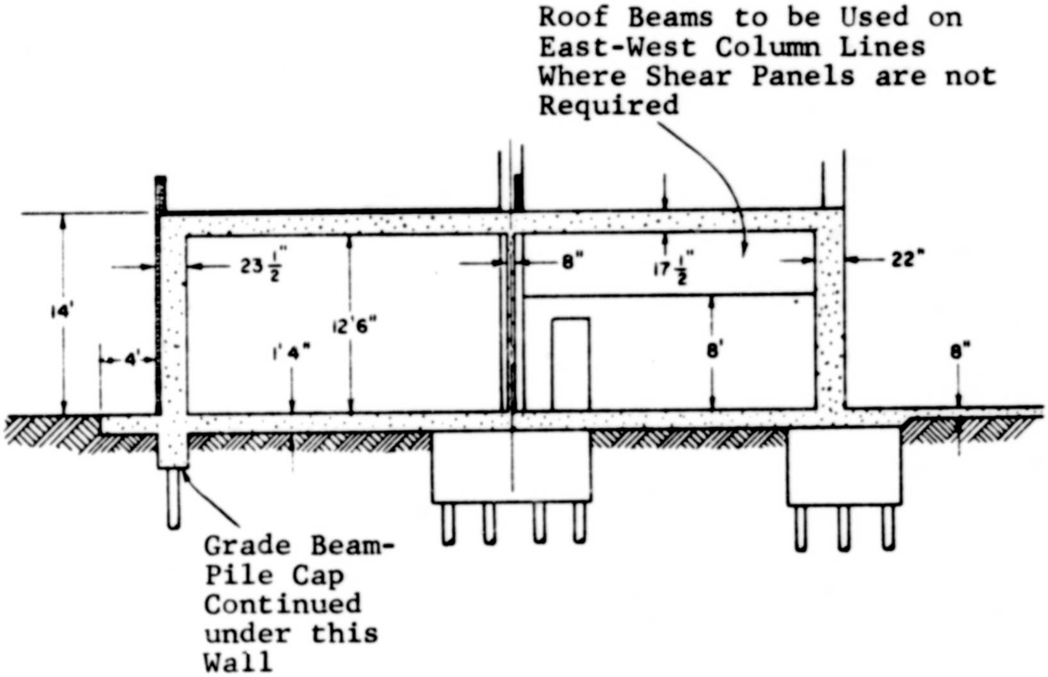


Fig. 2.24 CROSS SECTION THROUGH THE PROPOSED SHELTER PORTION OF PLAZA ONE BUILDING

	30 psi Fallout Shelter
Roof thickness, in.	17-1/2
Wall thickness	
Brick-faced wall, in.	23-1/2
Common wall, in.	22
Shear panel thickness	
Roof beams - stems of T-beams	18 in. wide 4 ft 6-1/2 in. deep

The structure under investigation is relatively high and in the case of a short warning time people on its upper floors may have some difficulty reaching the shelter. For this reason, an attempt was made to harden its central stairwell. The results of the stairwell shelter design are given below.

Plaza One Building Stairwell Shelter Data

Stairwell	
Floor Area	2200 sq ft
Height	113 ft 1 in.
Inside dimensions	12 ft 7 in. x 7 ft 8 in.
Design Incident Overpressure	30 psi
Hardening Cost (Structural)	
As a free standing shaft	$250,000 to $300,000 (Case 1)
As supported by building frame	$400,000 to $500,000 (Case 2)
Shelter Wall Thickness	76 in. to 30 in.
Fallout Protection Factor	1000+
Inside Dose of Initial Radiation (rad)	*

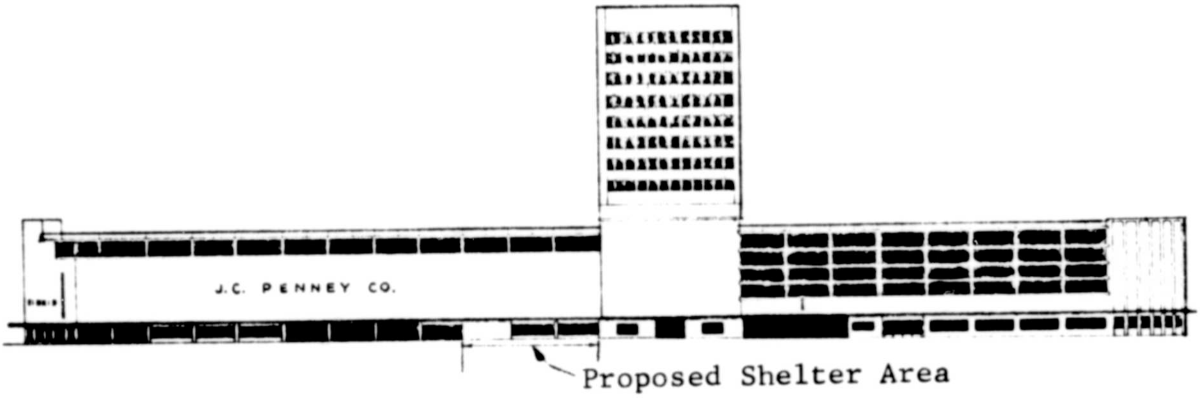
* Indicates that information is not available.

2.13.5 Rennert Building

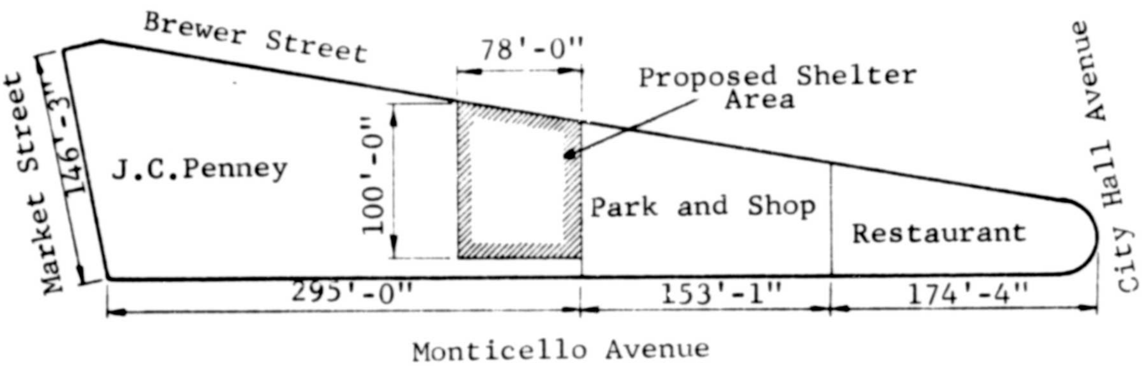
This is a large building complex adjacent to the Downtown Norfolk Redevelopment Project completed in 1958. It contains a retail store, a large parking garage and a cafeteria type restaurant. The building portion housing these facilities is five stories high. Rising above the central portion of the complex is a fifteen-story high office tower. An elevation view of the complex as well as its site plan are shown in Fig. 2.25.

The structure is of reinforced concrete with considerable window area. Its ground floor is a slab at grade and the whole structure rests on a pile foundation. The complex has a gross floor area of 426,190 sq ft and a normal operating occupancy of 960 persons.

The proposed shelter is located on the ground floor in the central portion of the complex (Fig. 2.26a). This portion in the existing structure is a shopping area with offices located on the third floor directly above. The shopping area has few existing partitions which could be reinforced to act as shear walls and thus does not lend itself easily (economically) for dual-use shelter purposes. The offices located on the third floor, however, contain a great many partitions having an advantageous distribution. Since it is more advantageous (economical) to have the shelter on the first floor, for purposes of the shelter study, the primary functions of the first and third floor were interchanged. It was assumed that the first floor portion would house the offices while the third floor portion would be a shopping area. This arrangement would not necessarily be acceptable to the retailers in question since a first floor is most always more advantageous for retailing purposes than one with more complex access.

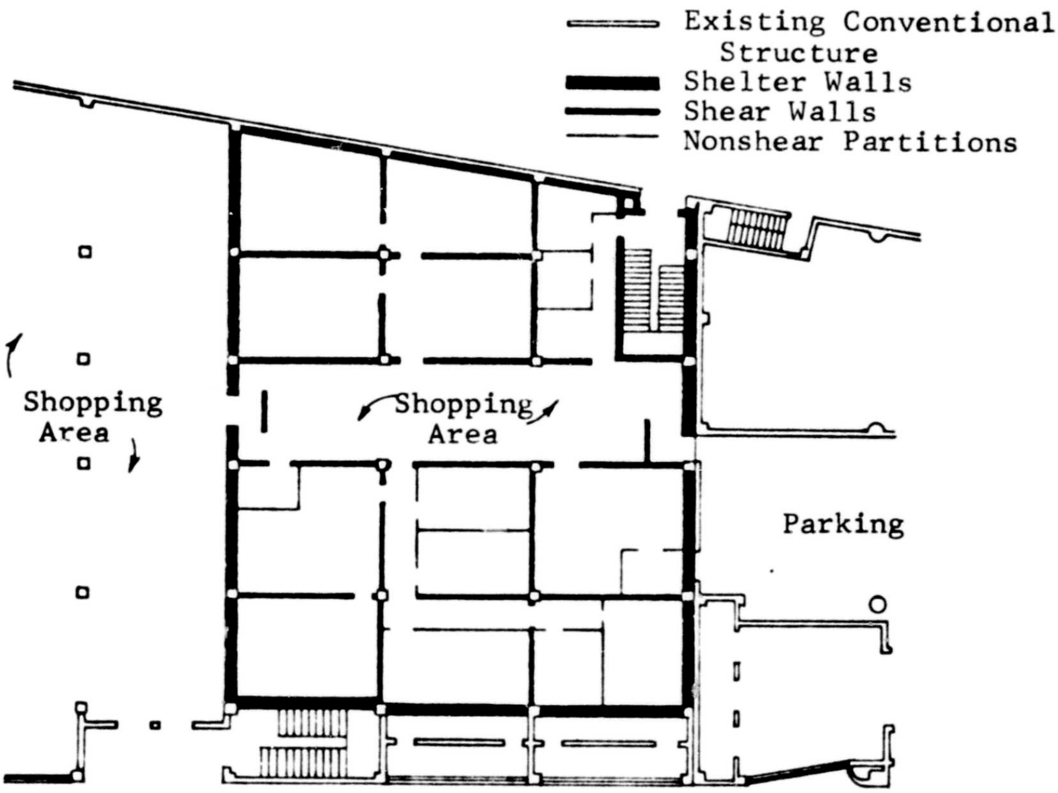


a) Elevation

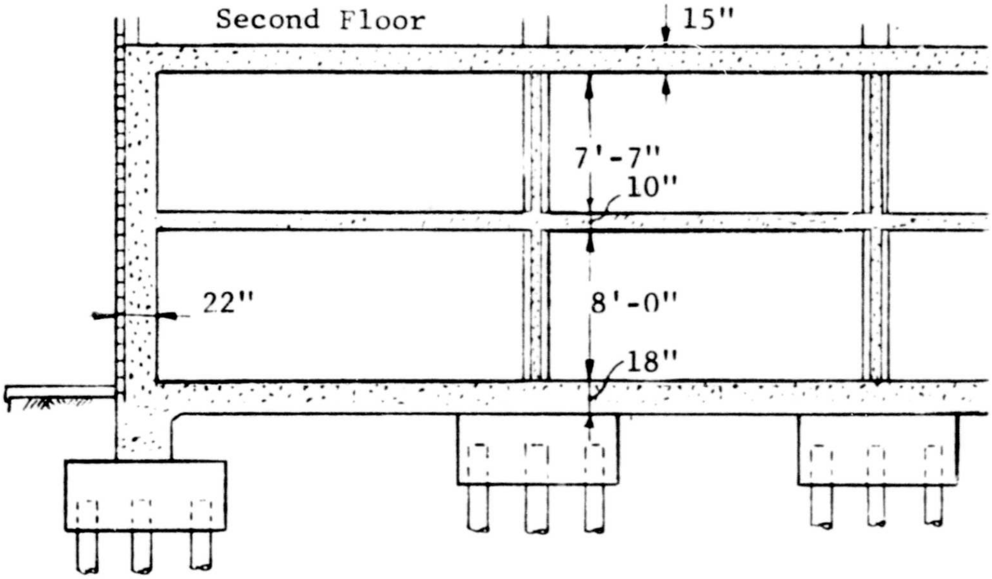


b) Site Plan

Fig. 2.25 RENNERT BUILDING, ELEVATION AND SITE PLAN



a) Partial Plan, First Floor Office, Shelter Arrangement



b) Partial Elevation Cross Section through Proposed Shelter

Fig. 2.26 RENNERT BUILDING, SHELTER LAYOUT

The proposed shelter plan, as well as a portion of its elevation cross section, are shown in Fig. 2.26. The shelter was designed as a continuous rectangular reinforced concrete structure internally braced by means of shear partitions on column lines in both directions. Since the clear ceiling height of the first floor is approximately 17 ft, it was possible to add an intermediate floor and thereby to reduce the unsupported span of the walls. The foundation of the shelter portion was strengthened by providing additional piles. Thicknesses of pertinent structural members of the shelter are given below. Other pertinent data on this shelter are given in Table 2.13

	30 psi Fallout Shelter
Roof thickness, in.	15
Exterior wall thickness, in.	22
Partition Thickness (shear panel), in.	6
Intermediate floor thickness, in.	15-1/2

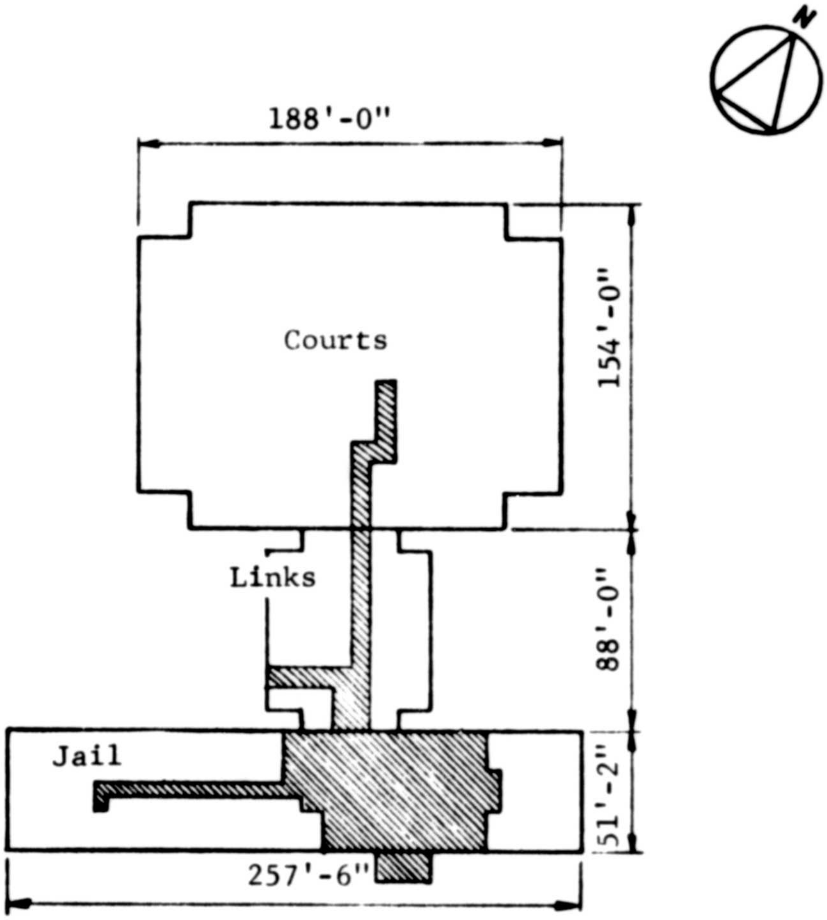
2.13.6 Public Safety Building

This structure is a newly constructed public building complex located within the Downtown Norfolk Redevelopment Project. It is the headquarters of the City Police Department. This complex is composed of three interconnected buildings (see building plan Fig. 2.27) which are designated as

- Jail
- Courts building
- Link building

The jail is an eight-story structure with a partial basement. The courts and link buildings are two-story structures. The whole complex, built of reinforced concrete, has a brick facing and rests on a pile foundation.

The sheltering attempt in this case is to harden the ground floor of the entire complex. The ground floor is about 2-1/2 ft above grade. As in the previous cases of this section, the proposed sheltered portion was designed as a continuous



Note: Basement shown shaded.

Fig. 2. 27 PUBLIC SAFETY BUILDING, GENERAL PLAN

windowless rectangular reinforced concrete structure internally braced by means of partitions acting as shear walls. In some cases it was necessary to add roof beams on this level in order to transmit the added load. Pile groups also required strengthening.

The shelter was designed for an effective overpressure of 30 psi, in which case the design overpressure on the external shelter walls was taken as 100 psi. In order to provide protection for the basement with a roof slab about 2-1/2 ft above ground level, the projecting external walls were considered backfilled with free draining granular material. With this it was assumed that the overpressure would be reduced to one quarter of its effective value and the existing 12 in. reinforced concrete walls should be sufficient if properly strengthened. Thicknesses of pertinent structural members of the shelter are given.

	Jail Building	Link Building	Courts Building
Roof thickness, in.	18	18	18 and 41
Wall thickness (including 4 in. brick), in.	22	22	26
Partition thickness, in.	6	6	6,8 & 12

2.13.7 Discussion

The attempt of reference 25 was to study the feasibility of providing shelter space in the above grade portions (predominantly ground floor) of schools, retail stores, office buildings and large public building complexes. Specific newly constructed buildings were considered for this purpose. These are located within the Downtown Norfolk (Virginia) Redevelopment Project. All structures studied possess no basements with the exception of the Public Safety Building which has a relatively small partial basement. This is due to the fact that in the geographic area under consideration the terrain is uniformly flat, with the ground water available only a few feet below the surface and basements therefore are only infrequently constructed. In the study under discussion one of the initial assumptions was that since basements were not considered feasible (economical) for conventional construction, the same applies to basement shelters. This is probably well founded in this specific case since the water table is very close to the surface.

References cited and discussed thus far either make no mention of or assume "favorable" foundation conditions. Favorable foundation conditions may mean different things for different buildings and for different geographic regions. One of the major implications of the word "favorable" as far as blast resistant design is concerned, is that the water table is located well below the foundation level. This state does not necessarily dominate all of the geographic regions where shelter construction may be required. Norfolk, Virginia is one such case and the shelter study in question considered real foundation conditions; the solution being avoidance of below grade construction.

A great deal depends on subsoil conditions; there are cases however, soils of high consistency and low permeability, in which basements are conventionally constructed such that at least a small portion is located below the water table. Such foundation conditions are not necessarily favorable. However, if conventional basements are constructed in this manner and if there are enough of them, they are potential candidates and should be studied as they exist.

With respect to blast protection, if protective shelters are to be located partially or fully below the ground water table several new problems need to be considered. One of them is pore water pressure.

In cases when the soil possesses moisture, the pore pressure, due to both the air pressure and pore water pressure, will depend upon the degree of saturation of the soil. In those cases in which the degree of saturation is high enough for a continuous water phase to exist, the pore air pressure caused by the overpressure will induce a stress in the continuous phase of the pore fluid. If a high degree of saturation extends close to the ground surface, the stress induced in the water phase will be large and should be taken into consideration in the design of the structure since it may significantly alter the state of stress in the surrounding soil.

In most practical cases the soil will possess moisture, and the degree of saturation of the soil above the maximum depth of pore air pressure penetration is of prime importance. The most critical case will occur when the water phase, or portions thereof, is continuous The problem then, is to be able to predict the magnitude of the induced pore pressure so as to evaluate the stress state of the soil surrounding the structure. This aspect has thus far not been considered in the design of blast resistant structures to any satisfactory degree.

In line with this problem, the structural elements of the shelter are ordinarily designed to develop their ultimate strengths and to fail by plastic yielding. This leads to the assumption that a monolithic reinforced concrete cubicle will undergo significant plastic strains under design loading without producing a structural collapse. There remains the question as to whether such a structure, including its connections and joints, will still be watertight after the dynamic loading has been removed. A comparable problem also exists for shelter above the ground water table if the shelter must function as a "sealed" container utilizing its own atmosphere.

2.13.8 Blast Resistant Shelters Without Blast Doors

As noted earlier the shelters under discussion do not include blast doors, however, the design loadings were based on the assumption that such doors would be installed Even though not specifically considered in this light, under certain conditions of blast loading (slow rising overpressure of long duration) blast shelters without blast doors are not necessarily undesirable Consider the following.

A shelter designed for fallout radiation alone has some inherent strength. This strength will result in the shelter structure withstanding blast effects to some overpressure level. There will of course be damage to the interior of the shelter even up to this level. The blast wave will pass through the shelter with little reduction in the free-field overpressure or drag (winds). However, with proper slanting techniques it is possible to have the shelter survive at overpressures up to 30 psi or more. The problem that one is concerned with for a shelter of this type is twofold.

- What level of protection would it provide for people within the shelter, and
- what the cost of such a design might be.

Obviously, if no survivors could be expected, then any shelter cost is too great. Therefore the controlling factor appears to be the "vulnerability" of people to the nuclear weapons effects they may experience in a structure of this type. The effects are:

- primary blast,
- blast translation,
- impacts from debris,
- thermal radiation and initial radiation.

Most people have a relatively high tolerance to primary blast[26] and initial deaths may begin at about 40 psi overpressure for this group. Thus, primary blast should not limit the design of such shelters. Blast translation has a lower limit and people may be borne by winds at overpressures below 10 psi. However, people may decrease exposed body areas and lower their center of gravity by lying down, they may decrease overturning by the spread of arms and legs. It seems possible that they might survive this effect up to 30 psi. Impact by debris can cause deaths at even lower overpressures. However most of such debris is from the building interior and can be minimized by effective planning. The other source of casualty producing debris may be from surrounding buildings.

By locating people in favorable locations within the shelter relative to the direction of blast, it is possible to minimize casualties resulting from thermal and initial radiation.

2.13.9 <u>Costs</u>

In his attempt to identify costs, Bennedsen makes the following comment:

> "Unit costs used in this study are the same as those used by the Protective Structures Division, Office of Civil Defense, Department of Defense, in its shelter design series SSS-2, revised Sept. 1962, Dual-Purpose Above Ground School and Community Shelter for 300, 550 and 1100 Persons.[12] These costs were used in order to have the results of this study directly comparable with the results of that series."[25]

It is clear that as far as "shelter costs" per se are concerned, these were based[25] on unit values given in reference 12. It will be recalled that these were classified[12] as "average suburban values" subject to local variations, and although not identified as such in reference 12 they most likely apply to midyear 1962. The buildings in which these shelters are proposed[25] to be located have the following dates of final completion:

1. Tidewater Park Elementary School	In 1962 (the date of reference 25) it was still in the proposed stage.
2. Horst Advertising Building	1962
3. Plaza One Building	1962
4. Rennert Building	1958
5. Public Safety Building	1960

It should also be kept in mind that even though shelter costs were based on "average suburban values," the corresponding parent buildings are located in an ordinarily high-priced downtown area.

In comparing "shelter costs" with costs of respective parent structures (see column 14, Table 2.13), the following comments are warranted.

1. The costs of conventional parent structures (column 13, Table 2.13) are not based on values given in reference 12 . They represent an estimate in the case of Tidewater Park Elementary School and final costs in the case of the four remaining structures. It does not appear that shelters and their respective conventional parent structures have a common cost base.

2. Incremental shelter costs are identified[25] as "structural costs" and are defined[25] as "the difference in capital investment required to construct a building with or without an integral shelter". This appears to be contradictory. If reference 12 is used as a base for shelter costs, then the expression "structural costs" includes the costs for labor and materials only. Capital investment to construct a building includes all costs, initial as well as final.

Some caution should therefore be exercised when drawing general conclusions from cost numbers given in column 14, Table 2.13.

