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Final Report *November 1971*

PROBABILISTIC AIR BLAST FAILURE CRITERIA FOR URBAN STRUCTURES

Prepared for:

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

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OCD Work Unit 1154F

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This report is one of a series covering research of a continuing nature in the evaluation of the air blast resistance of existing structures under sponsorship of the Office of Civil Defense, Department of the Army.

The objective of the work was to apply probabilistic techniques to estimates of air blast failure criteria for a cross section of urban building types and their components, such buildings and components possessing a wide variability among types and within types.

The problem to be solved is one of describing the strength variability and the form of its distribution function for the various building types and their components in the light of almost complete absence of experimental evidence, particularly exposure to high yield weapons.

The approach used is based on an analogy of the Program Evaluation and Review Technique (PERT) method of establishing the frequency distribution of completion times for work elements. In the PERT application, experienced judgment is used to establish most likely, optimistic, and pessimistic completion times. An approximate beta distribution function is defined from these three values from which a range of probabilities of completion time may be calculated. The application of the technique to the present problem uses the best available experienced