Variations of percent building cost increase with overpressure resulting from shelter incorporation are given in Fig. 2.28. As far as fallout shelters are concerned, the percent cost increases (less than 10 percent) are in magnitude similar to those discussed earlier,[1,2,8] however the 30 psi fallout shelters appear to be comparatively on the low side (Fig. 2.10). This is partially due to the fact that in the present case we are dealing with structural costs only.

Note: For cost identification see Subsection 2.13.9

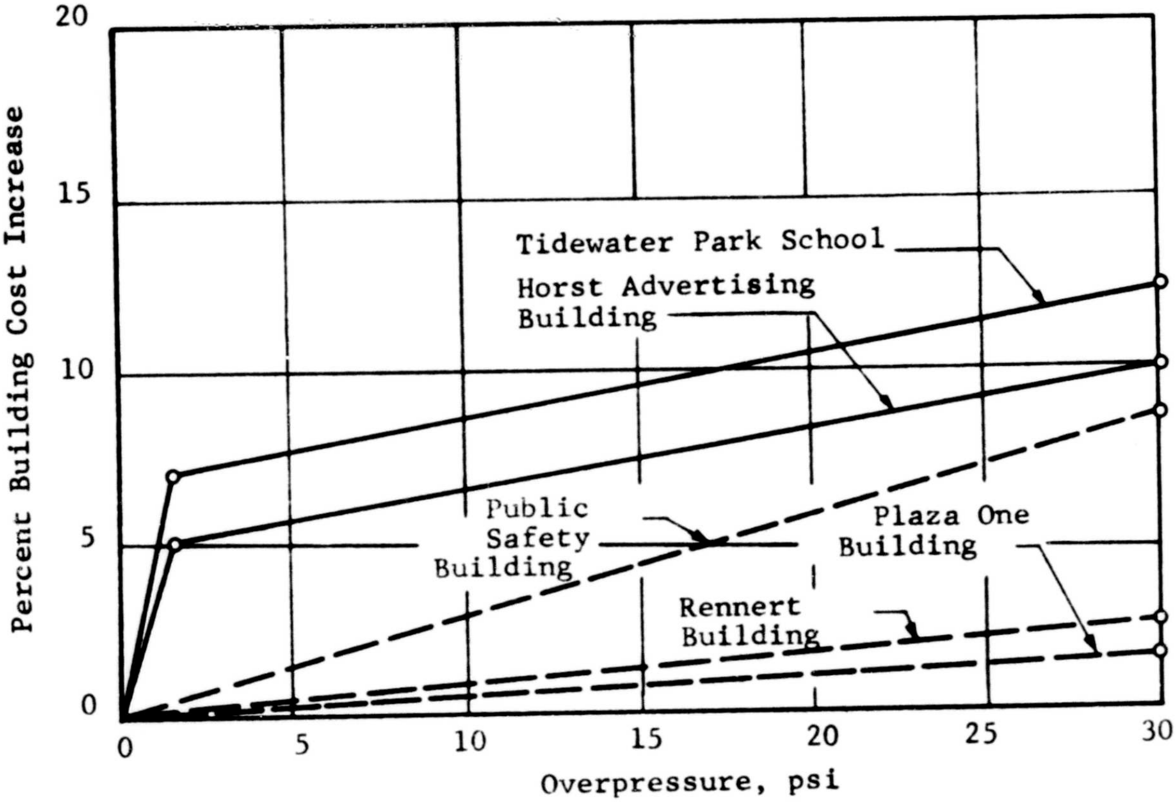


Fig. 2.28 VARIATION OF BUILDING COST INCREASE (DUE TO SHELTER INCLUSION) WITH OVERPRESSURE[25] (Shelters are assumed to be included in the construction stage of the respective buildings.)

2.14 STUDY OF THE PROPOSED EAST-WEST FREEWAY TUNNEL WEST ORANGE, NEW JERSEY AS A CIVIL DEFENSE PUBLIC SHELTER FACILITY[27]

2.14.1 General Description

The objectives of the study described herein were:

- To determine the feasibility of adapting a normal vehicular tunnel to a civil defense public shelter facility.
- To determine the features, modifications and facilities necessary to provide protection for various alternative conditions of weapon effects.
- To estimate the incremental costs of shelter adaptation, over and above the normal tunnel costs.
- To determine the unit cost per shelter occupant for the alternative degrees of protection.

The town of West Orange, New Jersey is located 24 miles due west of Central Park in New York City. The First Watchung Mountain, a basaltic ridge, divides the town along a north-south line. The existing streets that cross First Mountain constitute an important transportation link. Since these streets are characterized by steep grades and twisting alignments, the concept of a modern expressway across First Mountain has been discussed locally for many years. Two proposals currently under consideration are:

- A conventional open-cut and elevated alignment over the mountain.
- A depressed alignment featuring a twin tube vehicular tunnel.

The study discussed herein was based on a design concerned with the latter proposal.

The proposed vehicular tunnel is a two-tube affair which presents in each of its tubes 3300 linear ft of usable tunnel floor between the rock faces at the east and west portals, at which locations the installation of protective doors is proposed.

Of the 43 ft (approximate total width of each tube between the finished walls) 38 ft (roadway surface) is considered feasible for shelter use. The remaining width is employed primarily as a railed safety walk, approximately 18 in. above roadway level. This area is not considered available for general shelter use but has been reserved for shelter management personnel. The tunnel floor is crowned to provide lateral drainage to the gutters at the outer edges. The minimum vertical roadway clearance is 14 ft 2-1/2 in. The lining of each tunnel is a semicircular reinforced concrete arch with vertically reinforced concrete sidewalls. A reinforced concrete ceiling slab, with the arch, forms the air ducts for the ventilation system. A typical tunnel cross section (single tube) is shown in Fig. 2.29. The tunnels are separated by a rock core about 25 ft wide. At the portals, the reinforced concrete walls are placed against the sloped rock surfaces and anchored by bolts grouted in the rock. Reinforced concrete ventilation buildings, to house the equipment for operating the ventilation and electrical systems, are located one at each portal. These buildings abut the concrete wall mentioned and straddle the tunnel roadways. Where required by the nuclear weapons environment, radiation, blast and thermal protection portals have been considered and are included in the cost estimates.

The net available space in the two tunnel tubes is 250,800 sq ft. At a 10 sq ft per person space allocation, the nominal capacity of the tunnels is 25,000 persons. Due to the large shelter capacity, it was decided to incorporate an emergency hospital for the use of shelter occupants.

Two "shelter facility" cases were studied. These may be classified as follows:

- General public shelter
- One, 200-bed emergency hospital

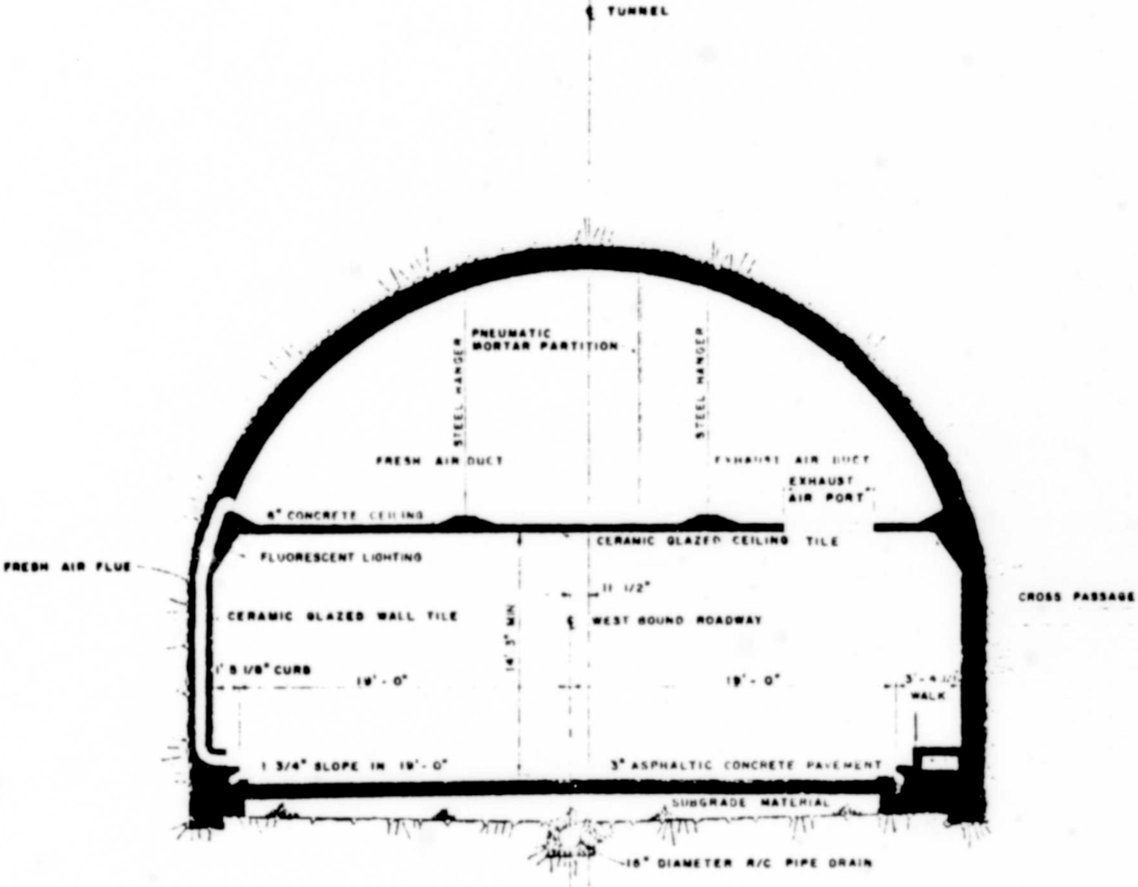


Fig. 2.29 TYPICAL TUNNEL CROSS SECTION
(Single Tube)

Facility Case II (Capacity 24,000)

- General public shelter
- One, 200-bed emergency hospital
- Area control center for Essex County Civil Defense Council

One incremental alternate plan was also considered for each of the two cases. The incremental alternate for Case I considers the inclusion of additional hospital units. This requires no construction modifications in the original plan, but rather, reallocation of floor and storage space and provision of a higher intensity of shelter lighting. The inclusion of contemplated hospital facilities reduces the shelter capacity by about 2000 persons. The incremental alternate to Case II considers the feasibility of providing a protected environment for the storage of the vital records of government and, possibly, private industry. Such storage space (500 cu ft) is provided by constructing additional lateral drifts from the main tunnel bores.

Four conditions of weapons effects were considered in the study. They are based on a 20 MT surface burst and are outlined below.

Condition I, Heavy Fallout
Distance from detonation: 50 mi, minimum.

- 10,000 r/hr initial dose-rate of delayed nuclear radiation, one hour after detonation.
- No direct blast or thermal effects.

Condition II, Low Blast and Subsequent Heavy Fallout
Distance from detonation: 13 mi, minimum.

- 10,000 r/hr initial dose-rate of delayed nuclear radiation, one hour after detonation.
- 2 psi incident overpressure applied after the full capacity of the shelter is secured.
- 15 cal/sq cm thermal radiation.
- Six hour fire.

Condition III, Moderate Blast and Associated Effects

Distance from detonation: 5.2 mi, minimum

- 10 psi incident overpressure.
- 130 cal/sq cm thermal radiation.
- 10,000 r/hr initial dose-rate of delayed nuclear radiation, one hour after detonation.

Condition IV, High Blast and Associated Effects

Distance from detonation: 3.3 mi, minimum.

- 25 psi incident overpressure.
- 380 cal/sq cm thermal radiation.
- 10,000 r/hr initial dose-rate of delayed nuclear radiation, one hour after detonation.
- Six hour fire.

Incremental shelter costs are given in Tables 2.14 and 2.15 and are plotted in Fig. 2.30. The costs are for shelter adaptation and are over and above the normal tunnel costs. They are based on receiving construction bids from local contractors during December, 1964. The cost items given are defined as follows:

Environmental Control

This item includes handling equipment as well as distribution and exhaust systems.

Supplies and Facilities

Included in this item are

- Water supply and handling systems.
- Food supply and storage space.
- Sanitary facilities.
- Bedding facilities.
- Miscellaneous supplies and equipment.

Electric Power

It is assumed that electric power will not be available for shelter use under any of the nuclear weapons environments considered, for this reason a complete emergency power plant was considered in the design.

Table 2.14

FACILITY CASE I, GENERAL PUBLIC SHELTER

(Capacity: 25,000 persons)

Item	Cost, dollars (Dec. 1964)			
	Fallout	2 psi	10 psi	25 psi
Portal Protection	34,000	474,000	827,900	1,544,300
Environmental Control	48,200	48,200	723,200	825,600
Supplies and Facilities*	386,100	386,100	386,100	386,100
Electric Power	236,700	236,700	268,000	268,000
Total Incremental Costs	705,000	1,145,000	2,205,200	3,024,000
Cost per Shelter Occupant	28.20	45.80	88.20	120.96

Table 2.15

FACILITY CASE II

GENERAL PUBLIC SHELTER PLUS AREA CONTROL CENTER

(Capacity: 24,000 persons)

Item	Cost, dollars (Dec. 1964)	
	10 psi	25 psi
Portal Protection	827,900	1,544,300
Environmental Control	723,200	825,600
Supplies and Facilities*	656,100	656,100
Electric Power	268,000	268,000
Total Increment Costs	2,475,200	3,294,000
Cost per Shelter Occupant	103.13	137.25

* Food, medical and sanitary kits plus radiological monitoring equipment is assumed to be provided on the same basis as in the National Fallout Shelter Marking Program.

Note: Costs are based on bids received in Dec. 1964, West Orange, New Jersey.

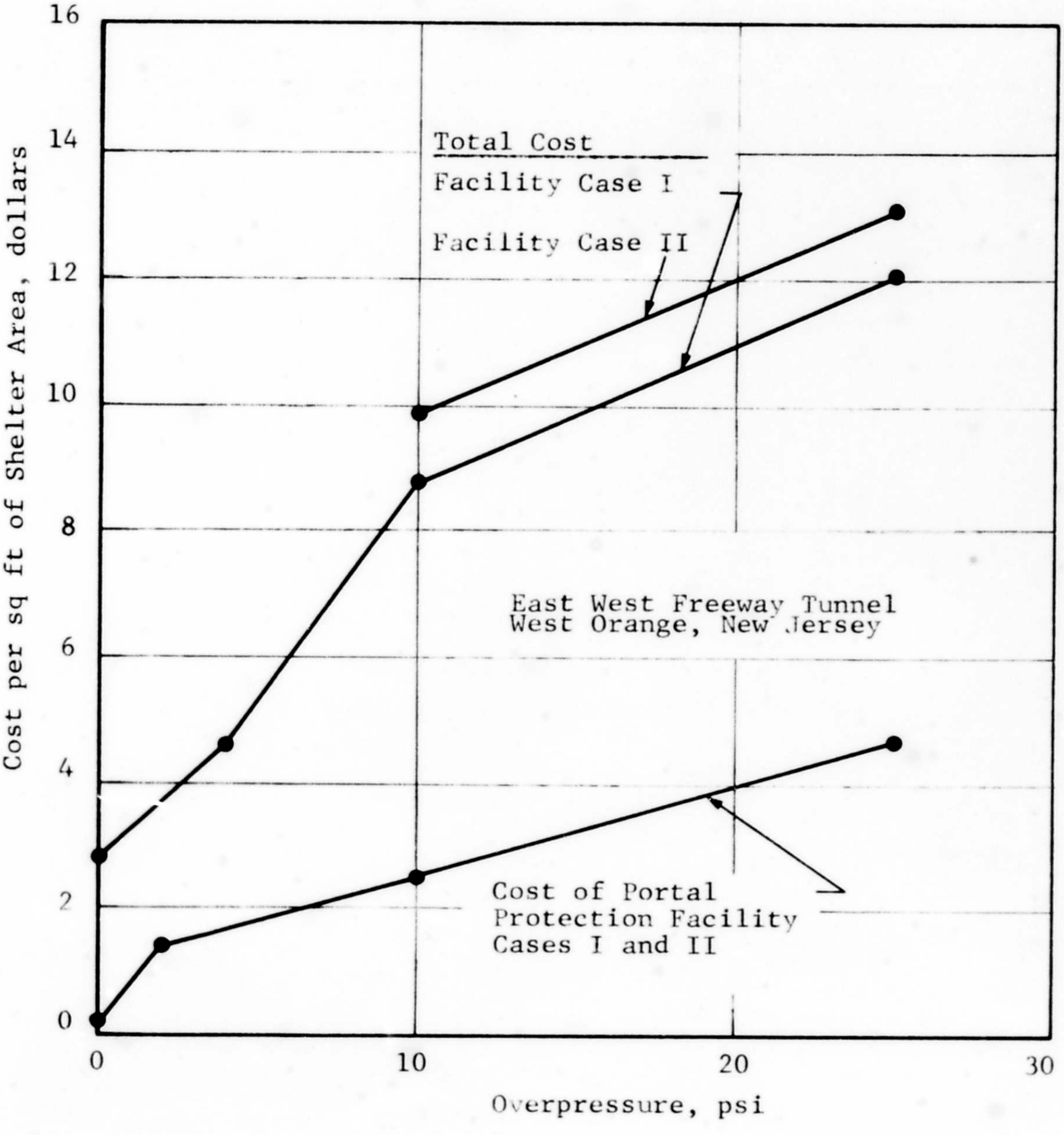


Fig. 2.30 VARIATION OF PUBLIC SHELTER COST VERSUS OVERPRESSURE[27]

Portal Protection

This subject includes closures at either end of the tunnel as required by the particular nuclear weapons environment. Specific items included for each nuclear effects environment are given below.

Item	Fallout	2 psi	10 psi	25 psi
Canvas Weather Barrier	X			
Decontamination Facility	X			
Radiation Barrier	X			
Portal Frame		X	X	X
Portal Blast Doors		X	X	X
Airfoil Louvers		X		
Ventilation Building Blast Doors		X		
Late Arrival Facility		X	X	X
Air Duct Blast Doors			X	X

2.14.2 Discussion

In the year 1965 the amount of railroad and vehicular tunnel space in the continental United States was approximately[28]

20,928,255 sq ft(railroad tunnels)
5,374,892 sq ft(venicular tunnels)

These numbers of course do not include additional space provided by subway and utility tunnels. Assuming 10 sq ft per shelter occupant, the gross overall potential is about 2.6 million spaces.

The use of railway and vehicular tunnels as protective shelters against a given nuclear weapons environment will be limited by

- Size.
- Distance to population centers.
- Inherent level of protection.
- Cost of adaptation to provide the given level of protection.

Evidently, this will reduce the gross potential. The extent of reduction for any nuclear weapons environment is difficult to estimate since the available information[28] is somewhat sketchy. It is evident, however, that the gross potential of existing tunnels is considerably less than 2.6 million spaces and when viewed in comparison to the current national population, this is rather small. Nonetheless, at certain specific locations, tunnels may provide a significant shelter source and should be considered on a local level when forming a shelter system. This topic however is treated in sufficient detail in reference 31 and will not be dealt with herein

The tunnel in question has a sheltering capacity for 25,000 persons, which is a significant portion of the neighboring population (the town of West Orange, New Jersey has a population of about 40,000 recorded by the 1960 census). At the same time, for the nuclear weapons environments considered, the protection and habitability provided is adequate and relatively inexpensive. It is difficult to make a realistic cost comparison of this shelter with those discussed earlier since the concept is different and the study more complete. By virtue of the type of facility, its accommodating capacity and design approach, the concept is more correctly classified as a dual-use shelter system rather than a dual-use shelter.

In addition to providing protection against the specified nuclear weapons environments, (i.e., blast overpressure, fallout radiation, thermal radiation, and a fire of assumed duration external to shelter entrance) the designs also include in respectable detail such topics as:

- Shelter access.
- Decontamination facilities for latecomers
- Emergency hospital
- Extensive habitability provisions.

Shelter access, or the size and type of entrance, was studied by means of a fluid flow analogy considering shelteree quantity and rate of movement as possible significant cost-influencing factors. This included the following topics:[27]

- Assembling of shelterees.
- Passing of shelterees through the portals.
- Shelter loading.

In the light of the above considerations, the corresponding shelter system costs are attractive. If we assume for the moment extreme austerity conditions, and consider only the cost of portal protection without a late arrival facility, the approximate lower bound on this shelter system cost is determined as in Fig. 2.30. It is evident that available and usable tunnels possess a high sheltering potential.

CHAPTER THREE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

3.1 INTRODUCTION

The primary objective of the effort reported herein was to explore the extent of the economic advantages of dual-use personnel shelters when nuclear weapons environments consist of direct effects in addition to fallout radiation.

In general, a dual-use shelter is any structure which in addition to performing its primary function is able to provide protection in times of emergency. The class of such potential shelters is extensive and for weapons environments having low effects intensities, may include virtually all of the man-made structures (both land based and water borne) having enclosed (protected) space, in addition to natural shelters such as caves.

By the extent of economic advantages in the use of this class of structures as dual-use shelters, we mean that level of costs beyond which the costs of sheltering considerations begin to outweigh those of the primary function. As used herein, this definition applies primarily to new construction. Its implications are discussed.

If the expected weapons environment is fallout radiation, a large number of conventional building concepts qualify as candidate shelters. If this class is now restricted to include only schools, available information[1,2] indicates that if fallout shelters are considered in the planning stage, the additional cost should not exceed 8 percent of the cost without a shelter for an average of 1700 spaces (see Fig. 2.3 and 2.4, Tables 2.1 and 2.2). Thus, if motivation to provide fallout shelters for schools exists, it is most often more economical to include them within the parent structure in its planning stage than to construct single-purpose shelters having the same capacity and resistance.

At the other extreme however, i.e., for weapons environments of increasing severity, the problem is no longer as clear-cut and the point at which any structural concept ceases to be a candidate is more difficult to establish. In any one case the solution may be found by means of a cost comparison on three different structures:

- Conventional structure.
- Conventional structure with dual-use shelter.
- Equivalent single-purpose shelter.

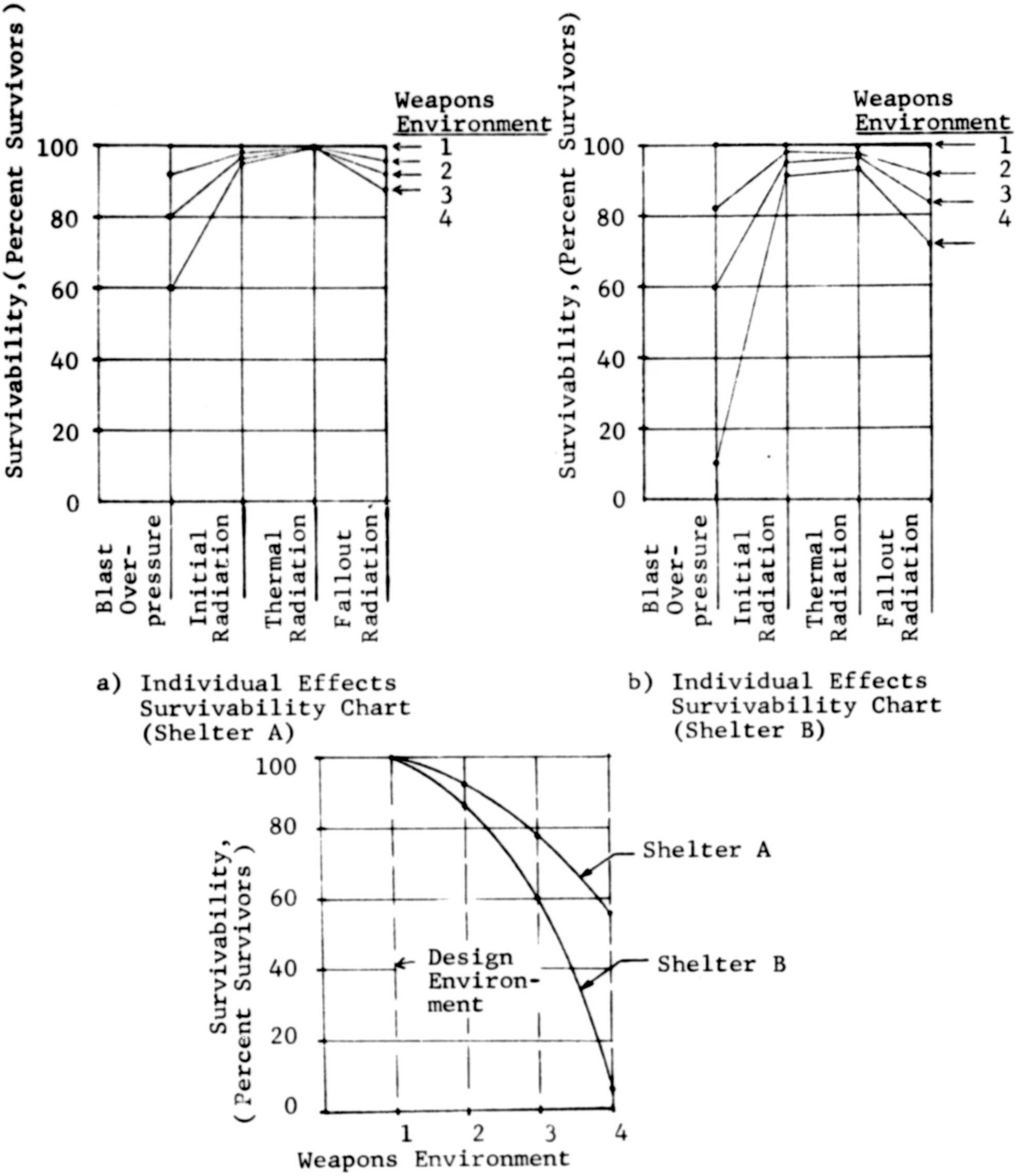
Such a cost comparison will provide the answer, however, the effort itself is costly and time consuming since these structures may be entirely different in concept depending on the severity of the given weapons environment. Also, in order to do justice to such a cost comparison, it is desirable to establish "survivability" functions in each case. This would add significantly to the overall effort. The importance of establishing "survivability" functions for personnel shelters is discussed below.

The effectiveness of a given shelter or shelter system relative to a weapons environment is its level of ability to provide protection against it. This level may be measured by the number or percent of expected survivors and, for purposes of this discussion, may be termed "survivability". For a given range of weapon environments then, the effectiveness of a shelter may be measured by the rate of survivability decline expressed in functional form. It is evident that two shelters having different structural systems but the same design environment will not necessarily have the same survivability functions for any given range of weapons environments. This may be illustrated as follows.

Consider two shelters having equal sheltering space capacities but different structural systems, and such that each has been designed to resist the same weapons environment consisting of blast overpressure and associated effects. Let it also be assumed that the habitability conditions in the two shelters are essentially the same. If for a given range of weapons environments a survivability analysis is performed on each shelter, the results may have the form shown in Fig. 3.1 a and b. These are hypothetical "individual effects" survivability charts with data points indicating levels of superiority of "Shelter A" over that of "Shelter B". The degree of integrated effects superiority (effectiveness) is indicated in Fig. 3.1 c and may be measured by the rate of decrease in the two functions. Thus, although sheltering capacities and design environments are the same, these shelters are quite different and in comparing costs, knowledge of protection effectiveness (survivability) is desirable.

Survivability, even though not referred to as such, is always considered in the design of conventional structures. In such a design process the designer determines the range of expected load magnitudes and loading conditions and within the scope of their influence selects the structural system most ideally suited to resist them. Under conventional circumstances a great deal of data is ordinarily available on expected loading conditions, so that specifications assuming a high degree of performance-safety and longevity (survivability) may be written. Thus the problem of predicting loading conditions as well as survability is ordinarily insignificant.

In the case of shelters however, loads and loading conditions depend on expected weapon environments. These are extremely difficult to predict and therefore "survivability functions" for possible ranges of weapons environments become important in planning and evaluating potential shelter systems. Such functions may be related to shelter costs, and when thus related become extremely useful planning and analysis tools. They would be especially useful in evaluating the sheltering and economic potential of dual-use shelters. In summary, a meaningful evaluation of the extent of economic and sheltering advantages or potential of a dual-use shelter or shelter systems would include a survivability related cost analysis for an expected range of weapon environments.



a) Individual Effects Survivability Chart (Shelter A)

b) Individual Effects Survivability Chart (Shelter B)

c) Comparative Integrated "Survivability Chart" (Shelters A and B)

Fig. 3.1 SURVIVABILITY FUNCTIONS

Up to the present time, dual-use shelter research has received a significant amount of attention. However, in the light of the previous paragraph, available results capable of meaningful answers on economics or sheltering potential of this class of shelters (especially if the weapons environments include direct effects in addition to fallout radiation) are relatively few. Quantitative evaluation of survivability, as described briefly above, is one area which has received virtually no attention

Postulating the end result to be a set of data and analysis methods capable of answering the questions posed in the above discussion, it was the object of the effort reported herein to collect directly applicable and related information on the subject, determine and discuss the extent of its usefulness, update it where necessary and possible, and present it in a form usable for further investigation. Also, it was intended to bring into sharper focus those areas of the overall problem where further investigation is warranted.

Applicable data collected and analyzed in the course of this study are contained in Chapter Two. All of it is useful, even though in many respects it is not as complete as would have been desirable. It is not capable of definitive conclusions, but rather probable disconnected trends.

3.2 CONCLUSIONS AND DISCUSSION

On the basis of available data it is concluded that if a given condidate dual-use structure is to have a large quantity of enclosed space favorably distributed above and/or below grade, favorable foundation conditions, advantageous supporting system, type and materials of construction, as well as favorable location, there is good reason to believe that it is economically advantageous to incorporate blast and radiation resistant shelters in such structures having at least a 20 psi blast overpressure resistance and a high level of survivability. By the expression "economically advantageous", we mean that it is still substantially more economical to consider dual-use shelters in such environments than single-purpose shelters.

When the task is to provide fallout protection and if the problem is tackled in the planning stage, a great deal can be done to provide a highly acceptable level of protection at little or no cost increase relative to the total cost of the structure. For the majority of such existing structures presented herein this average cost increase is in the neighborhood of 4 percent for an average of 1700 protected spaces (see Fig. 2.2 and 2.4 as well as Tables 2.1, 2.2, 2.3, and 2.4). This is of course a fallout radiation environment and sufficient other information is available to substantiate this conclusion. When the environment includes direct effects in addition to fallout radiation, reliable data is more scarce. Reference 10 (Section 2.4 of this report) indicates that if incident blast overpressure is in the neighborhood of 10 psi, dual-use shelters, at least in school buildings, are economically advantageous. Reference 10 is a study conducted in connection with National Fallout Shelter Design Competition structures. These are conceptual studies that were originally designed by various architects to provide fallout protection but were not costed in the process. At a later date they were evaluated by a group of engineers in order to determine what modifications and additional costs (over and above a fallout radiation environment) are necessary to provide a low level (about 10 psi) of blast protection Relative cost increases are thus not available. However, if the absolute cost increases for this group of structures (Table 2.5) are compared to those with deliberate fallout protection (Tables 2.1, 2.2, 2.3, and 2.4) it is evident that they are magnitudewise comparable. Further, reference 25 indicates that if blast resistant shelters having 30 psi incident free-field overpressure resistance are included in above grade portions of certain large conventional structures, the maximum relative cost increase is in the neighborhood of 12 percent for 600 protected spaces. (See Fig. 2.28 and Table 2.13.) This reference is discussed in Section 2.13 of this report. This is a conceptual study dealing with the feasibility of above grade shelters in structures without basements. Assuming that the given costs are reasonable, shelters at this level of overpressure appear to be also economically advantageous. If the nuclear weapons environment is now increased in severity such that the incident free-field overpressure is in the neighborhood of 50 psi, on the basis of available data it can no longer be stated that dual-use shelters in conventional buildings are still economically advantageous (see Fig. 2.10 and discussion, Section 2.7.2; also Fig. 2.18, Table 2.12 and accompanying discussion - Section 2.12.2).

As has been mentioned earlier, the level of economic advantages for any given candidate dual-use building is sensitive to a host of parameters which include:

- size (see Fig. 2.8, 2.9, 2.30),
- type of structural system,
- type of construction,
- materials of construction, and
- foundation conditions (see Section 2.13.7) etc.

Some trends of their gross influence on the cost of hardening of overall conventional structures as well as on providing personnel shelters within them in order to resist three different levels of overpressure, are indicated in Table 2.12 (see also accompanying discussion - Section 2.12.2).

The class of conventional structural or architectural concepts, even if limited to as specific a group of buildings as schools, is extremely large. A logical classification as to type (structural systems, type and materials of construction etc.) - a formidable task in itself - followed by a design-costing-survivability effort briefly described earlier, would in all probability answer most questions posed by this study. However, an effort of such magnitude may not be justified.

Although above grade architectural concepts vary considerably, their basements are in most cases surprisingly similar. Basements by their very nature are considerably better suited for sheltering purposes than are corresponding superstructures. Generally, much beyond an overpressure level of 10 psi, hardening of superstructures becomes increasingly expensive. There are, of course, exceptional cases where the architectural concept is especially advantageous and amenable to slanting techniques. However, such cases become increasingly rare with increasing levels of overpressure and associated nuclear weapons effects, and thus tend to tax to a considerable extent the skill and ingenuity of the designer.

If it is accepted that for nuclear weapons environments in excess of 10 psi and ranging up to 40 or 50 psi in special cases, basements of conventional buildings are the only logical dual-use shelter candidates, then there exists a fairly reliable means for determining their incremental shelter cost and consequently the extent of their capabilities. Specifically, the previous refers to new construction and considers the class of those conventional buildings in which basements would be included subject to their primary function.

In the light of the previous statement, consider the design of a conventional building with a basement and assume that its "general contract" cost estimate has been broken down under two main subheadings:

- cost of superstructure,
- cost of basement.

The basement design can be modified to suit the requirements of a given nuclear weapons environment without affecting the architectural concept, support system or the cost of the superstructure. The difference in cost between conventional and modified basements without reference to the cost of the superstructure is certainly a good approximation to the incremental (shelter) cost.

Thus, it appears that in order to determine the extent of the potential of this class of dual-purpose candidate structures, it is only necessary to investigate the capabilities and cost effectiveness of a set of basements. To this end a catalog consisting of a series of basements designed and costed for various reasonable weapons environments and foundations conditions, together with a set of survivability functions, would serve as a powerful tool.

Such a catalog for which a better title would be "Dual-Use Basement Shelters - Alternatives, Costs and Protection Capabilities" could contain the following information. A compendium of "basic" basement type structures designed, evaluated and costed as conventional structures, as well as for several "applicable" nuclear weapons environments other than fallout radiation alone, and such that the foundation conditions represent several basic soils both in dry and saturated states. This would include:

- Small basements - such as are typical of single family dwellings and which occur in large numbers throughout the country at the present time and will be constructed at some rate in the future.
- Large, single and multilevel basements, typical of those that frequently occur in various parts of the country in

    multifamily dwellings,
    department stores,
    office buildings,
    parking garages,
    churches, etc.

Even if thus limited, it is evident that these two categories of conventional structures represent a significant sheltering potential which for nuclear weapons environments above fallout radiation alone, is virtually unknown.

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APPENDIX A

ESTIMATED CONSTRUCTION TRENDS IN SELECTED TYPES OF CONSTRUCTION

The general trends in construction of expressway viaducts, schools, and public housing structures are implied in the growth of population and construction estimates by the U. S. Bureau of the Census Population growth and construction trends are compared for three types of construction in Fig A.1 through A.3 and in Table A.1 From these figures it is seen that:

- Urban population in the 1950-1960 period was increasing at a rate 50 percent greater than total population
- Total population is expected to increase at an annual rate of 1 3 to 1 6 percent in the 1965-1970 period Urban population could be 2 0 to 2 4 percent in this period
- Total new construction is expected to increase at an annual rate of 4 4 percent or about twice the rate of population growth
- Trends in new construction types which include potential dual-use structures are expected to increase faster than population growth in the 1965-1975 time period

    Highway construction at an average annual rate of 4 2 percent as shown in Fig. A 1

    Public residential construction at an average annual rate of 3 5 percent as shown in Fig A 2

    Public educational construction at an average annual rate of 2 7 percent as shown in Fig A 3

    Commercial construction at an average annual rate of 3 5 percent.

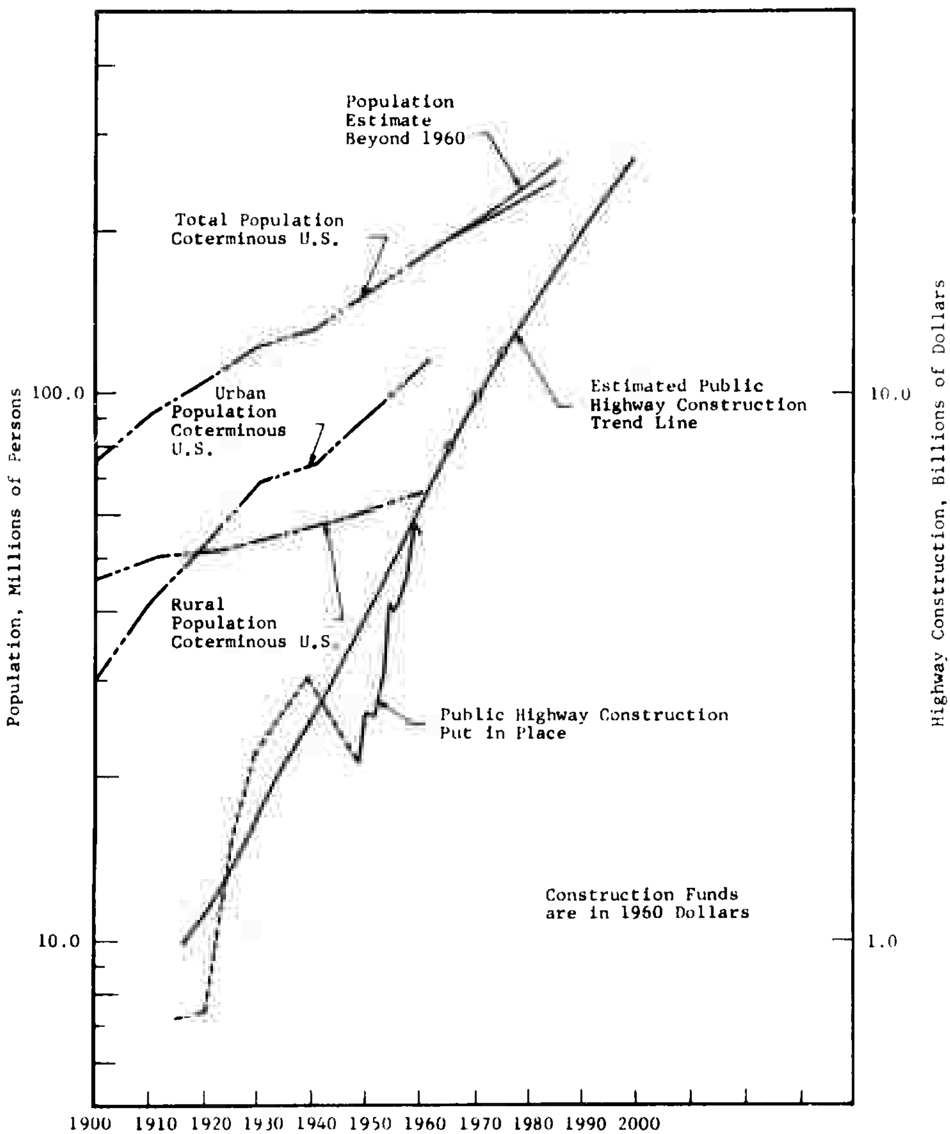


Fig. A.1 ESTIMATED POPULATION GROWTH AND HIGHWAY CONSTRUCTION TREND

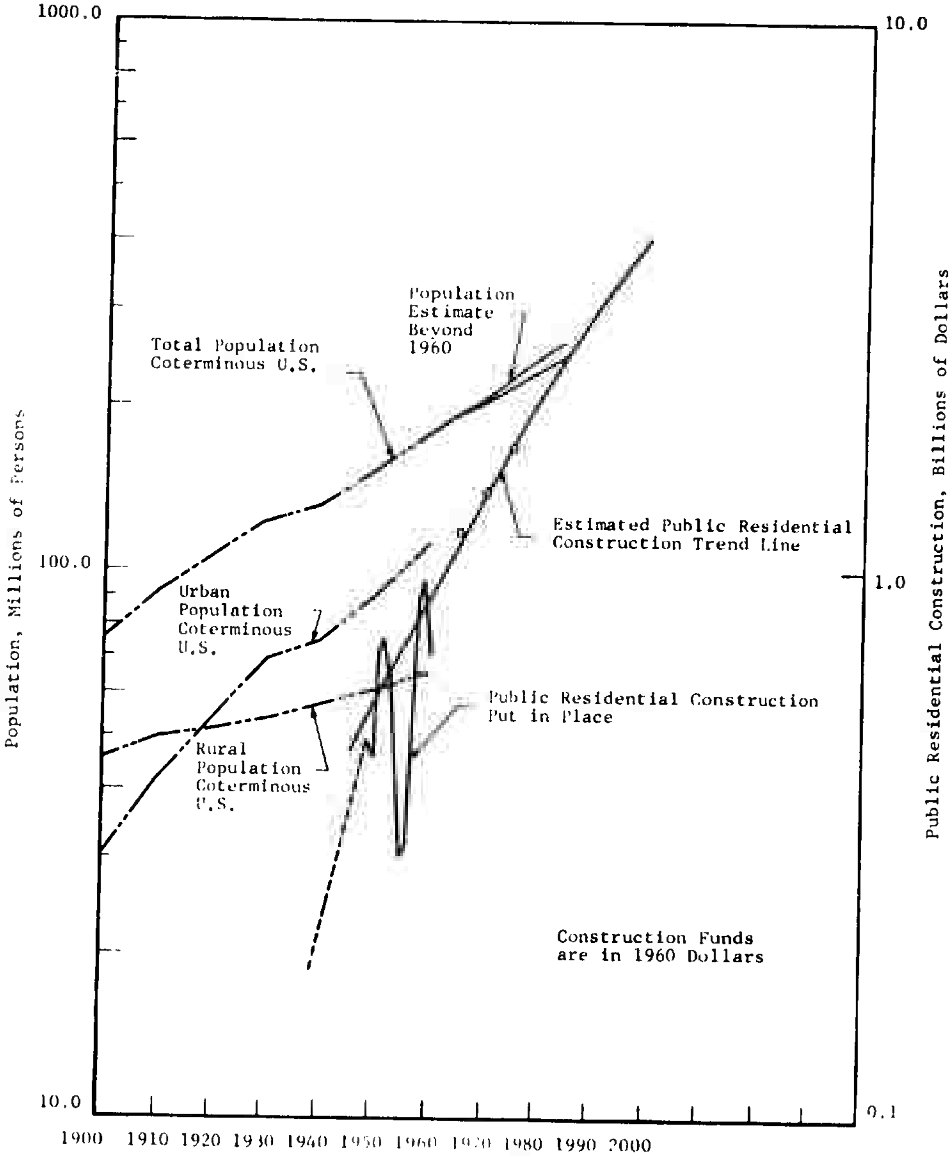


Fig. A.2 ESTIMATED POPULATION GROWTH AND PUBLIC RESIDENTIAL CONSTRUCTION TREND

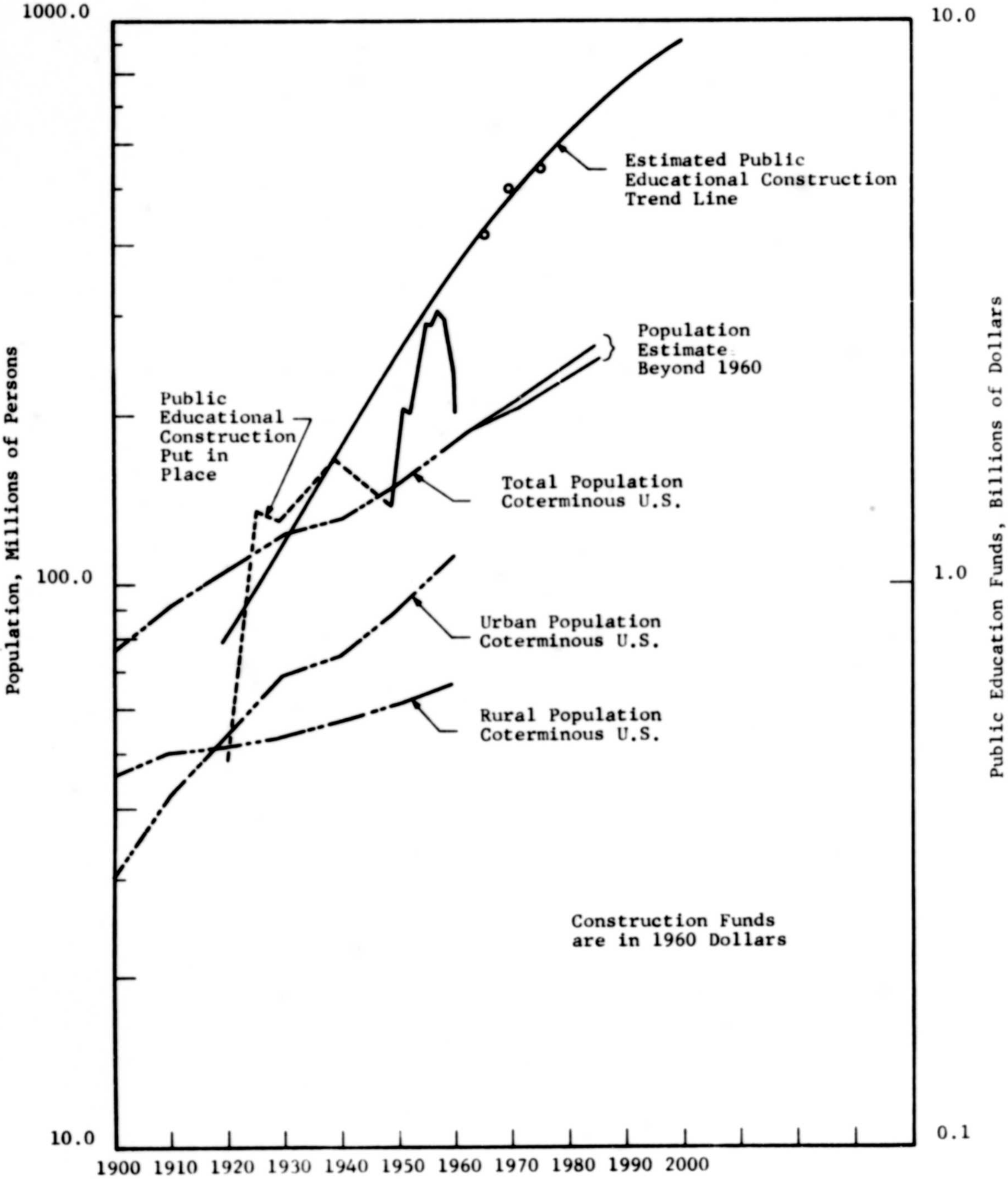


Fig. A.3 ESTIMATED POPULATION GROWTH AND PUBLIC EDUCATIONAL CONSTRUCTION TREND

Table A.1

ESTIMATED PCPULATION GROWTH AND CONSTRUCTION TRENDS

Item	1950	1960	Average Annual Increase percent 1950-1960	Estimated Volume 1965 (1000)	Estimated Volume 1970 (1000)	Estimated Volume 1975 (1000)	Increase percent 1965-1970	Increase percent 1965-1975	Average Annual Increase percent 1965-1970	Average Annual Increase percent 1965-1975	Remarks
Total Population*	150,697	178,464	1.7	191,334	208,249 218,018	225,123 218,018	8.84 7.21	17.7 13.9	1.4 1.2	1.6 1.3	
Urban Population	89,749	112,532	2.3								
Rural Population	60,948	65,932	0.8								
Private Non-Farm Residential				27,200	35,800	45,500	31.6	67.3	5.7	5.3	Most structures probably at low hardness levels
Commercial Construction				4,900	5,800	6,900	18.6	40.8	3.4	3.5	Many structures at low hardness levels; includes shopping centers
Private Industrial Construction				3,300	4,000	5,000	21.2	51.5	3.9	4.2	
Public Utilities Construction				6,480	7,685	9,200	18.6	42.0	3.5	3.6	Considerable construction in nonshelter category
Farm Construction				1,200	1,200	1,300	0.0	8.3	0.0	0.8	Not applicable to urban studies
Private Institutional and Miscellaneous				4,575	5,950	7,600	30.1	66.1	5.3	5.2	Includes private schools and colleges, churches, and hospitals
Total Private Construction				47,655	60,615	75,500	27.2	58.4	4.9	4.7	
Public Residential Construction				1,200	1,400	1,700	16.7	41.7	3.1	3.5	Shows trend in public housing projects
Public Rrsidential Construction				4,200	5,000	5,500	19.0	31.0	3.5	2.7	Shows trend in public school and college construction
Highway Construction				8,000	10,000	12,100	25.6	51.3	4.6	4.2	One indicator of trends in viaduct construction
Military and Public Industrial Construction				1,925	2,200	2,500	14.3	29.9	2.7	2.7	
Water and Sewer Construction				1,950	2,400	2,900	23.1	48.7	4.2	4.0	Large storm sewers in this category may be suitable candidates
All Other Public Construction				4,675	5,700	7,200	19.6	54.0	3.6	4.4	
Total Public Construction				21,950	26,700	31,900	21.6	45.3	4.0	3.8	
Total New Construction, Public and Private				69,605	87,315	107,400	25.4	54.3	4.6	4.4	

*Two population estimates for 1970 and 1975 are based on different conception (birth) rates.

These growth rates, general as they are, imply that dual-purpose shelter spaces in selected categories of new construction offer desirable and economically advantageous opportunities for increasing the number of available shelters. Taken alone, these growth rates do not necessarily suggest that specific potential structural types will provide sufficient space to accommodate the expected increase in urban population plus a percentage of the current urban population. Assurance of this requires that future siting for candidate structures be in high population density regions. New schools and new public housing might be expected to satisfy this siting criterion. Expressway viaduct shelter estimates would depend on the manner in which total highway construction expenditures are proportioned between intercity expressways and other classes of road building. Other types of construction, notably private industrial construction, are expected to increase at equally or greater annual rates, but may be less favorable candidates for dual-purpose usage due to acquisition problems or other reasons.

A.1 UTILIZATION OF VIADUCT SHELTERS

The need for providing automobile transportation from the outlying residential areas to the central business districts of major cities has, in many cases, been followed by construction of expressway networks passing through or in close proximity to the most dense residential, business, and industrial districts. Often these expressways are depressed below original grade and are crossed at frequent intervals (say 1/2 mi) by overpasses. These viaducts can be expected to be promising sites for shelter locations.

The merit of any single shelter or shelter system can be graded quantitatively in numerous manners. Indices can be developed for computing the value of a shelter in terms of 1) cost per sheltered person, 2) percent of total population capable of being sheltered in a system, and 3) likely utilization of the system, as well as others. Since abutment shelters are fixed-site and limited capacity installations, we have considered 1) cost per sheltered person as an index of economic feasibility and 2) potential utilization as an index of merit for the siting of the system as a whole.

Potential utilization of the individual abutment shelter is directly related to the population density in the region of the site and the accessible area, and inversely related to shelter capacity, as follows:

$$\text{Shelter Utilization} = \frac{\text{Accessible Population}}{\text{Shelter Capacity}}$$

$$= \frac{\text{Population Density} \times \text{Accessible Area}}{\text{Shelter Capacity}}$$

$$= \frac{\begin{matrix}\text{Population}\\ \text{Density}\end{matrix} \times \pi \left[\begin{matrix}\text{Personnel}\\ \text{Transit Speed}\end{matrix} \times \begin{matrix}\text{Travel}\\ \text{Time}\end{matrix} \right]^2}{\text{Shelter Capacity}}$$

By this computation alone, a shelter utilization figure much greater than 1.0 indicates a high likelihood of its usage to capacity. A shelter figure much less than 1.0 would indicate that siting may be marginal or that too large a shelter is being considered. Abutment shelters are limited capacity shelters and would be only one component of a total shelter system. For this reason, the inverse of the utilization index, which could otherwise be considered a measure of potential effectiveness, is not considered as such here.

By means of developing a sample problem, the accessibility and potential utilization of expressway viaducts as protective shelters is demonstrated in Fig. A.4 and Table A.2. Figure A.4 shows:

- An outline of the city of Chicago.
- The major expressways going through the city, the North Lake Shore Drive, and the circumscribing Illinois Tollway.

- Overpasses on the above thoroughfares, indicated by a "dot."

- Regions of 5, 10 and 15 min. travel times around overpasses, based on a walking pace of 5 mph for family groups.*

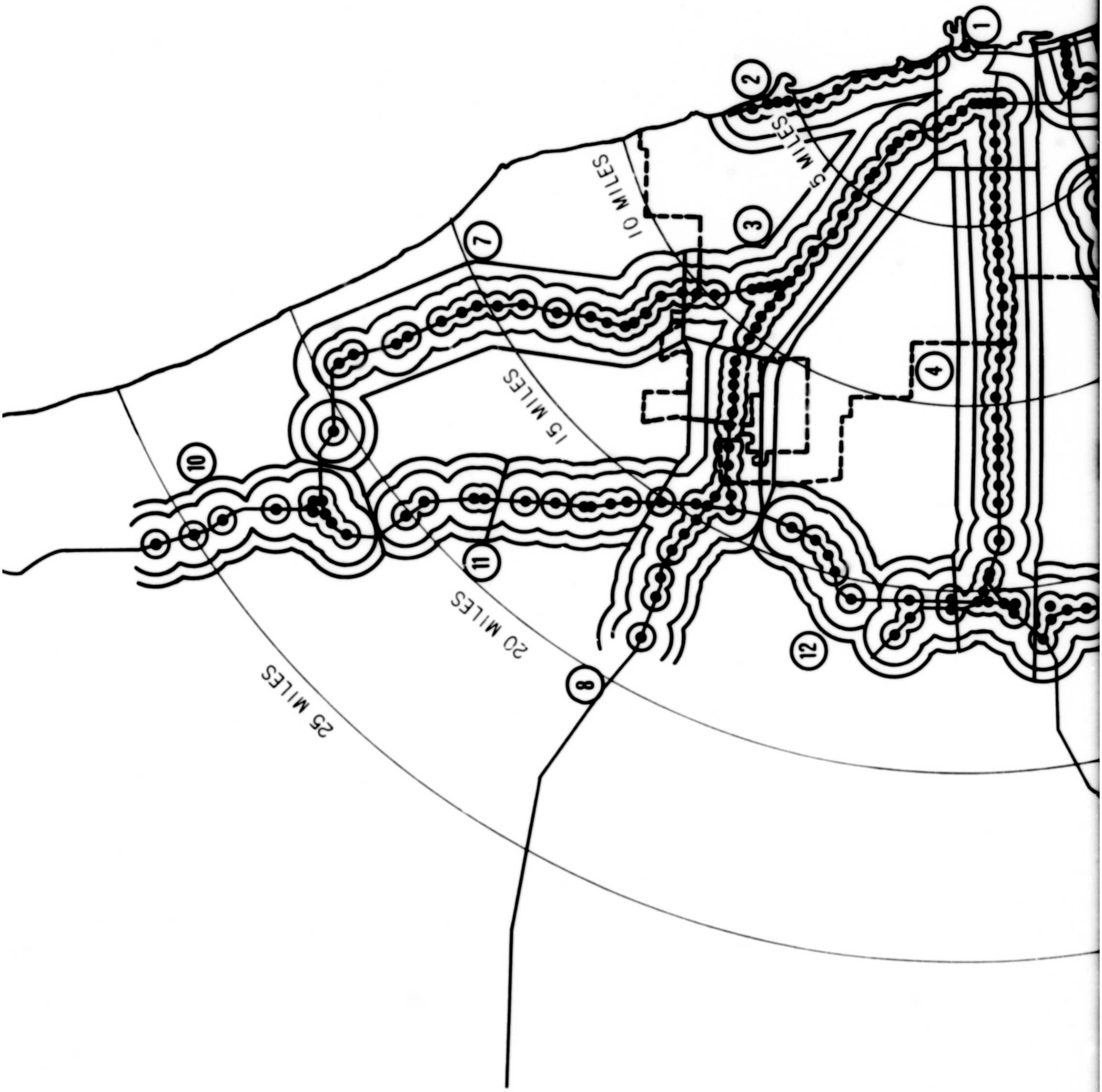
By this mapping technique, we find that the following percentages of the total land area (not population) of Chicago are within accessible walking distances to expressway viaducts for the selected warning times.

Walking Time, min	Percent of Total City Land Area	Cumulative Percent of Total City Land Area
5	16	16
10	18	34
15	16	50
More than 15	50	-

Capacities and potential utilization of expressway viaduct shelters are estimated in Table A.2. The total system of expressways defined in Fig. A.4 contains 244 expressway bridges. At an average capacity figure of 750 persons per abutment shelter (1500 per bridge), it is estimated that about 366,000 shelter spaces could be provided in this system. Much larger numbers of people are within reasonable travel distances of the expressway viaducts, as follows:

Walking-time to Viaducts Based on 5 mph Pace for Family Groups, min.	Number of Persons Within Accessible Range	
	Daytime	Night-time
5	1,174,000	739,000
10	3,000,000	1,742,000
15	4,168,000	2,461,000

*Design pace of 5 mph for family groups is selected from the report: Design of Entrance Systems for Personnel Protective Shelters, IIT Research Institute for U. S. Naval Civil Engineering Laboratory, NCEL Contract NBy-3163, Port Hueneme, California, 1959.



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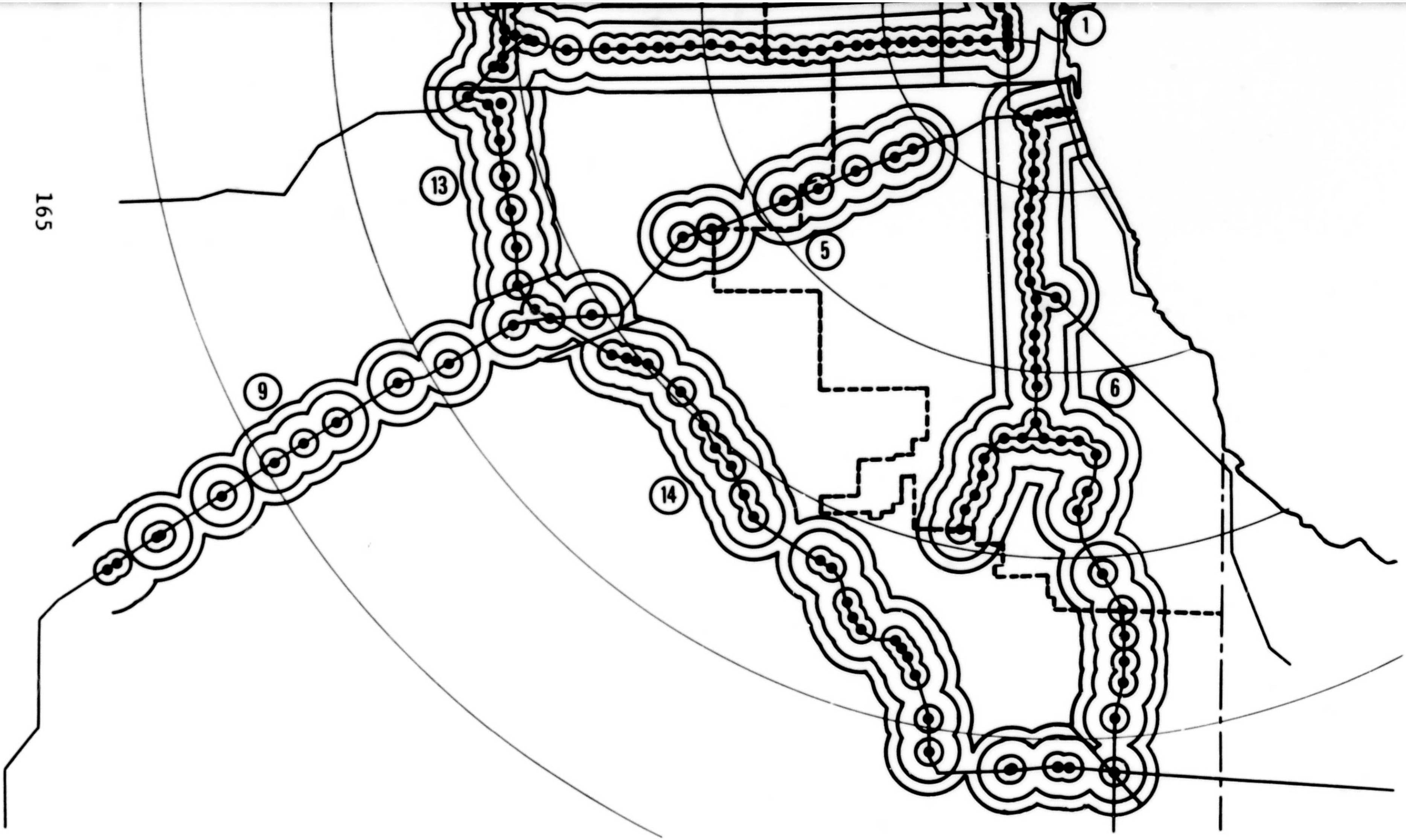


The three concentric radii about each viaduct location represent 5, 10 and 15 min. pedestrian travel regions.

Fig. A.4 ACCESSIBILITY OF EXPRESSWAY VIADUCTS AS PROTECTIVE SHELTERS, CITY OF CHICAGO

Table A.2

CAPACITIES AND POTENTIAL UTILIZATION OF EXPRESSWAY

Expressway Designation	Section of Expressway	Area, sq mi: 5 min. Region	Area, sq mi: 10 min. Region	Area, sq mi: 15 min. Region	Average Population Density persons, sq mi[1]: Night-Time	Average Population Density persons, sq mi[1]: Daytime	Total Night Population persons: 5 min. Region	Total Night Population persons: 10 min. Region	Total Night Population persons: 15 min. Region	Total Day Population persons: 5 min. Region	Total Day Population persons: 10 min. Region	Total Day Population persons: 15 min. Region	Number of Bridges	Bridge Capacity, persons[2]	Util: 5 mi Night-
Downtown Region	1	2.4	7.3	10.0	11,500	139,000	27,600	84,000	115,000	333,000	1,150,000	1,390,000	13	19,500	1.4
Lake Shore Drive, North	2	3.8	6.2	8.7	24,300	62,900	92,300	151,000	211,000	239,000	390,000	547,000	13	19,500	4.7
Kennedy Expressway, Northwest	3	7.0	15.8	21.7	18,700	22,700	131,000	295,000	405,000	159,000	358,000	492,000	23	34,500	3.8
	8	7.2	14.7	22.1	5,050	2,730	36,300	74,100	112,000	19,600	40,100	60,300	21	31,500	1.2
Eden's Highway	7	6.5	17.4	29.3	4,380	2,360	28,500	76,100	128,000	15,300	41,000	69,200	18	27,000	1.1
Eisenhower Expressway, West	4	9.9	20.2	31.1	13,000	12,300	129,000	262,000	405,000	122,000	248,000	382,000	29	43,500	3.0
Southwest Expressway	5	3.6	10.1	19.1	10,400		37,400	105,000	198,000	28,700	80,500	152,000	7	10,500	3.6
	9	6.0	19.7	34.7	581	378	3,480	11,400	20,200	2,270	7,450	13,100	14	21,000	0.2
Dan Ryan Expressway, South	6	13.8	36.5	56.3	14,700	16,300	203,000	536,000	828,000	225,000	595,000	918,000	43	64,500	3.1
Illinois Tollway	11	3.6	10.9	17.7	2,070	1,130	7,450	22,600	36,600	5,060	12,300	20,000	10	15,000	0.5
	10	3.0	10.6	15.7	486	326	1,460	5,150	7,630	980	3,450	5,120	11	16,500	0.1
	12	3.6	10.5	16.7	3,530	2,030	12,700	37,000	59,000	7,300	21,300	33,900	10	15,000	0.8
	13	3.4	8.8	13.6	2,750	1,650	9,350	24,200	37,000	5,400	14,500	22,400	9	13,500	0.7
	14	8.9	26.9	44.8	2,190	1,420	19,500	58,900	98,000	12,600	38,200	63,500	23	34,500	0.6
							739,000	1742000	2461000	1174000	3000000	4,168,000	244	366,000	

[1] Average population densities computed from curves.

[2] Based on a capacity figure of 750 persons/abutment shelter, or 1500 persons/bridge.

[3] Percentage of population outside structures as computed in Development of Typical Urban Areas, 5th Quarterly Report, Dikewood Corporation, for Office of Civil Defense, Contract OCD-PS-64-47, Albuquerque, September 1963.

Table A.2

ΓΙΟΝ OF EXPRESSWAY VIADUCT SHELTERS IN CHICAGO

lation	Number	Bridge	Utilization Based on Total Population Distribution						Utilization Based on Outside (Street) Population Alone								
									11:00 A.M. 9.0 percent			5:30 P.M. 18.5 percent			2:30 A.M. 0.7 percent		
			5 min. Region		10 min. Region		15 min. Region										
15 min. Region	of Bridges	Capacity, persons[2]	Night-Time	Daytime	Night-Time	Daytime	Night-Time	Daytime	5 min. Region	10 min. Region	15 min. Region	5 min. Region	10 min. Region	15 min. Region	5 min. Region	10 min. Region	15 min. Region
1,390,000	13	19,500	1.4	17.1	4.3	59.0	5.9	7.14	1.5	5.3	6.4	1.7	5.9	7.2	0.1	0.3	0.4
547,000	13	19,500	4.7	12.2	7.7	20.0	10.8	28.0	1.1	1.8	2.5	1.6	2.6	3.6	0.03	0.05	0.08
492,000	23	34,500	3.8	4.6	8.5	10.4	11.7	14.3	0.4	1.0	1.3	0.8	1.7	2.4	0.03	0.06	0.08
60,300	21	31,500	1.2	0.6	2.4	1.3	3.6	1.9	0.05	0.1	0.2	0.2	0.3	0.5	0.008	0.02	0.03
69,200	18	27,000	1.1	0.6	2.8	1.5	4.7	2.6	0.05	0.1	0.2	0.2	0.4	0.7	0.008	0.02	0.03
382,000	29	43,500	3.0	2.8	6.0	5.7	9.3	8.8	0.3	0.5	0.8	0.5	1.1	1.7	0.02	0.04	0.07
152,000	7	10,500	3.6	2.7	10.0	7.7	18.9	14.5	0.2	0.7	1.3	0.6	1.6	3.1	0.03	0.07	0.1
13,100	14	21,000	0.2	0.1	0.5	0.4	1.0	0.6	0.01	0.04	0.05	0.03	0.08	0.2	0.001	0.003	0.007
918,000	43	64,500	3.1	3.5	8.3	9.2	12.9	14.2	0.3	0.8	1.3	0.6	1.6	2.5	0.02	0.06	0.09
20,000	10	15,000	0.5	0.3	1.5	0.8	2.4	1.3	0.03	0.07	0.1	0.07	0.2	0.3	0.004	0.01	0.02
5,120	11	16,500	0.1	0.1	0.3	0.2	0.5	0.3	0.01	0.02	0.03	0.02	0.05	0.07	0.0007	0.002	0.004
33,900	10	15,000	0.8	0.5	2.5	1.4	3.9	2.3	0.05	0.1	0.2	0.1	0.4	0.6	0.006	0.02	0.03
22,400	9	13,500	0.7	0.4	1.8	1.1	2.8	1.7	0.04	0.1	0.2	0.1	0.3	0.4	0.005	0.01	0.02
63,500	23	34,500	0.6	0.4	1.7	1.1	2.8	1.8	0.04	0.1	0.2	0.1	0.[illegible]	0.4	0.004	0.01	0.02
4,168,000	244	366,000															

For the system as a whole, the accessible population appears to be from two to ten times the capacity of the shelter system itself. This alone is considered to justify, on the basis of likelihood of usage, serious consideration of expressway abutment shelters as a part of a total shelter system.

The various expressways in Fig. A.4 pass through regions where average population densities vary from 326 to 139,000 persons/sq mi. Local studies of actual population densities in immediate regions about shelter sites would certainly be required before planning actual installations. However, from potential utilization figures based on the total population distribution tabulated in Table A.2, we would expect most expressway viaducts within the Chicago city limits to be at highly-utilizable sites, even with short warning times (of the order of 15 min.). Viaduct sites within the city limits alone would provide about 192,000 spaces, whereas about 174,000 spaces could be provided along the circumscribing Illinois Tollway and within other less urbanized regions.

Site Category	Expressway Sections	Number of Spaces
Highly utilized sites within city	1,2,3,4,5,6	192,000
Illinois Tollway	10,11,12,13,14	94,500
Other suburban regions	7,8,9	79,500

Indication of lesser utilization figures for suburban expressway viaducts in Table A.2 does not negate their actual potential utilization. This estimate is based on average population density figures and does not reflect the trend for expressways to follow population movements to major suburban centers. Individual expressway viaducts in the suburbs may actually be at densely populated residential or business districts. In addition the population in vehicles on expressways constitutes a base population which would also tend to seek known viaduct shelters.

This latter population source has not been included in utilization estimates.

Potential shelter utilization has also been estimated on the basis of the population outside structures (on streets) for various significant times-of-day in Table A.2. Though we do not imply that shelter site planning should be based on the population outside structures, we find it significant that near the central business district, potential shelter utilization estimates based on the outside population alone exceed 1.0 in all cases. It also appears that during morning and evening rush hours the outside population is sufficient to fully utilize the abutment shelters throughout most of the central city.

A.2 PUBLIC SCHOOL SHELTER SITES

Usage of public and parochial schools, churches, and Park District field houses offers certain advantages as shelter sites:

- Sites are expected to be distributed about the city in approximately the same manner as the residential (night-time) population.
- Their locations are well known to the bulk of the populace; the population would know how to reach them quickly.
- Site acquisition negotiations involve relatively few organizations; municipal and religious organizations would normally be expected to show interested cooperation in establishing shelter systems.
- These sites provide excellent coverage of the city, providing shelters within reasonably short pedestrian travel times for family groups in almost all residential areas of the city.

As an example, the high accessibility of public school sites to the residential population of Chicago is demonstrated in Fig. A.5. This figure shows the location of all public elementary and high school sites in Chicago and regions of the city within 5, 10, and 15 min. travel time from these sites, based on a 5 mph pace for family groups. The distribution of the total land area of Chicago among the travel-time zones is as follows:

Travel Time to Shelter, min.	Percent of Total City Land Area	Cumulative Percent of Total City Land Area
5	73	73
10	22	95
15	4	99
More than 15	1	100

The percentage of people in the lower time zone regions would be expected to be higher than indicated earlier, since areas where schools are more widely separated are expected to be either industrial, commercial, or sparsely-settled residential areas.

The system of sites shown in Fig. A.5 includes 469 elementary school sites and 59 high school sites. Assuming the system could be enabled to provide 500 shelter spaces in each elementary school and 2000 in each high school and junior college, then a total of 352,500 spaces would be added to the total shelter system. This is equivalent to 9.9 percent of the total city population, and 59 percent of the school population.

Type of Schools	Number in Chicago	Total Enrollment	Average Enrollment per School	Shelter Spaces Added
Public Elementary	469	418,200	892	234,500 @ 500 per school
Public High and Junior Colleges	59	179,700	046	118,000 @ 2000 per school
Totals		597,900		352,500

On the other hand, provision of 598,000 spaces for the entire school population would potentially shelter 17 percent of the total city population. It should also be noted that these figures would be materially increased by adding parochial schools to the shelter system.

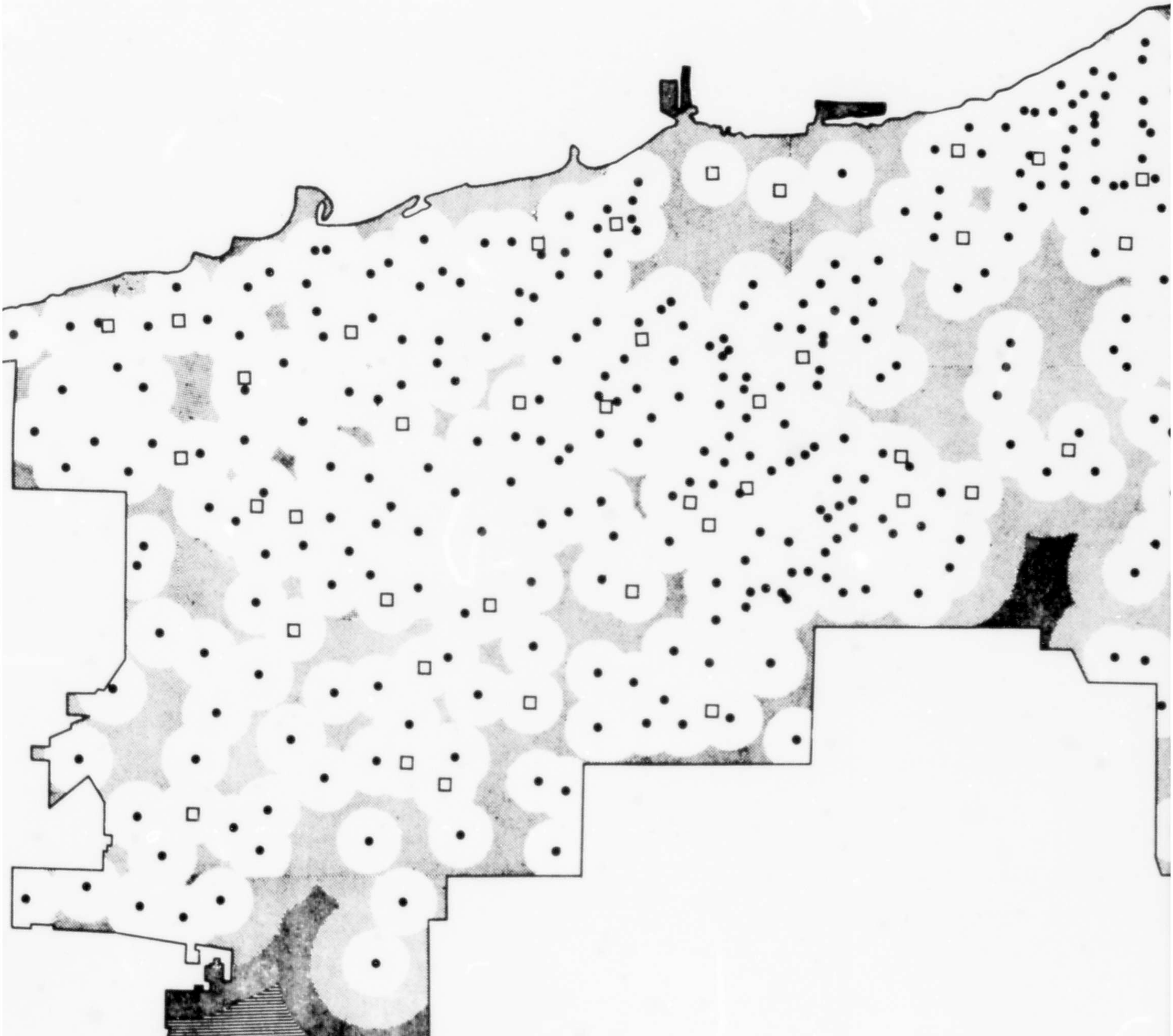


Fig. A.5 ACCESSIBILITY OF PUBLIC SCHOOL SHELTER SITES TO POPULACE OF CHICAGO

A.3 SHOPPING CENTER STRUCTURES AS DUAL-PURPOSE SHELTERS

Shopping centers may be divided into two general categories, i.e., conventional (older) and modern. Modern shopping centers are usually located in outlying areas of towns and contain within them a significant number of stores (ordinarily having like structural systems) conveniently arranged. A conventional shopping center on the other hand is commonly located at the center of a town (business district). The principal buildings are usually different both in structural systems as well as age and are less conveniently located than in the case of the modern counterpart. Both categories are considered herein. Evaluation of shopping centers as potential protective shelter sites requires consideration of the nature of the center, the types of structures present, and the population density of the regions in which centers are located. This is done in a general manner in this section. A large city, say above 500,000 in population, will usually include a number of older shopping centers of various sizes scattered throughout the city. It will also frequently have a smaller number of modern (post World War II) planned shopping centers, usually located in outlying regions. Both these existent types of centers, as well as yet-to-be-constructed shopping centers present potentialities for increasing the number of shelter spaces through dual-usage.

A general view of one very large city indicates that the older shopping centers have the following characteristics:

- They are numerous and well-distributed over the entire city as shown in Fig. A.6.
- They developed before the era of extreme automobile usage and the larger ones contain a concentration of sturdily constructed department stores, office buildings, banks, and hotels.
- Structures were built in an era of large heating facilities, when large basements were commonly provided
- They developed in or near regions of high population density, which has generally not decreased substantially in the intervening decades.

Structures in these older shopping centers include many found to be satisfactory in the National Fallout Shelter Survey.

On the other hand, the modern planned shopping centers generally have the following characteristics:

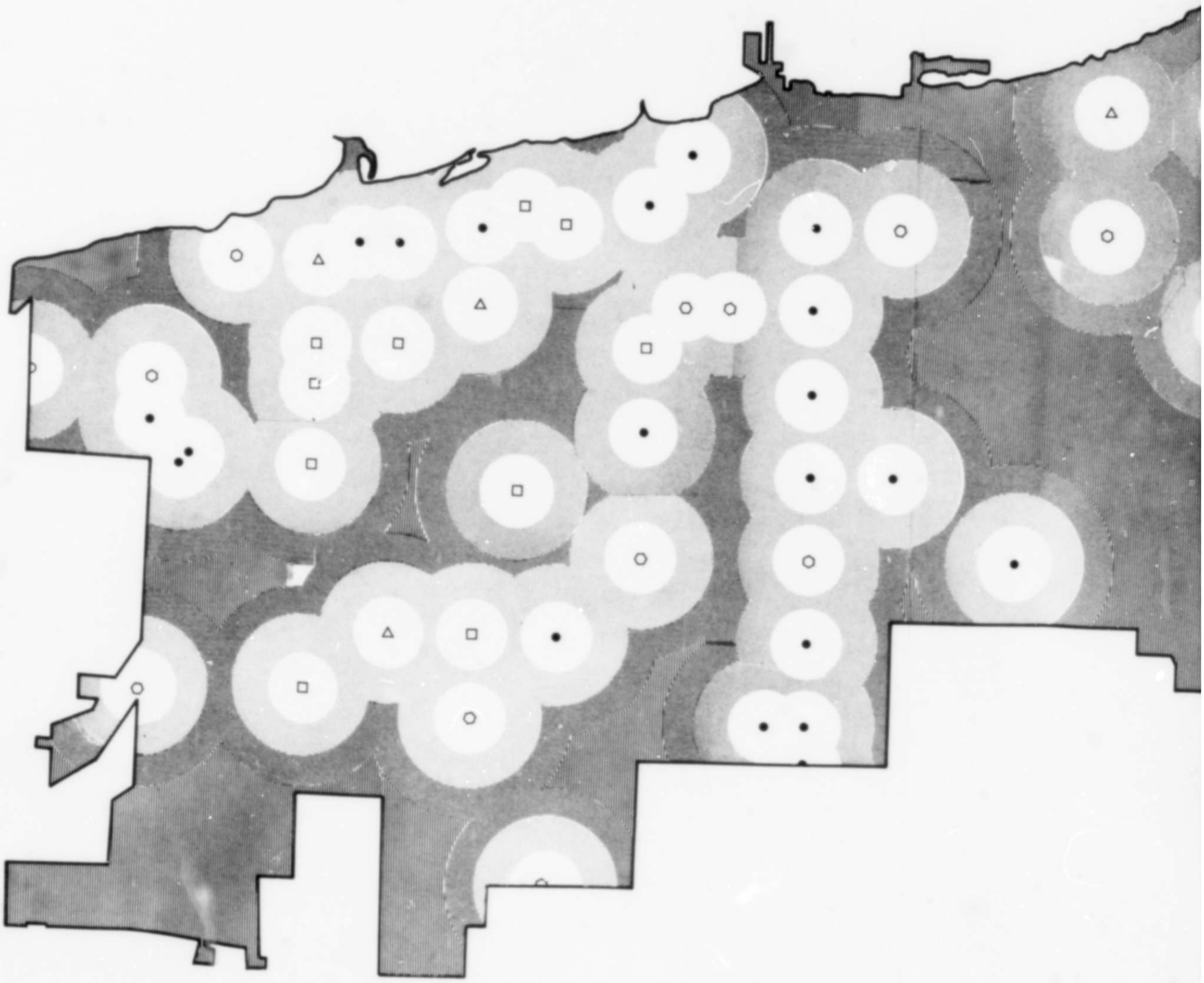
- By comparison they are fewer in number and most are located in outlying areas of lower population densities, as shown in Fig. A.6. (Suburban centers are not included on this map.)
- Structures are generally of lighter construction and frequently do not have basements.

For the system of 73 shopping centers shown in Fig. A.6, the percentage of city land area within various travel times of the centers is as follows.

Travel Time at 5 mph Pace, min.	Percent of Total City Land Area	Cumulative Percent of Total City Land Area
0 to 5	17	17
5 to 10	30	47
10 to 15	20	67
15 or more	33	100

Some of these centers are small and may contain few buildings that by actual inspection are suitable as blast shelters. However, with two-thirds of the city population within 15 min. travel time of this system, the potential value of the locations appears high.

Selected statistics for 73 shopping centers within the city limits of Chicago, graded into five general size and functional categories, are tabulated in Table A.3. The Central Business District is not included in this tabulation. That region, with a daytime population estimated at from 250,000 to 300,000 persons in an area of about 1.2 is certain to be a region of high potential shelter utilization. Containing many large heavily-constructed buildings with basements and often with sub-basements, subway tubes, and commercial and utility tunnel systems, the central business districts of large cities can be expected to offer many potential dual-purpose shelter spaces. Shopping centers



A

Fig. A.6 POPULATION ACCESSIBILITY OF SHOPPING CENTERS AS PERSONNEL SHELTERS, CITY OF CHICAGO

Table A.3

SELECTED STATISTICS FOR SHOPPING CENTERS IN CITY OF CHICAGO

Center	Peak Land Value Dollars/ frontage ft	Number of[3] Establish- ments	Total Front ft	Ground Floor Area sq ft	Number of Retail Employees	Number of Person Shopping Trips	Shopping Goods Area[1] sq mi	Shopping Goods Area[1] Population Served	Remarks[4]
Major Regional Business Centers (4)									
63rd and Halsted	7,000	253	8,055	799,025	4,034	27,095	15.5	353,220	Average Building Depth = 88 ft
Irving Park and Cicero	4,000	185	6,100	553,625	2,348	19,166	18.8	323,500	Average Store Width = 32 ft
Lincoln, Belmont and Ashland	5,000	208	7,024	579,750	2,851	20,583	9.3	304,420	Estimated minimum district daytime occupancy = 11,004 + 0.25(87,722) = 32,700 persons
Lawrence and Broadway	2,500	176	5,135	397,700	1,771	19,878	5.3	186,260	Average radius of shopping goods area = 1.98 mi.
Totals		822	26,314	2,330,100	11,004	86,722	48.9	1,167,400	
Other Shopping Goods Centers (16)									
79th and Halsted	2,500	137	3,640	332,910	1,112	15,438	3.3	61,390	
Belmont and Central	2,000	178	5,190	438,900	2,166	12,976	3.3	56,140	
Fullerton, Grand and Harlem	2,000	156	4,515	429,750	1,296	14,095	7.0	71,950	
North and Pulaski	2,000	94	2,555	244,425	959	11,100	4.5	102,070	
Devon and Western	1,250	102	2,625	214,615	1,742	13,290	3.8	83,360	
Madison and Pulaski	4,000	108	3,485	380,205	2,104	21,073	12.4	333,070	
47th and Ashland	2,500	88	2,940	317,400	1,579	10,239	8.0	113,570	Average Building Depth = 94 ft
Division, Ashland and Milwaukee	1,750	87	2,980	252,250	1,341	13,113	4.0	139,110	Average Store Width = 28 ft
Roosevelt and Halsted	1,700	97	2,820	246,850	1,823	14,749	2.8	54,590	Estimated minimum district daytime occupancy = 21,961 + 0.25(194,585) = 70,600 persons
Chicago and Ashland	1,600	133	3,910	338,725	1,148	10,091	2.3	90,820	
47th and South Parkway	1,200	130	3,360	298,775	1,100	17,641	1.3	53,190	
35th and Halsted	850	91	2,450	205,300	639	9,672	6.3	213,420	Average radius of shopping goods area = 1.38 mi.
111th and Michigan	2,500	119	3,775	414,200	2,463	18,037	17.0	163,040	
91st and Commercial	1,800	90	2,755	926,475	1,142	13,070	8.0	88,150	
Lake Meadows		30		160,675	385		no data		
Scottsdale		41		154,375	962				
Totals		1,681	47,000	4,725,830	21,961	194,584	84.0	1,623,870	
Cumulative Totals		2,503	73,314	7,055,930	32,965	281,306	132.9	2,791,270	
Class B: Community Business Centers (28)									
71st and Jeffery	2,000	41	1,540	187,330	1,034	14,409	2.5	62,620	
63rd and Western	1,500	73	1,995	171,400	1,155	12,245	1.5	21,220	
53rd and Lake Park	1,400	62	1,410	99,215	639	4,685	2.0	74,100	
63rd and Kedzie	1,400	82	2,360	213,475	1,177	10,361	1.9	36,080	
79th and Ashland	1,200	65	1,600	121,825	770	11,275	1.8	34,320	
79th and Cottage	1,200	88	2,075	161,250	1,625	10,444	2.8	48,470	
63rd and Ashland	1,000	56	1,755	130,375	430	7,649	0.9	20,040	
67th and Stony	1,000	93	2,055	149,310	530	8,729	2.3	80,830	
75th and Cottage	850	58	1,620	105,660	343	7,091	0.8	12,370	
75th and Exchange	750	69	1,595	110,155	487	9,693	3.8	85,600	Average Building Depth = 78 ft
Lawrence and Milwaukee	1,800	77	2,305	191,675	931	7,717	2.0	28,970	Average Store Width = 27 ft
Diversey and Kimball	1,750	93	3,775	319,165	1,703	12,167	2.3	53,680	Estimated minimum district daytime occupancy = 23,867 + 0.25(240,548) = 84,000 persons
Devon and Central	750	73	1,945	153,325	286	1,938	1.3	6,550	
Belmont and Cicero	850	52	1,580	117,150	632	7,041	1.3	24,820	Average radius of shopping goods area = 0.78 mi.
Diversey and Clark	2,750	136	3,985	356,400	1,070	11,407	2.3	104,380	
Lawrence and Kedzie	1,200	112	2,695	216,540	1,250	7,656	1.5	41,900	
Lawrence and Western	1,700	90	2,525	181,100	1,068	9,553	1.3	36,140	
Howard and Paulina	1,200	87	2,135	148,250	750	9,327	1.4	34,440	
Bryn Mawr and Broadway	1,000	98	2,540	169,530	1,393	10,369	1.3	37,880	
Irving Park and Damen	1,000	73	2,425	188,500	994	10,267	2.1	48,470	
Lawrence and Damen	800	64	1,830	147,090	885	9,559	2.5	85,940	
Fullerton and Halsted	900	60	2,205	119,175	556	4,549	1.0	42,510	
63rd and Cottage	1,750	94	2,725	206,895	1,132	16,725	2.3	101,100	
North and Milwaukee	1,200	68	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]									

Totals		1,681	47,000	4,725,830	21,961	194,584	84.0	1,623,870
Cumulative Totals		2,503	73,314	7,055,930	32,965	281,306	132.9	2,791,270
Class B: Community Business Centers (28)								
71st and Jeffery	2,000	41	1,540	187,330	1,034	14,409	2.5	62,620
63rd and Western	1,500	73	1,995	171,400	1,155	12,245	1.5	21,220
53rd and Lake Park	1,400	62	1,410	99,215	639	4,685	2.0	74,100
63rd and Kedzie	1,400	82	2,360	213,475	1,177	10,361	1.9	36,080
79th and Ashland	1,200	65	1,600	121,825	770	11,275	1.8	34,320
79th and Cottage	1,200	88	2,075	161,250	1,625	10,444	2.8	48,470
63rd and Ashland	1,000	56	1,755	130,375	430	7,649	0.9	20,040
67th and Stony	1,000	93	2,055	149,310	530	8,729	2.3	80,830
75th and Cottage	850	58	1,620	105,660	343	7,091	0.8	12,370
75th and Exchange	750	69	1,595	110,155	487	9,695	3.8	85,600
Lawrence and Milwaukee	1,800	77	2,305	191,675	931	7,717	2.0	28,970
Diversey and Kimball	1,750	93	3,775	319,165	1,703	12,167	2.3	53,680
Devon and Central	750	73	1,945	153,325	286	1,938	1.3	6,550
Belmont and Cicero	850	52	1,580	117,150	632	7,041	1.3	24,820
Diversey and Clark	2,750	136	3,985	356,400	1,070	11,407	2.3	104,380
Lawrence and Kedzie	1,200	112	2,695	216,540	1,250	7,656	1.5	41,900
Lawrence and Western	1,700	90	2,525	181,100	1,068	9,553	1.3	36,140
Howard and Paulina	1,200	87	2,135	148,250	750	9,327	1.4	34,440
Bryn Mawr and Broadway	1,000	98	2,540	169,530	1,393	10,369	1.3	37,880
Irving Park and Damen	1,000	73	2,425	188,500	994	10,267	2.1	48,470
Lawrence and Damen	800	64	1,830	147,090	885	9,559	2.5	85,940
Fullerton and Halsted	900	60	2,205	119,175	556	4,549	1.0	42,510
63rd and Cottage	1,750	94	2,725	206,895	1,132	16,725	2.3	101,100
North and Milwaukee	1,200	68	2,340	172,600	1,110	12,910	3.3	105,570
63rd and Woodlawn	750	51	1,350	126,575	633	12,690	1.8	87,950
Hyde Park Shopping Center		20		72,675				
Chatham Park		31		174,950	666			
Lincoln Village		27		98,545	618			
Totals		1,993	53,365	4,610,135	23,867	240,458	48.0	1,315,950
Cumulative Totals		4,496	127,679	11,666,065	56,832	521,764	180.9	4,107,220

Average Building Depth = 78 ft
Average Store Width = 27 ft
Estimated minimum district daytime occupancy = 23,867 + 0.25(240.548) = 84,000 persons
Average radius of shopping goods area = 0.78 mi.

Class C: Neighborhood Centers (21)[2]								
69th and Halsted	800	40	1,095	90,125	676	3,968	2.0	58,120
Fullerton and Cicero	750	30	900	48,025	567	5,082	2.0	32,480
Devon and California	1,000	39	1,020	73,575	1,181	14,261	1.3	23,980
Montrose and Broadway	800	40	1,497	88,625	613	12,129	2.3	96,330
Irving Park and Sheridan	800	57	1,505	99,000	353	6,812	2.3	97,090
Peterson and Lincoln	750	10	445	38,270	385	3,634	1.3	25,930
Belmont and Clark	750	34	1,375	78,350	368	5,753	0.8	45,990
Division and Clark	2,000	70	1,877	112,065	1,080	11,188	3.4	87,360
Madison and Halsted	2,000	56	1,305	118,025	2,620	23,049	3.4	42,520
North and California	1,250	45	1,350	126,550	461	6,895	2.5	84,360
Madison and Central	1,250	51	1,160	87,925	600	11,428	3.0	66,160
Madison and Cicero	1,250	28	825	49,000	1,246	9,924	1.9	51,050
Lake and Central	1,200	43	1,100	79,200	248	9,164	2.0	40,200
Madison and Kedzie	1,200	49	1,650	149,325	621	7,843	1.0	29,290
26th and Pulaski	1,100	58	1,975	165,725	581	5,713	2.1	52,470
Madison and Austin	1,000	31				12,171		
Madison and Western	800	45	990	111,500	272	8,748	1.6	55,530
Madison and Ashland	800	64	1,675	98,730	1,284	10,518	0.8	20,070
Roosevelt and Kedzie	750	40	1,340	105,500	590	18,238	2.8	129,470
63rd and Stony	750	35	1,010	49,450	198	3,892	0.8	49,370
North and Larrabee	750	41	1,200	92,400	537	2,780	0.5	22,130
Totals		906	25,234	1,861,365	14,481	193,190	37.8	1,109,900
Cumulative Totals		5,402	152,973	13,527,430	71,313	714,954	218.7	5,217,120

Average Building Depth = 74 ft
Average Store Width = 28 ft
Estimated minimum district daytime occupancy = 14,481 + 0.15(193,190) = 29,000 persons
Average radius of shopping goods area = 0.77 mi.

Planned Neighborhood Centers								
115th and Michigan		14		46,900	449			
Jeffery Center		19		47,850				
South-east Village Center		15		59,250				
Howard and Western		17		71,750				
Totals		65		225,750	449			

[1]Shopping areas overlap, the 1964 land area of the city of Chicago is 226.7 sq mi and the 1960 census population is 3,550,400 persons.

[2]Only neighborhood centers with peak lot valued at more than $750/front ft are included.

[3]Number of establishments is greater than number of structures.

[4]Average store width is based on number of establishments rather than structures, the estimated widths are therefore low.

B

outside the central business district require more detailed study to estimate their potential utilization as dual-purpose shelter sites.

Using data from Table A.3 , we estimate that the availability of space for dual-purpose shelters in these shopping districts is from 2.8 to 3.5 times the minimum daytime occupancy level (employees and customers) of the shopping district, as shown in Table A.4 .

Daytime occupancy levels for the shopping districts are computed as total retail employees in the district plus a portion of daily person-trips into the district, the latter based on an estimate of average duration of shopping excursions. Employees and shoppers, computed in this manner, represent a daytime and early evening base population of persons in structures and on streets which could reach shelters even if warning times were short. Full utilization of dual-purpose shelter spaces would be attained by admission of the residential population around the shopping centers.

Assuming the advantage of the various shopping centers as dual-purpose shelter sites to be directly related to their relative sizes, the cumulative total populations and potential shelter spaces are also of interest as shown in Table A.5 .

As indicated previously, it is estimated that the 116,000 dual-purpose shelter spaces could be developed in the four major regional business centers alone. A more complete system of dual-purpose shelters in the 69 shopping centers shown in Fig. A.6 , might provide as many as 676,000 shelter spaces.

Several attendant merits to providing dual-purpose shelters in shopping centers include the following:

- The centers almost invariably include medical offices, contributing doctors to the shelter population at least during certain hours of the day.

- Occurrence of drug stores at shopping centers provides some availability of drugs and medicines, at least at time of limited reentry.

Table A.4

ESTIMATED AVAILABLE SHELTER SPACE FROM SHOPPING DISTRICTS

Type of Center	Number of Centers	Minimum Occupancy of Centers During Business Hours	Residential Population about Centers* Travel Time, min.			Total Ground Floor Area	Available Shelter Spaces 10 sq ft/person**	Potential Utilization Indices
			5	10	15			
Major Regional Business Centers	4	32,700	34,300	137,000	308,000	2,330,000	116,000	0.3 to 2.5
Other Shopping Goods Centers	16	70,600	137,000	547,000	1,230,000	4,276,000	214,000	0.6 to 5.2
Community Business Centers	28	84,000	240,000	958,000	2,159,000	4,610,000	231,000	1.0 to 9.3
Neighborhood Centers	21	29,000	180,000	718,000	1,619,000	1,861,000	93,100	1.9 to 17.3

* Average residential density of 15,700 persons/sq mi.

** Assumed available basement area to be 50 percent of ground floor area.

Table A.5

CUMULATIVE TOTAL POPULATION RELATIVE TO POTENTIAL SHELTER SPACES IN SHOPPING CENTERS

Type of Center	Cumulative Number of Centers	Minimum Occupancy of Centers During Business Hours	Cumulative Total Residential Population about Centers, Travel Time, min.			Cumulative Total Ground Floor Area	Cumulative Total Available Shelter Spaces 10 sq ft/person**
			5	10	15		
Major Regional Business Centers	4	32,700	34,000	137,000	308,000	2,330,000	116,000
Other Shopping Goods Centers	20	103,300	171,000	684,000	1,528,000	7 056,000	353,000
Community Business Centers	48	187,300	411,000	1,642,000	3,687,000	11,666,000	583,000
Neighborhood Centers	69	216,300	591,000	2,360,000	5,306,000	13,527,000	676,000

** Assumed available basement area to be 50 percent of ground floor area.

- Department store basements contain counter space which can be used as cots, fabric articles which can be used as bedding, and nearby drug and frequently food sources.

- Shopping centers outside the Central Business District include food stores with available stocks at time of limited reentry.

One difficutly in utilizing structures in these shopping centers as dual-purpose shelters is site acquisition. Though many structures in the centers tabulated in Table A.3 house a number of establishments, it is apparent from this table that basement acquisitions for a complete system of 676,000 spaces as described earlier would involve negotiations with thousands of individual building owners. This problem has been successfully accomplished for those buildings marked and stocked for the National Fallout Shelter Survey. Difficulties attendant upon retrofit construction, however, lead us to consider the largest buildings alone in these centers: chain department stores, independent department stores, banks, large office buildings and hotels. Basements in these structures are expected to be large and, consequently, to permit a large shelterable population. Many have been studied, to some extent, in the National Fallout Shelter Survey.

A.4 SHELTERS IN CHAIN DEPARTMENT STORES

Sites for 18 major chain department stores with basements within the city limits of Chicago are plotted in Fig. A.6. Circles corresponding to 5, 10, and 15 min. travel times around these sites at a 5 mph pace, are circumscribed around the sites. The following percentages of total city land area are contained within these zones:

Travel Time at 5 mph Pace, min	Percent of Total City Land Area	Cumulative Percent of Total City Land Area
0 to 5	5	5
5 to 10	11	16
10 to 15	16	27
More than 15	69	-

Basement floor areas and shelterable populations for dual-purpose shelters in these structures are estimated as follows.

Item*	Approximate Basement Area sq ft	Maximum Shelterable Population
Store with largest basement area	57,500	5,750
Store with smallest basement area	8,800	880
Average basement size	29,200	2,920
Total basement area 18 stores	525,000	52,500

Assuming an average residential population density of 15,700 persons/sq mi for the city, the population within the various travel-time zones of this system of 18 chain department stores is as follows.

Travel-Time Zones at 5 mph Pace, min.	Population persons	Shelter Utilization Index Based on 52,500 spaces
0 to 5	212,000	4.1
5 to 10	460,000	8.8
10 to 15	600,000	11.4
More than 15	2,260,000	-

From the above it appears that the effectiveness of planning to utilize shopping centers as dual-purpose shelter sites can be increased by detailed study and selection of classes of structures affording relatively high shelter populations.

*In this tabulation, sub-basement areas are included along with basement areas.

Acquisition of shelter rights in 18 chain department stores can add 52,500 spaces throughout the city through negotiation with only three commercial organizations. Acquisition of sites in other large buildings such as banks, hotels, office buildings and independent stores may add considerably more shelter space, though involving negotiation for rights with a larger number of organizations.

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APPENDIX B

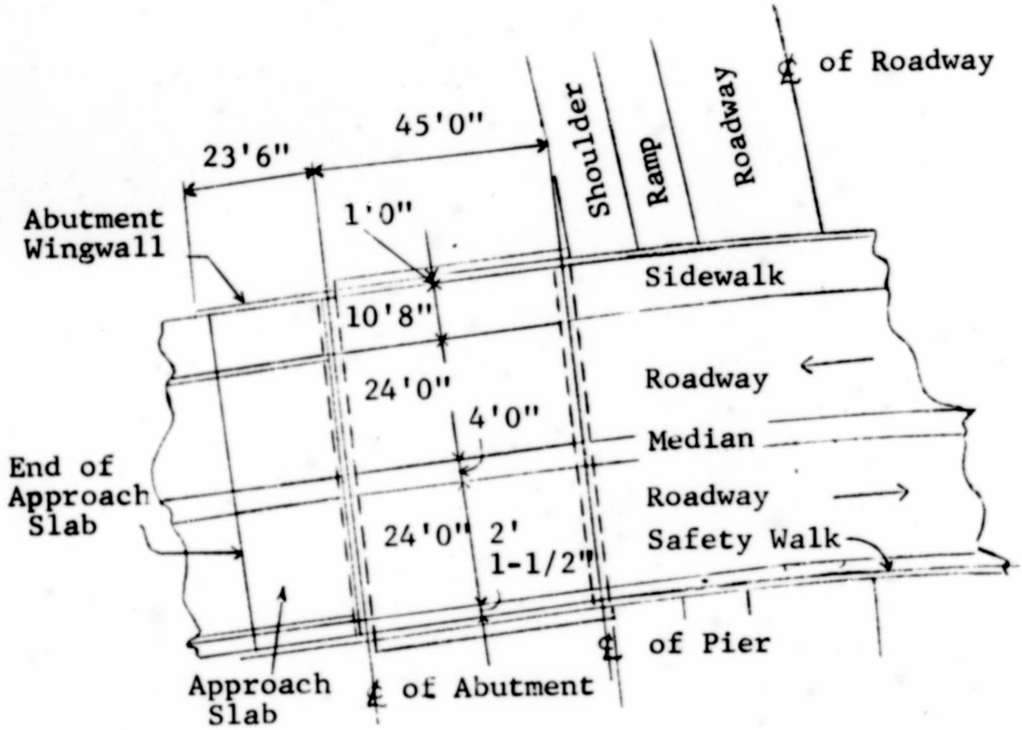
EXPRESSWAY GRADE SEPARATIONS AS DUAL-USE PROTECTIVE SHELTERS

B.1 INTRODUCTION

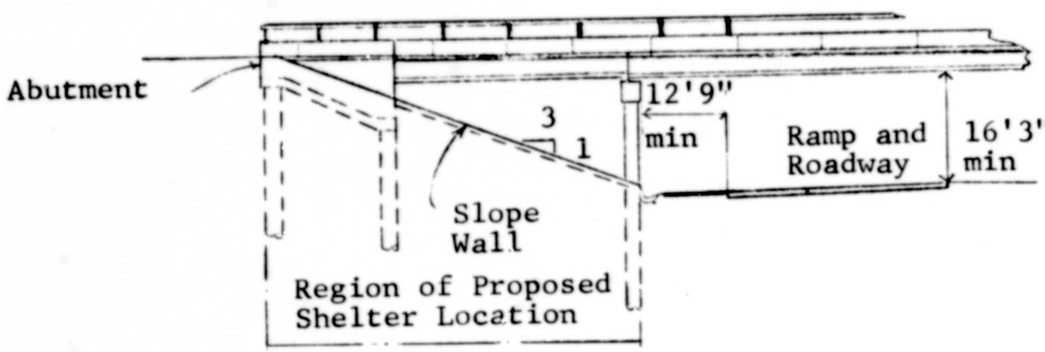
The objective of this appendix is to explore in a relatively general sense, the potential of utilizing the abutment portions of expressway grade separations as dual-use protective shelters. General reasons for choosing this category of structures have already been discussed in some detail in Appendix A to this report.

Consider the grade separations shown in Fig. B.1.[1]* The portion of the structure that appears to offer a sheltering potential and which is investigated herein, is located between the first pier and the end of the approach slab. The size of this portion is dependent on the width of the overpass (roadway, sidewalk, median, etc.), required vertical clearance for the depressed roadway, and the prescribed embankment slope. The portion between the face of the abutment and the pier is shown in Fig. B.2 and represents the structure illustrated in Fig. B.1 in its construction stage. This portion alone, appears to offer an obvious sheltering potential, with a gross plan area of approximately 2900 sq ft which ordinarily is unused. In order to realize this potential, at least for a fallout radiation environment it would be necessary in the construction stage to eliminate the slope wall, level and pave the surface, provide three protective walls and several entranceways. With a leveled surface (at about the same elevation as the adjoining roadway) the headroom would be over 16 ft, therefore a two-level shelter is possible. Viewed thus, the shelter would have a gross space potential for about 580 persons (10 sq ft per occupant, or over 1100 spaces for a single grade separation of the size shown.

*Superscript numbers refer to appendix references listed at the end, page 213.



Plan



Elevation

Fig. B.1 A PORTION OF A TYPICAL GRADE SEPARATION

Fig. B.2 TYPICAL GRADE SEPARATION (Pier and Abutment Portion)

As far as size is concerned, this grade separation (Fig B.1) is average at least for the city of Chicago where it is located.

Further use of this structure can be made by expanding into the abutment portion This would require a considerably more extensive redesign effort of the initial structure, however, with two levels it is possible to provide an additional gross area of 3200 sq ft if one stays within the plan limits of the original structure.

The grade separation shown in Fig. B.1 and B.2 is one general type and for purposes of our study is characterized by the open area between the face of the abutment and the first pier. A variation of this structure that warrants some consideration is shown in Fig. B.3, B.4[4] and B.5.

In places where the proximity of streets running parallel to an expressway is such that a full embankment with a prescribed slope cannot be realized without encroaching on existing construction (water mains, sewers, etc.), a variation of the structure discussed can be employed Ordinarily, use is made of a closed rectangular supporting structure. This is shown in detail in Fig. B.4. It will be noted that the variation consists of replacing the first span by an approach slab and the first pier by a wall-like abutment with wingwalls running the full length of the span. The enclosed space is ordinarily empty down to the slope line. For the structure shown in Fig B.4 the abutment has a thickness of 3 ft 4 in, the wingwalls vary in thickness from about 1 ft 6 in. at the top to about 3 ft at the base. The abutment portion has a gross shelter space potential of approximately 7000 sq ft if a two-level shelter is considered. In order to realize this potential, at least as far as fallout radiation protection is concerned, it would be necessary to eliminate the soil in the initial construction stage, provide an internal retaining wall at the end of the approach slab, and incorporate entranceways For nuclear weapons environments above fallout radiation alone a more complete redesign would be requisite.

Fig. B.3 GRADE SEPARATION WITH CLOSED ABUTMENTS

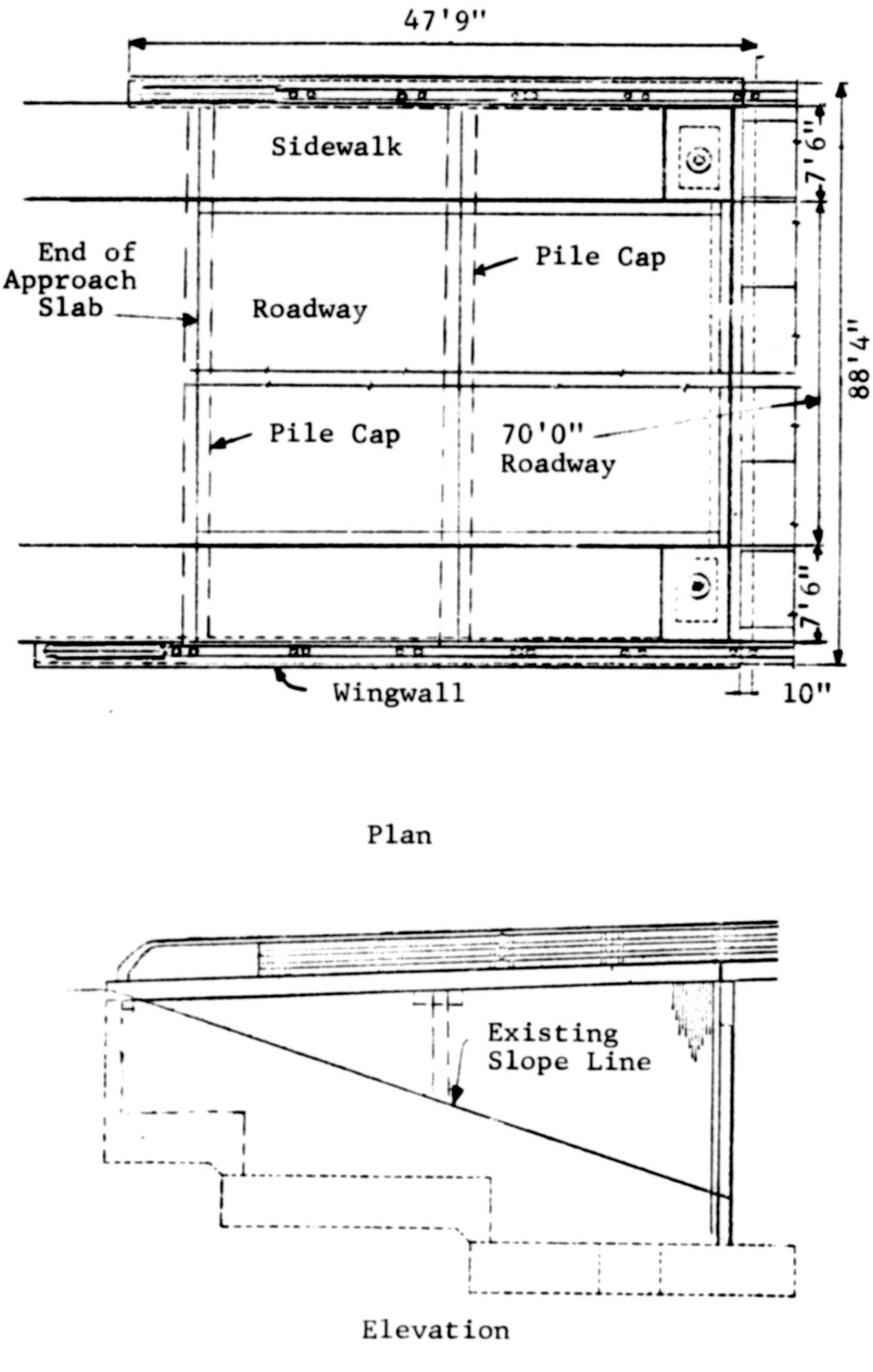


Fig. B.4 ENCLOSED ABUTMENT

Fig. B.5 GRADE SEPARATION WITH CLOSED ABUTMENTS

Fig. B.6 GRADE SEPARATION ADJOINING AN ACCESS RAMP

Another interesting variation of the structures discussed is shown in Fig. B.6. On its left side the structure is similar to the one discussed in connection with Fig. B.1, on its right, however, it is joined to an access ramp. Only about one half of this ramp is shown in the photograph. Such structures are less frequent than the ones discussed earlier, nonetheless, it is evident that where they exist, they possess a large shelter potential in terms of space.

Grade separations, of the type discussed (Fig. B.3, B.4 and B.5) are fairly commonplace along city expressways and are relatively densely spaced in dense population areas, as is evident in Fig. A.4. In such areas they are in close proximity to utility lines (electricity, water, sewerage) and are accessible by both vehicular and pedestrian means. As far as fires are concerned, these structures have the advantage of being depressed below grade and having their exposed portions face a relatively wide and open area (the expressway). This should be considered carefully in making cost effectiveness comparisons with shelters located in high fire hazard areas.

For reasons given previously and those stated in Appendix A, a preliminary investigation was performed and is given in the following paragraphs. Structures arbitrarily selected for this purpose are those shown in Fig. B.1 and B.4. For the structure shown in Fig. B.1, a shelter was designed and costed for three levels of overpressure (5, 25 and 50 psi) and associated nuclear weapons effects resulting from a 10 MT burst. In the case of the structure shown in Fig. B.4, only the feasibility of incorporating a fallout shelter was considered. In the following paragraphs the two structures investigated are designated as Structure I (Fig. B.1) and Structure II (Fig. B.4), respectively.

B.2 SHELTER DESCRIPTION

B.2.1 Structure I

As mentioned, the design was approached from the standpoint of integrally constructing a hardened personnel shelter with the bridge abutment. In this state it would function as a supporting structure for the bridge, provide storage space for expressway maintenance equipment and supplies, and hardened shelter space in the event of an emergency.

The shelters were designed for three levels of overpressure (5, 25 and 50 psi) resulting from a 10 MT burst, and have a minimum protection factor against fallout radiation of 600. The weapons data are given below.[5,6]

Weapon Size 10 MT
Fission: Fusion 100:0

Incident Overpressure, psi (Surface burst)	Peak Normal Reflected Pressure, psi	Range, mi
5	11.5	6.10
25	80.0	2.65
50	200.0	1.88

Shelter structures were designed for the weapon exploding at the surface, while "prompt radiation" calculations were based on an air burst at a critical height as suggested in reference 4. Ground shock was not considered.

An isometric view of the typical shelter is shown in Fig. B.7 with floor plans in Fig. B.8 and B.9. This is a two-story rectangular monolithic reinforced concrete structure with outside dimensions that conform closely to those of the bridge portion in question.[1] Shelter access is by means of a protected entranceway on the side facing the depressed expressway.

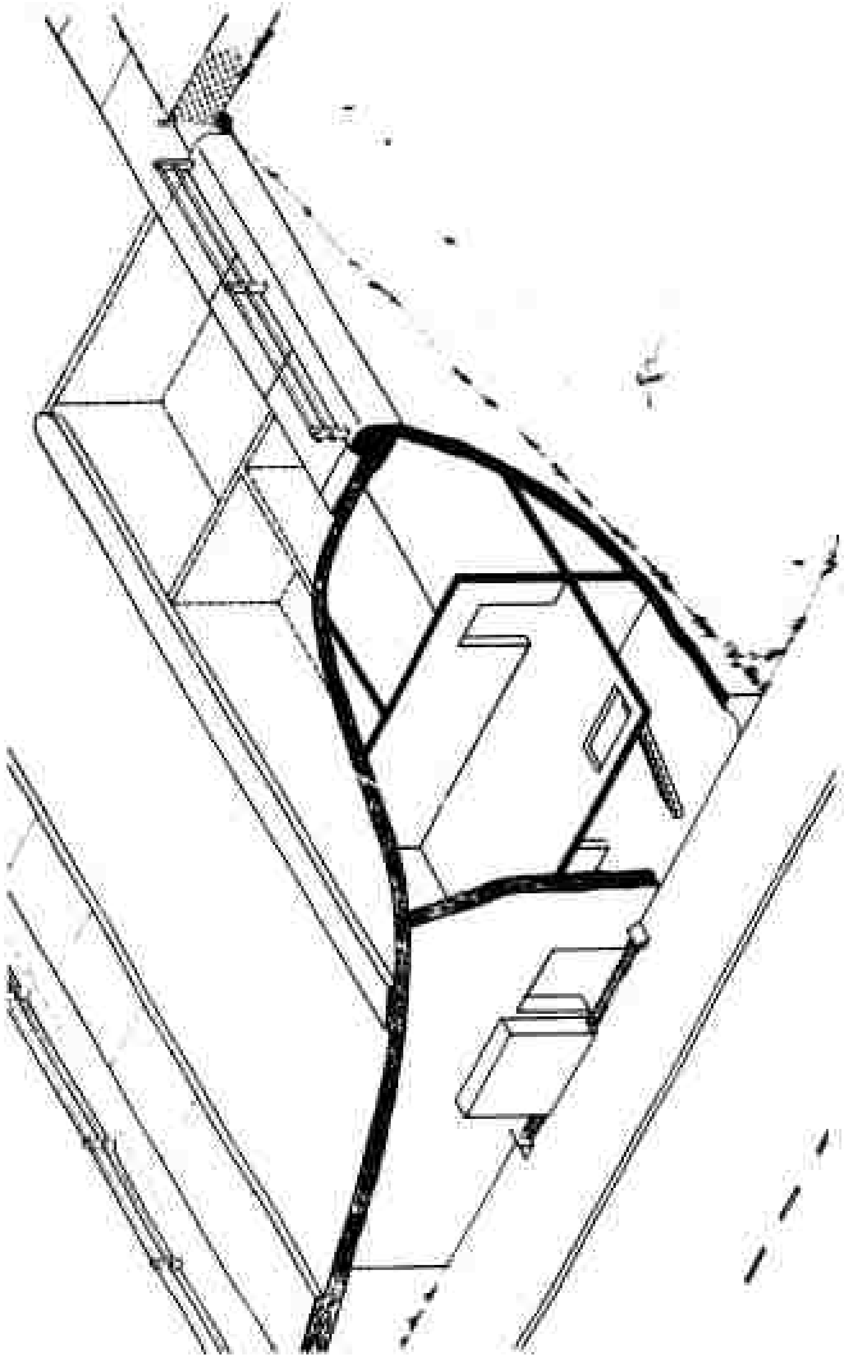


Fig. B.7 CUTAWAY VIEW OF A GRADE SEPARATION PROTECTIVE SHELTER

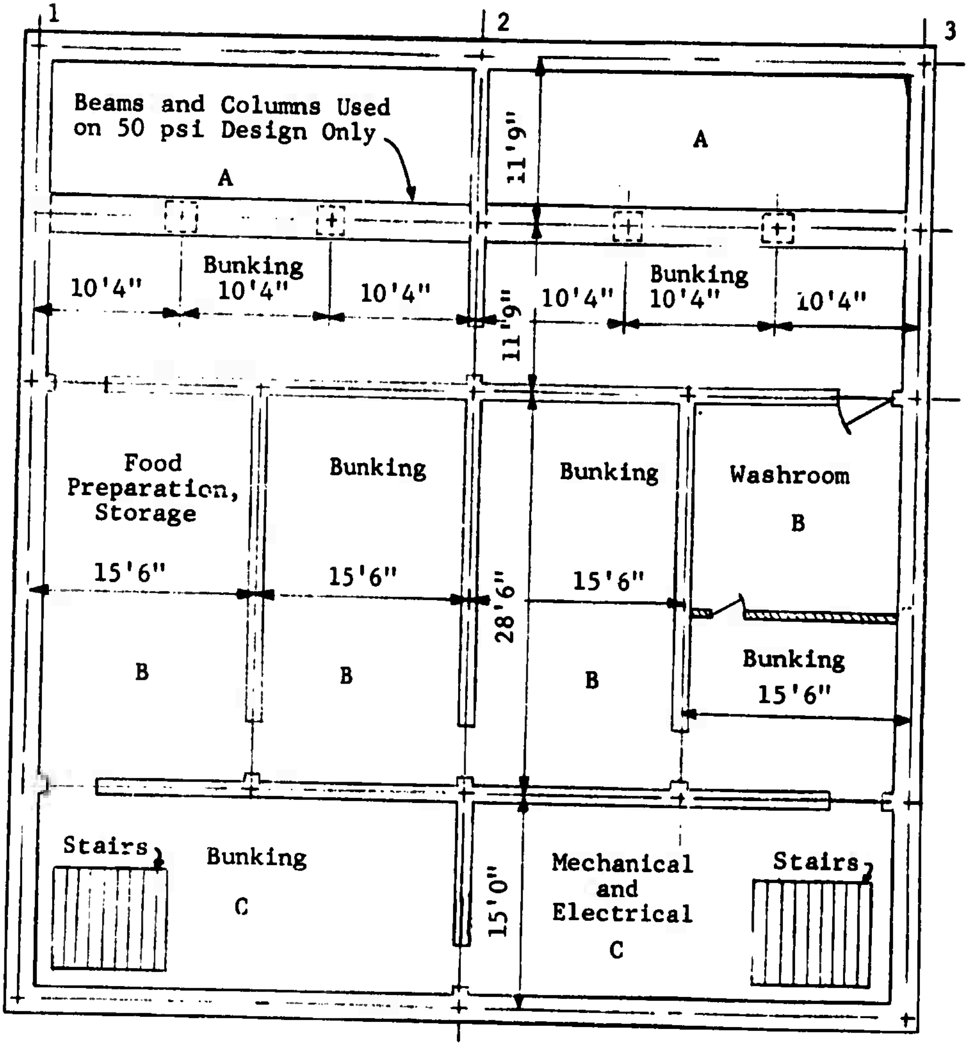


Fig. B.8 UPPER LEVEL FLOOR PLAN

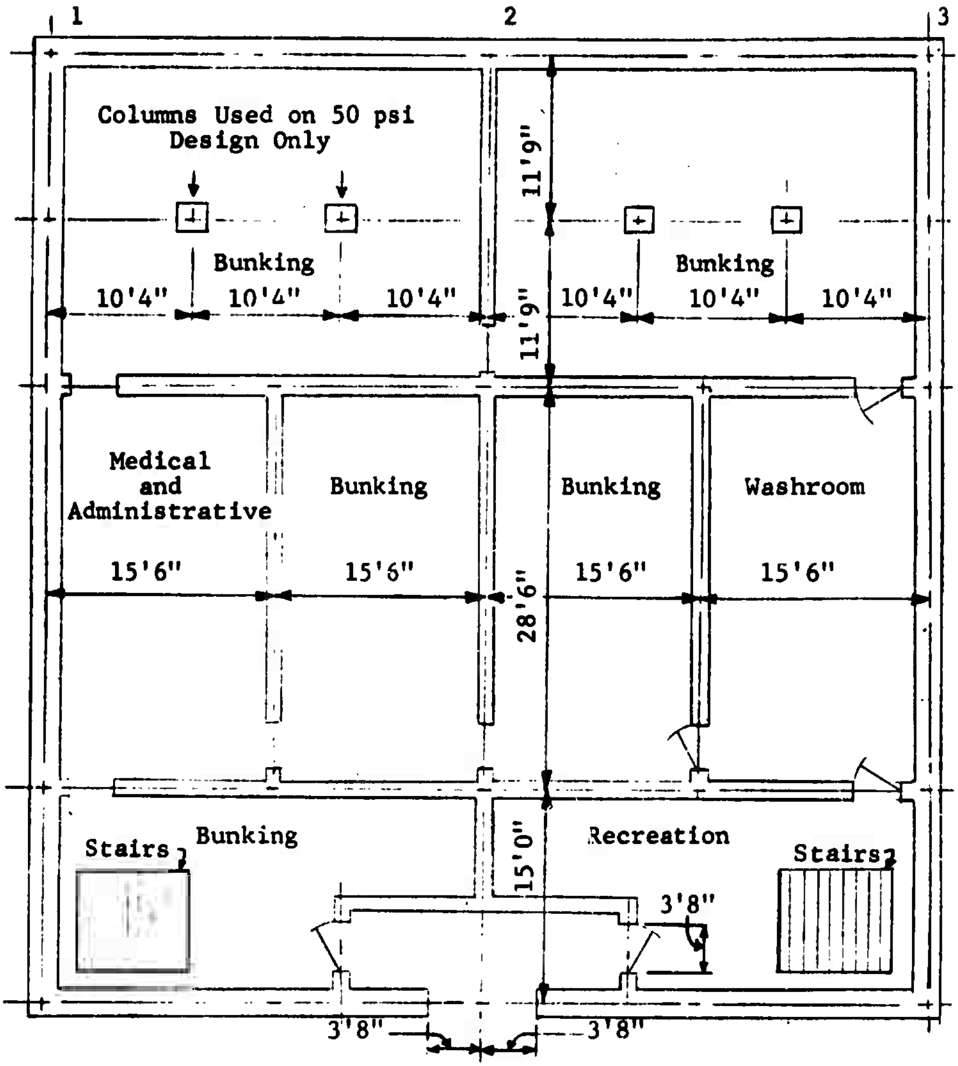


Fig. B.9 LOWER LEVEL FLOOR PLAN

The assumed personnel loading time of 5 min was based on 800 persons. This required an opening of 7 ft 4 in. wide and 8 ft high.[7] The entrance closure is blast and radiation resistant, its movement is facilitated by means of rollers, and it is provided with a latch to resist movement under blast loading. If desirable, an emergency access could be provided in the form of a removable section of the roof slab. This was not considered in the present design.

Structural design was carried out on the basis of ultimate strength with a ductility ratio of 1.3.[8,9] In the case of 5 psi and 25 psi designs, the structure consists entirely of continuous one-way reinforced concrete slabs; while in the case of the 50 psi design, additional supporting members such as beams and columns were found to be necessary. In addition to resisting flexure and axial load, the vertical members also act as shear walls. In all cases the roof slab, which carries vehicular and pedestrian traffic, satisfies the strength requirements of AASHO 1953 specifications. Interior floor slabs (not subject to direct blast pressures) were designed for a uniformly distributed live load of 100 psf with load factors of 1.5 for dead load and 1.8 for live load. Properties of materials considered herein are summarized below.[8]

- Compressive strength of concrete (f'_c) = 4000 psi
- Dynamic compressive strength of concrete $(1.25\ f'_c)$ = 6000 psi
- Dynamic yield strength of reinforcing steel (f_{yd}) = 52,000 psi
- Allowable dynamic soil pressure 8^T/sq ft

Structural component thicknesses for the three shelters are given in the following table.

Table B 1

STRUCTURAL COMPONENT THICKNESSES FOR THREE SHELTERS

Component	5 psi	25 psi	50 psi
Roof Slab			
Section A (Fig. B 8)	18"	22"	20"
Section B	18"	18"	22"
Section C	18"	18"	22"
External Walls			
Sections 1-2, 2-3	10"	12"	14"
All Others	18"	18"	22"
Partitions	6"	6"	6"
Floor Slabs	6"	6"	6"
Columns			15" x 15"
Beam			18.5" x 36"
Footings			
Wall	2'7" x 8"	4'3" x 10"	7'8" x 1'10"
Column			6'0" x [illegible]

Provisions for environmental control have been considered and are summarized as follows:

- Sanitary facilities are provided in accordance to reference 7 and are based on 800 occupants for a period of 14 days.
- It is assumed that no outside utilities will be available in the event of attack. Thus, storage tanks for potable water are provided. Also a motor-generator set is provided to furnish a power source for electric lighting and other electric power requirements.[1] The generator is to be run by a diesel engine drawing fuel from an underground tank

- Ventilation is provided by shelter package ventilation kits with filters.[11] No period of complete closure to the outside is contemplated, thus no internal oxygen supply is considered.

- Lighting is assumed to be provided by public service on ac current until the time of attack, and thereafter by means of a dc generator within the shelter.

All emergency electrical power will be provided by means of a 20 kw generator powered by a 35 hp diesel engine.[10] The diesel engine is provided with a 14-day fuel supply based on continuous use. The 2000 gal of fuel required is stored in an underground tank. The lighting provided is based on a 1-ft candle level in berthing and standing areas, 5 ft candles in exercise and toilet areas, and 15 ft candles in food preparation, reading, and medical attention areas.[7] It is also assumed that the lights will be wired such that they can run on ordinary 115 V 60 cycle ac power when it is available, and dc generator power when ac power is not available.

Sanitary facilities and water for personal consumption are provided according to the recommendations in reference 7 and are summarized below.

Facility	Unit Quantity	Total Provided
Water	28 gal/person	22,400 gal
Toilets	5/100 people	40
Urinals	1/100 people	8

Although medical supplies, food, sleeping accommodations, and communications equipment are not included herein, they may be provided without drastically reducing the assumed (800 persons) capacity.

Ventilation will be supplied by four shelter package ventilation kits.[11] Four of these units will supply a total of the minimum requirements set down.[7] The ventilation unit can ordinarily be run off the generator, but in case there is a power failure, the generators are provided with bicycle drives.

The costs are summarized in Table B.2. In general, these represent average values in the Chicago Metropolitan area for the year 1964. Items included in the mechanical, electrical, and architectural portions are listed in Table B.3.

Table B.2

SUMMARY OF COSTS

Item	5 psi	25 psi	50 psi
Structural and Earthwork	64,800	68,600	83,500
Mechanical	18,300	18,300	18,300
Electrical	10,100	10,100	10,100
Architectural	4,000	4,000	4,300
Cost	97,200	101,000	116,200
Credit for Portions of the Original Structure	-30,300	-30,300	-30,300
Net Cost	66,900	70,700	85,900
Contractor's Profit and Overhead Contingencies (25%)	16,700	17,700	21,500
Final Cost	83,600	88,400	107,400
Gross Floor Area, sq ft	7,725	7,725	7,635
Final Cost per sq ft	$10.82	$11.44	$14.07

Table B.3

ARCHITECTURAL, ELECTRICAL AND MECHANICAL COSTS

Type	Description	Units	Cost dollars	Quantity	Total dollars
Mechanical[7,11,12]	1. Toilet Units	each	250	8	2000
	2. Urinal Trough	each	250	8	2000
	3. Partitions	lot	400	1	400
	4. Preparation of Sanitary Pit	lot	2000	1	2000
	5. Installation, items 1 to 4	lot	1200	1	1200
	6. Potable Water Tank	each	4500	1	4500
	7. Piping	lot	1200	1	1200
	8. Wash Fountains	each	375	10	3750
	9. Ventilation Units	each	305	4	1220
					18,270
Electrical[7,10]	1. Public Hook-Up	lot	75	1	75
	2. Fuse and Switch Box	each	400	1	400
	3. Wiring	lot	1200	1	1200
	4. Light Fixtures	lot	800	1	800
	5. Installation, items 2 to 4	lot	3200	1	3200
	6. Engine Generator Set	each	3690	1	3690
	7. Tank and Fuel for Item 6	lot	760	1	760
					10,125
Architectural[7,12]	1. Stairs	each	440	2	880
	2. Roller Unit for Blast Door	each	2160*	1	2160
	3. Blast Door Latch	each	410**	1	410
	4. Interior Doors	each	82	7	575
					4025

* For 5 and 25 psi only, cost is $2400 for 50 psi.
**For 5 and 25 psi only, cost is $450 for 50 psi.

B.2.2 Structure II

The objective of this section is to determine the approximate cost of incorporating an austere shelter in an expressway structure of the type shown in Fig. B.3, B.4 and B.5. Consider the structure shown in Fig. B.4, the plan and elevation cross sections are shown in Fig. B.10 and B.11 respectively. In order to incorporate a very basic shelter and take maximum advantage of the available space, one approach is to:

- lower the wingwall pile caps (see Fig. B.4),
- provide a retaining wall at the end of the approach slab,
- excavate the soil to a practical elevation and pave the surface,
- reinforce the central pile group which becomes exposed when the soil is removed,
- provide an intermediate floor in order to take advantage of the large available headroom,
- provide stairs and incorporate an entranceway.

This synopsizes the general approach taken in this instance and is illustrated in Fig. B.10 and B.11 (stairs and entranceways are not shown).

The rear retaining wall was designed taking advantage of the rear pile group. The central pile group was encased in concrete, allowing an internal passageway at each end. The intermediate floor was designed as a one-way reinforced concrete slab with stairwell openings (not shown). The lower floor surface is a 6-in. wire mesh-reinforced concrete slab. The resulting incremental shelter costs, as well as other data, (assuming that the task is undertaken in the initial construction stage of the structure) are summarized as follows.

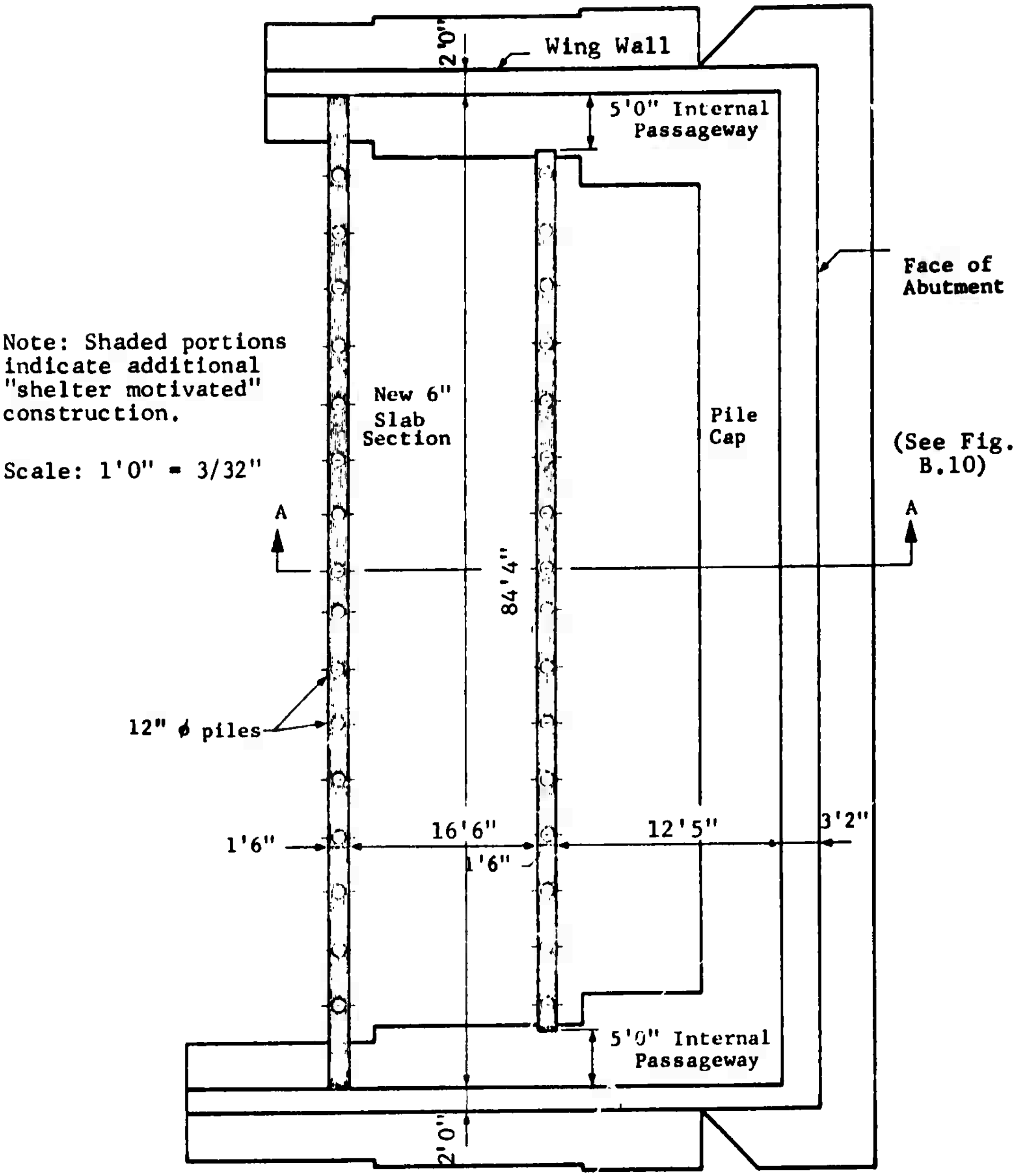


Fig. B.10 PLAN CROSS SECTION THROUGH A CLOSED ABUTMENT

Note: Shaded portions indicate additional "shelter motivated" construction.

Scale: 1'0" = 3/16"

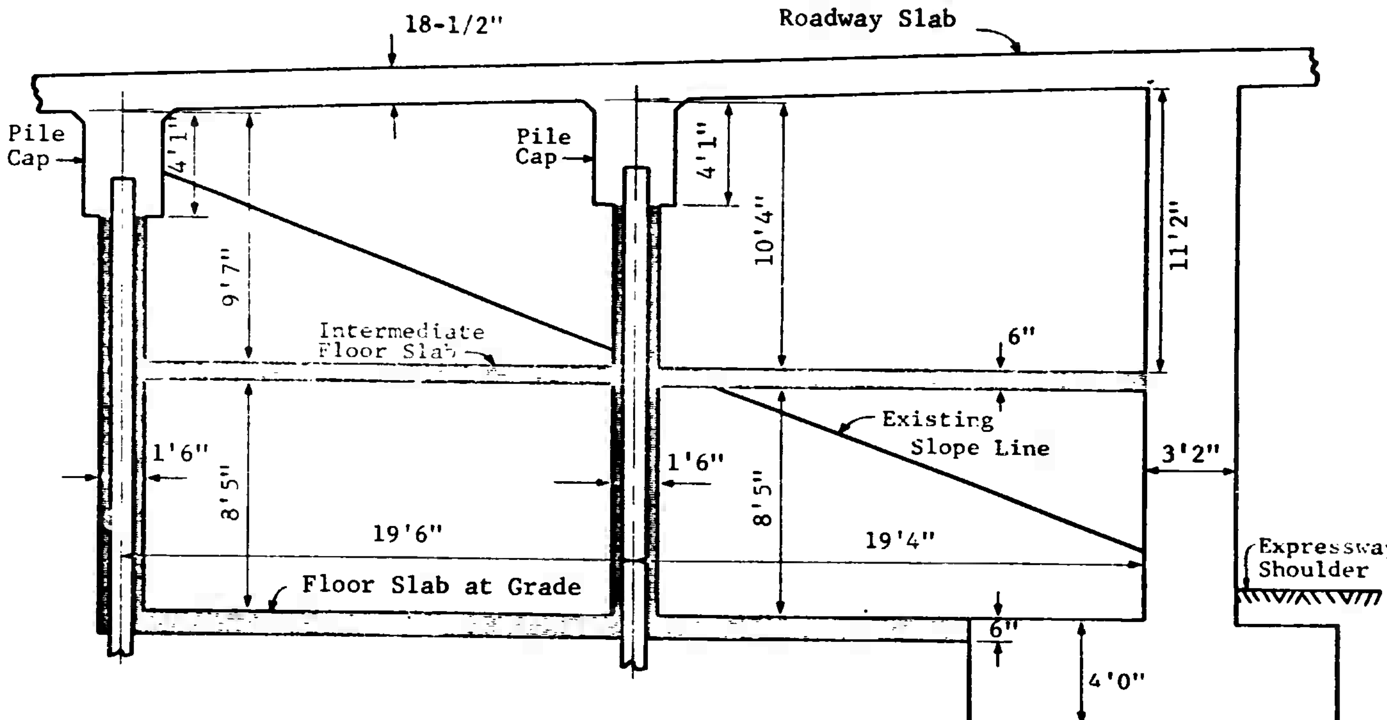


Fig. B.11 SECTION A-A CROSS SECTION THROUGH A CLOSED ABUTMENT

Shelter Area sq ft	Minimum Headroom ft	Shelter Volume cu ft	Fallout P.F. (minimum)	Total Cost Dollars	Cost/ sq ft
5962	1st floor-8'5" 2nd floor-9'7"	56,200	300	22,200	3.72

The costs given are direct contract costs and represent average values in the Chicago Metropolitan area for the year 1964. They include 25 percent for contractors profit and overhead contingencies. These costs may be broken down in the following manner.

Structural and Earthwork	=	\$20,800
Architectural		
Conventional Stairs (two sets)	=	1,100
External Door and Hardware	=	300
Total	=	\$22,200

It must be emphasized that the conceptual approach taken is not necessarily the most economical one, however, it does appear evident that these structures possess a sheltering potential and should be investigated in more detail.

B.3 DISCUSSION

An all-inclusive investigation of the extent of the sheltering potential of expressway grade separations, was beyond the scope of the study reported herein. For this reason, no attempt was made to study vulnerability or to seek an optimum shelter structure within a given set of constraints. The objective, as discussed earlier, was to explore the sheltering potential of these structures in a relatively general sense, i.e., to:

- estimate their construction trends (Appendix A),
- classify the structures generally as far as sheltering utility is concerned as to structural type,

- determine an average shelter space potential for a single typical structure,
- determine the probable cost of incorporating a shelter in a typical grade separation during the construction stage.

In addition to designing and costing a basic shelter capable of resisting all of the major effects of the arbitrarily assumed nuclear weapons environment (blast and associated effects), an attempt was made to provide habitability aspects.

A basic (structure) shelter as defined herein includes:

- enclosing structure,
- internal doors and stairs,
- blast doors and associated hardware.

This definition is sufficiently inclusive as far as protective shelters are concerned and should not be extended to include such items as basic wiring, plumbing and ducts. The definition is, of course, arbitrary and may be subject to some criticism. Ordinarily, in conventional construction a basic structure is one that just fulfills its essential function. However, the expressions "just fulfills" and "essential function" are again subject to definition and for any given function, interpretations may vary considerably even in the same locality. The function of a basic shelter is to provide a "minimum acceptable degree" of protection given a nuclear weapons (design) environment. This warrants some discussion.

If an above grade shelter (without blast doors) is designed to resist a given level of overpressure only, this would seem to imply that for a series of weapon types and sizes exploded individually or in combination (air bursts and/or surface bursts) at specific critical range or ranges with respect to the shelter, the vulnerability of the shelter relative to the blast overpressure is zero percent (or 100 percent survivability). The structure thus survives to an acceptable degree. At the same time, however, even assuming that necessary precautions are taken, the shelter occupants do not experience the same degree of survivability relative to this effect. Also, since the associated effects (prompt nuclear radiation, thermal radiation and subsequent fallout radiation) were not specifically considered, the vulnerability of shelter occupants relative to them is not necessarily zero, and would depend on shelter characteristics as well as the weapons environments. This is demonstrated in graphical form in Fig. B.12, which is a fictitious representation of occupant vulnerability to several weapon sizes in a shelter without blast doors designed for a single nuclear weapons effect; namely, blast overpressure. If such a vulnerability analysis were carried to different overpressure levels for the set of expected weapons, a possible combined overpressure vulnerability plot is shown in Fig. B.13. The discussion only serves to illustrate that what constitutes a basic shelter will depend on the expected environment as well as on the physical well-being of the group being sheltered. For the shelter concepts discussed herein, the costs of the basic shelter as defined earlier are given in Fig. B.14. This graph also contains total costs including the costs of the basic structure and also that of environmental control equipment and supplies. These items and costs are given in Table B.3, and although the items are not necessarily the least expensive or the most efficient in their class, they convey a rough idea of the cost of habitability for a two week stay.

In terms of structures with "closed abutments" investigation of their potential was limited. It is evident that the sheltering potential of closed abutment structures is greater than that of the ones discussed earlier and should be pursued further.

The idea of incorporating shelters in highway structures is not new. As an idea it was briefly discussed in a Life magazine article (Jan. 12, 1962) and again in reference 13. However, it does not seem to have been investigated in the detail that this concept deserves. Pertinent data for the two investigated structures are summarized in Table B.4.

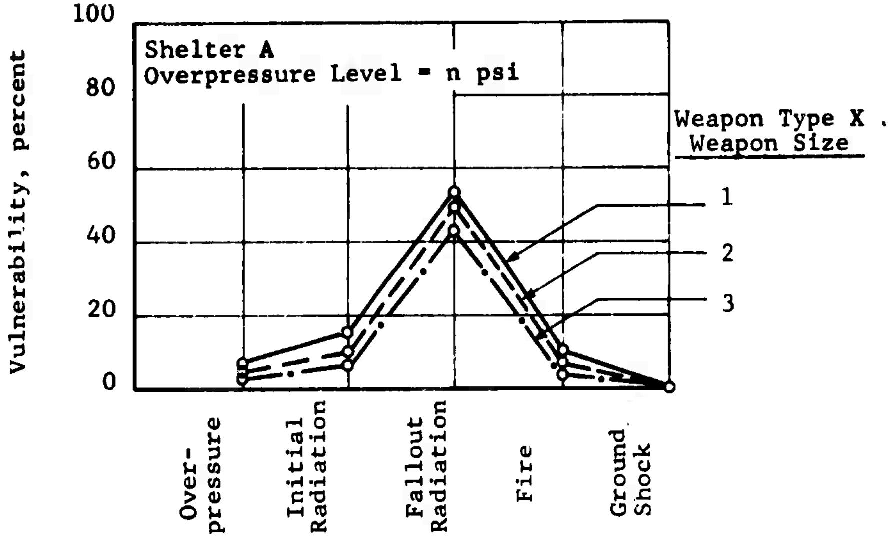


Fig. B.12 VARIATION OF VULNERABILITY FOR A GIVEN OVER-PRESSURE LEVEL WITH WEAPON SIZE

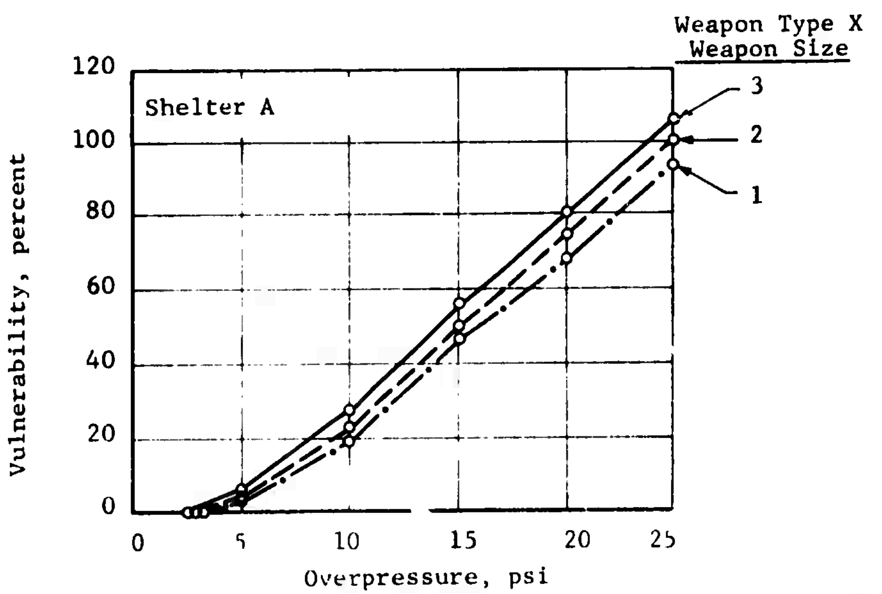


Fig. B.13 VARIATION OF COMBINED VULNERABILITY WITH OVERPRESSU

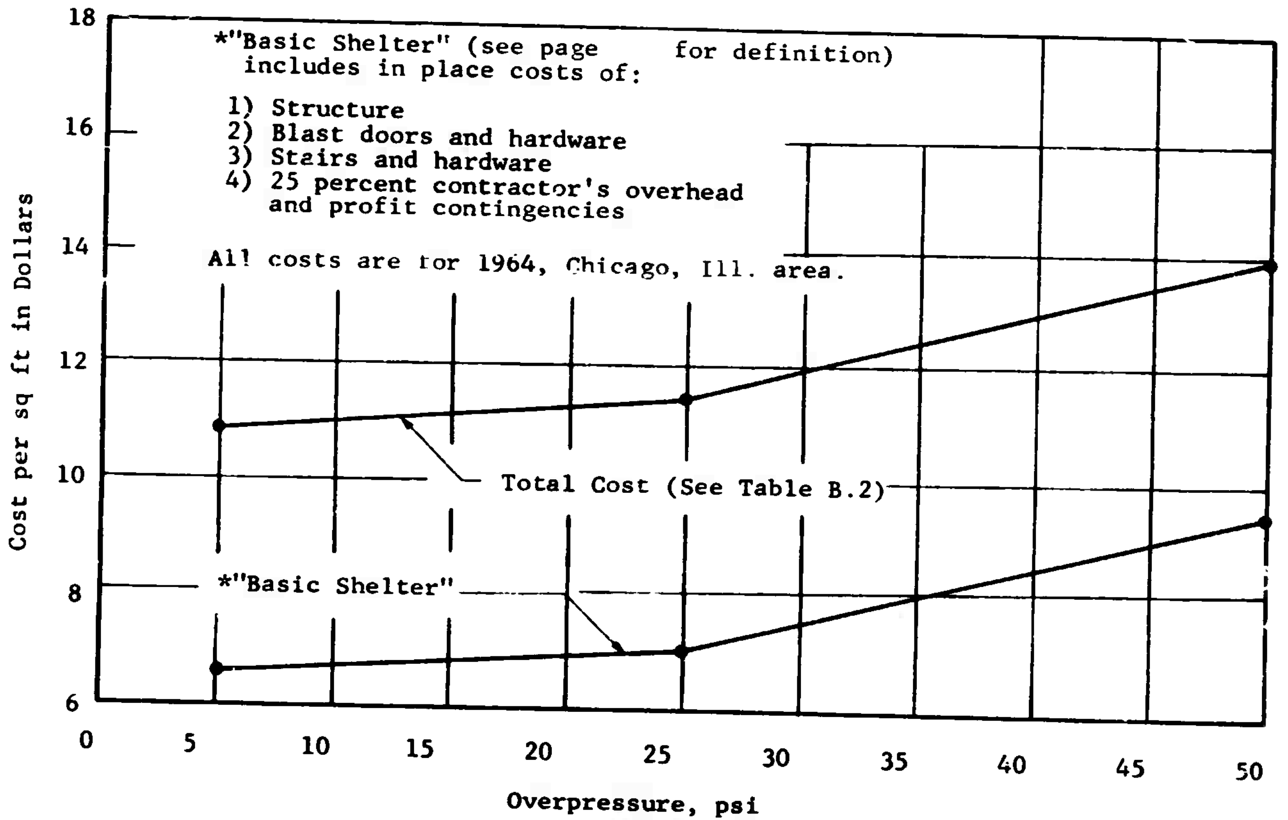


Fig. B.14 VARIATION OF SHELTER COST WITH OVERPRESSURE (Expressway Grade Separation Shelters, Structure I)

Table B.4

EXPRESSWAY GRADE SEPARATION PROTECTIVE SHELTERS (Conceptual Study)

Structure	Type and Materials of Construction	Shelter Location, above or below grade	Shelter Area, gross sq ft	Minimum Headroom ft	Shelter Volume gross cu ft	Shelter** Capacity, number of persons	Fallout P.F.	Incident Overpressure Resistance psi	Shelter Cost (See Table B.2, Fig. B.14) Total dollars	Per sq ft of Shelter, dollars	**Basic Shelter
Structure I 5 psi design	R/C one way slabs	Partially above grade	7725	1st Floor 9.3 2nd Floor 9.0	70,600	800	600	5	83,600	10.82	6.24
Structure I 25 psi design	R/C one way slabs	Partially above grade	7725	1st Floor 9.3 2nd Floor 9.0	70,600	800	600	25	88,400	11.44	6.85
Structure I 50 psi design	R/C one way slab	Partially above grade	7635	1st Floor 9.3 2nd Floor 7.8	69,900	800	600	50	107,400	14.07	9.41
Structure II fallout protection design	R/C one way slabs	Partially above grade	5962	1st Floor 8.4 2nd Floor 9.6	5962	600	300	N/A	22,200	3.72	N/A

R/C Reinforced Concrete

N/A Not applicable

* Shelter capacity is based on 10 sq ft per shelter occupant. Costs are average values for 1964 in the area of Chicago, Illinois. Contractor's profit and overhead contingencies was taken at 25 percent.

** The "Basic Shelter" as defined herein includes in-place costs of:

- enclosing structure
- internal doors and stairs
- blast doors and associated hardware
- 25 percent for Contractor's profit and overhead contingencies.

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APPENDIX C

DUAL-USE PERSONNEL SHELTERS
COST ESTIMATING AND COST REPORTING

C.1 INTRODUCTION

From the material presented and discussed in the foregoing chapters of this report, it is evident that a significant amount of effort has been expended in studying the feasibility of dual-use shelters. It is also evident that costs constitute an extremely important parametric area and basis for comparison.

In the area of conventional structures, no single unifying procedure for estimating costs exists at this time. This is due to the fact that factors that influence building costs are numerous and vary locally in their effects. Costs are strongly influenced by locality, climate, time of the year bids are taken, rigidity in building codes, construction labor practices, interest rates, etc. Variables are many and in performing a cost estimate it is important to know what they are and how they vary in significance relative to the local conditions.

Although no single universal cost estimating approach is available, many acceptable methods resulting from long experience in dealing with costs exist. A contractor in any area of construction, if he is to be successful, will develop an estimating procedure capable of comparing the costs of his buildings. Such a procedure would reflect all significant cost influencing factors typical of his locality and would allow him to make an estimate - opinion - judgment. His buildings would thus have a common basis and cost estimates, even if approximate, are possible.

The Office of Civil Defense has been and is now engaged in studying the feasibility of dual-use shelter systems. Work has been performed by numerous organizations in different parts of the country over the past several years. A large number of conventional structures have been considered for this purpose. Shelters to be included in them have been designed, evaluated and costed. The costing aspect, however, in most cases lacks the uniformity and completeness necessary for a meaningful cost comparison. In this area of investigation, matters would be greatly facilitated if the utility of any shelter could be reflected by means of its cost.

Shelter cost estimating on a country-wide basis is extremely complex, however if acceptable data capable of comparison is to arise from this area of investigation, it is important to adapt at least a format whereby costs may be grouped and identified. A procedure for estimating shelter costs has been presented in reference 2* and if adapted should prove useful. This procedure is lengthy and is not discussed herein.

The objective of this appendix is to discuss some of the more important general aspects of cost estimating, list several sources of cost data, present a format for grouping contract costs and a procedure for reporting shelter costs for dual-use shelters.

*The references for Appendix C appear at the end of the section.

C.2 COST ESTIMATING

Cost estimates may be divided into at least two different categories, depending on the purpose for which they are intended, i.e., approximate and detailed. These two categories may be subdivided further.

For certain purposes the use of approximate (shortcut) procedures is wholly justified. This is especially true in the preliminary (planning) stages of a project. At such a time the structural designer may reduce a typical unit of a structure to square feet of area or cubic feet of volume and determine the cost thereof.

In order to obtain a dependable estimate of this type, a great deal of experience and sound judgment are required. The estimator must be able to adjust the various unit costs in order to allow for variations resulting from construction difficulties, qualities of material, workmanship, etc. As far as formal bids are concerned, this category of estimate is not sufficiently accurate.

A detailed cost estimate on the other hand is prepared by combining in detail and in some prescribed order all the cost contributing items.

In preparing a detailed cost estimate it is advisable for the estimator to follow the various operations in the same sequence that will be followed on the actual project. Thus in the case of a protective shelter the first direct cost may be site clearance. This item would be followed by the cost of moving in, excavation, forming, framing and thus continuing in sequence through the last operation performed, which may be site cleanup. The following of such a sequence would result in a check list of operations which may then be used in summarizing direct project costs. A check list of direct project costs on a shelter project may evolve to have the form shown in Table C.1.

Table C.1

SEQUENTIAL ITEMIZATION OF DIRECT PROJECT COSTS

Item	Amount	Unit Cost	Total Cost
1. Site Clearance			
2. Temporary construction: office, storage sheds, etc.			
3. Excavation, grading, backfill, special fill			
4. Foundation support: piles, caissons, cribs			
5. Shoring, sheeting: temporary and permanent			
6. Underpinning: temporary and permanent			
7. Drains, sewers, conduits			
8. Concrete forms: wood, metal			
9. Reinforcing rods and mesh			
10. Concrete			
11. Structural steel			
12. Air intake and exhaust pipes			
13. Water and damp-proofing			
14. Calking			
15. Interior panel, stair and door work			
16. Plumbing and fitting			
17 Sprinkler system (decontamination)			
18 Electrical wiring			
19. Electrical fixtures			
20. Heating and ventilating			
21 Tanks			
22. Toilets			
23 Blast doors			
24. Special equipment not otherwise listed			
25. Special interior fixtures			
26. Landscape: leveling, sodding, planting			
27. Total direct cost			

The final format of a cost estimate is of course arbitrary, however for the purposes of comparing costs of protective shelters developed by different contractors, a great deal of time and effort may be saved if some arbitrary, flexible but standard format is adhered to by all concerned. For this reason the following format and breakdown are suggested.

C.2.1 Breakdown of Project Cost

I COST OF LAND

II COST OF SITE PREPARATION

A. Clearance of existing structures
B. Unusual site preparation
C. Temporary construction
   1. office
   2. storage shed
   3. temporary road
   4. landscaping, etc.

III CONSTRUCTION COST

A. Earthwork and structural
B. Architectural
C. Mechanical
D. Electrical
E. Contractor's overhead and profit

IV FEES AND TAXES

A. Architect and engineer fees
B. Legal fees
C. Taxes and interest
D. Owner's insurance

This cost breakdown is by no means unique, and with several variations in grouping is widely used.

Having completed a cost estimate, it is of benefit, for purposes of comparison, to list sources of cost data. Several such sources which are in general use are given in the following paragraphs.

C.2.2 Sources of Cost Data

The following sources of periodically published and updated cost data have been found to be reliable and are in popular use at this time. Several others are given in the list of references at the close of this appendix.

(a) "Building Construction Cost Data", Published and compiled annually by Robert Snow Means Co. Engineers and Estimators, P. O. Box 36, Duxbury, Mass.

This publication provides average unit prices on a wide variety of building construction items for use in making up engineering cost estimates. The book is primarily aimed at industrial and commerical buildings costing $50,000 and up or large housing projects. The costs are for new construction of complete buildings rather than repairs or minor alterations. Material costs are primarily for metropolitan areas. Overhead and profit contingencies are discussed, and recommended percentages are given.

(b) "Engineering News-Record" Quarterly Cost Round-up, McGraw-Hill Publishing Co., Hightstown, N.J.

This publication includes both Construction and Building Cost Indexes which have been designed to measure the effects of wage rates and material price trends.

(c) "Military Construction Pricing Guide", Air Force Pamphlet No. 88-088 - 1 and 2, Department of the Air Force, Washington, D.C. (Annual Publication).

This publication contains average prices intended to be used for reviewing and preparing cost estimates for planning and programming construction. Prices represent those prevailing in Washington, D.C. and are assigned a location factor of 1.00. Factors for other geographic areas are indicated.

There are numerous other sources of cost data, many of which are given in references 1 and 2 . Several of these are given in the list of references at the end of this appendix.

C.3 PROCEDURE FOR REPORTING DUAL-USE SHELTER COSTS

One of the conclusions reached in the course of this study is that it would simplify analysis and cost comparisons in the area of dual-use shelters if a standard cost data reporting procedure were adapted. One such procedure is presented herein and illustrated by means of a hypothetical example.

The structure in question is a rural school to be constructed and which is to contain a low overpressure type blast resistant shelter (fallout and direct effects). The school described is assumed to be in its planning stage and the costs are thus of the "preliminary" type. The final cost may be less or more depending on conditions prevailing during the construction period.

DUAL-USE SHELTER SUMMARY
(Description and Costs)

I. PARENT STRUCTURE

Building J.E.B. STEWART ELEMENTARY SCHOOL

Address 14 W. Brighton St. City, Town Oakton State ILL.

Year Constructed Construction planned for summer 1967

Type of Community: (✓) Residential ✓ Industrial ____

Urban ____ Suburban ____ Rural ✓

GENERAL DESCRIPTION

A. Primary Function: Educational facility for elementary school grades 1 through 8.

B. Construction Type: (✓)

1) Wood Frame ____
2) Masonry Bearing ____
3) Concrete Frame ✓
4) Steel Frame ____
5) Tilt Up ____
6) ____
7) ____

C. Roof: (✓)

1) Asph and Gravel ____
2) Tar and Gravel ____
3) Tile ____
4) Finished Deck ✓
5) ____
6) ____

D. Exterior Walls: (✓)

1) Concrete ______

2) Concrete Masonry ______

3) Brick ✓

4) Cut Stone ______

5) ______

6) ______

E. Number of Floors Above Grade 2

F. Basement: Yes ✓ No ______

1) Number of Levels 1

2) Area per Level (sq ft) 4140

3) Percent Finished 100

4) Materials and Type of Construction Reinforced concrete, one and two-way slabs, no columns.

G. Fire Protection

	No.
1) Fire Alarm	1
2) Fire Escape	1
3) Fire Pump	
4) Hose Racks	
5) Hydrants	
6) Extinguishers	6
7) Sprinklers	
Dry System	
Wet System	
8) Fire Doors	2
9)	
10)	

H. Building Occupancy (Number of Persons) 340 including students, faculty and maintenance personnel.

I. Building Area - Gross (Based on Inside Dimensions) sq ft 12,420

J. Building Volume - Gross cu ft 8(12,420)=99,360

II. SHELTER

A. Type of Protection Provided: (✓)

1) Fallout ______

2) Fallout and Direct Effects ✓

B. Design Weapons Environment

1) Weapon
type (fussion-fission) not considered
size 1 to 20 MT

2) Design Level of Free Field Incident Overpressure (psi) 5

3) Fallout: 10,000 r/hr initial dose rate of delayed nuclear radiation, 1 hr after detonation.

4) Thermal Radiation: 15 cal/sq cm

5) Assumed External Fire Environment (explain)

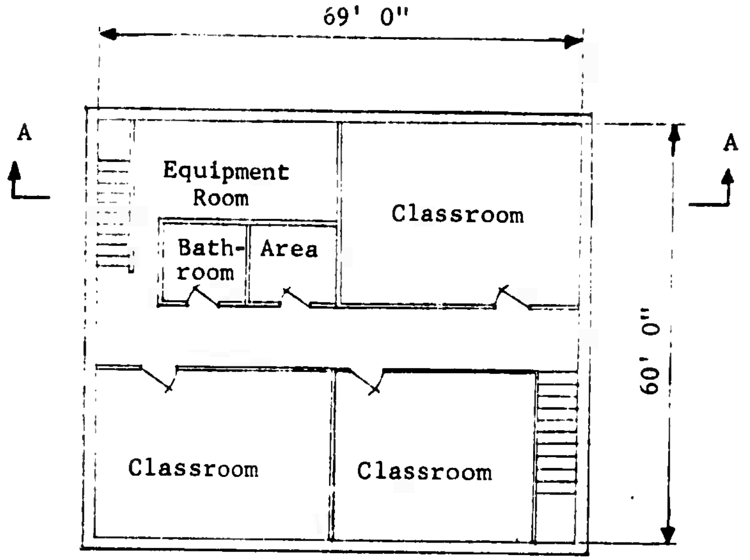
The building is to be located in a relatively isolated area. The danger of fires external to shelter is considered to be minimal.

C. Shelter Location: (✓) (Provide Plan View) See Fig. C.1

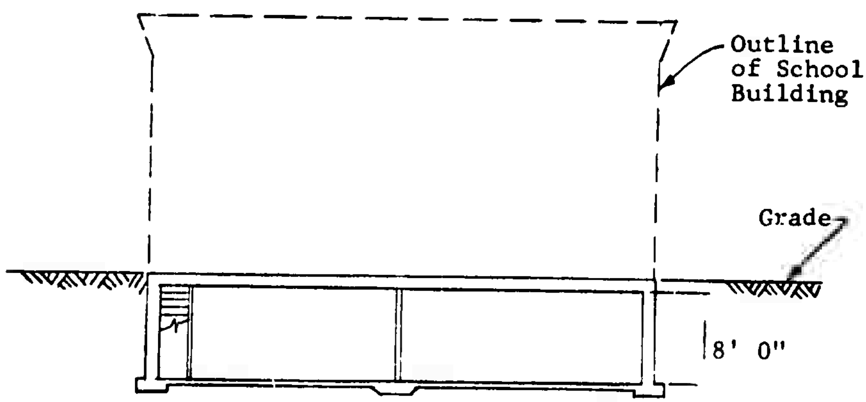
1) Above Grade ______

2) Below Grade Basement Area

3) Above and Below Grade ____



a) Dual-Use Basement Shelter, Plan



b) Section A-A

Fig. C.1 DUAL-USE SCHOOL AND SHELTER

D. Shelter Size - Gross (Based on Inside Dimensions)

1) Area (sq ft) 4140

2) Headroom (ft) 8.5

3) Volume (cu ft) 35,190

4) Capacity 414 persons

based on 10 sq ft per person.

E. Construction Materials and Structural Members

1) Shelter Roof Continuous reinforced concrete two-way slab, 10-in. thick.

2) External Walls Continuous reinforced concrete one-way slab, 10-in. thick.

3) Interior Walls, Columns or Partitions 8-in. cinder block partitions.

4) Foundation Continuous reinforced concrete wall footings, 1 ft 10 in wide.

5) Entranceways Reinforced concrete doors on structural steel frames.

number 2

size 3 ft 0 in. x 6 ft 8 in.

F. Design Properties of Construction Materials

1) Concrete, f'_c (psi) 3000

compression, (axial or flexural) (psi) $1.25\ f'_c$

pure shear (psi) $0.15\ f'_c$

allowable bond (psi) $0.15\ f'_c$

diagonal tension (psi) reference 1

2) Reinforcement (psi) 78,000

3) Structural Steel

tension (flexural) (psi) 60,000

compression (flexural) (psi) 60,000

4) Allowable Soil Bearing Pressure (tons/sq ft)

static	4
dynamic	8

G. Foundation Conditions

1) Soil Classification (Identify System Used)

Sandy clay (no detailed classification available).

2) Pertinent Soil Water Characteristics

Water table is below the basement slab. There is little seasonal variation in its location.

H. Summary of Shelter Aspects Considered in Addition to Basic Structure and Entranceways

1) Sanitary Facilities	
2) Heating	
3) Air Conditioning	
4) Ventilation	✓
5) Water Supply	
6) Medical Supplies	
7) Bunks	
8) Decontamination Facilities	
9) Communication Equipment	
10) Food	
11)	
12)	

BASE COSTS

(Parent structure and shelter.)

	Cost dollars	Unit Cost sq ft	Unit Cost cu ft	Percent of Total Cost
1. Structure and Earthwork	110,000	8.86	1.11	61.6
2. Architectural	23,900	1.92	0.24	13.4
3. Mechanical				
Heating and Ventilation	9,450	0.76	0.10	5.3
Plumbing	9,900	0.80	0.10	5.5
4. Electrical	8,470	0.67	0.08	4.7
Total without shelter	161,670	13.01	1.63	90.5
Total	178,570	14.37	1.80	100.0

In addition to contract costs, the above estimate includes the costs of the following equipment:

- Heating and Vencilating
- Gas fired forced air, unit heater distribution. Central duct system.
- Plumbing
- Lavatories, two showers, two drinking fountains, nine center closets, six urinals, four sinks, one service sink, gas fired water heater.
- Electrical
- Transformer, 110-120 v AC in rigid conduit. Incandescent and flourescent lighting.
- Costs are based on bids received in October 1966 for the region indicated and include contractor's profit and overhead contingencies.

SUMMARY OF SHELTER COST

(Cost increments over and above the cost of parent structure.)

	Cost dollars	Unit Cost			Percent of Total Shelter Cost
		ft.	ft	person	
1. Structure Earthwork	13,500	3.26	0.38	32.60	79.80
2. Architectural	560	0.14	0.02	1.40	3.30
3. Mechanical	1,980	0.48	0.06	4.80	11.70
4. Electrical	880	0.21	0.03	2.10	5.20

Items Included in the Above Costs

Item	Cost
1. Concrete Reinforcement Blast Doors	8,750.00 4,250.00 500.00
2. Toilet Partitions	560.00
3. Additional Plumbing Two shelter package utilization kits (MIL-V-40645)	1,802.00 88.85 (each)
4. Additional wiring and switches	880.00

REFERENCES

1. Building Cost Manual, John Wiley and Sons, Inc., New York, 1957.

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13 ABSTRACT

The effort reported herein is concerned with civilian dual-use personnel shelters. Its primary objectives are: 1) to determine for nuclear weapons environments other than fallout radiation alone, the extent of the economic advantages of dual-use shelter systems with respect to expected percent of population thus sheltered. 2) To bring into sharper focus those areas in which more research or analysis is necessary in order to increase the effectiveness of this sheltering concept. Topics supplementary to the above objectives include: estimated construction trends in selected types of construction, a limited study on the use of expressway grade separations as dual-use shelters, and cost estimating and cost reporting as applied to dual-use shelters. Results of this effort dealing with a large number of existing related topics are contained in this report. These results are in the form of assembled and updated costs as well as physical and environmental data and conclusions.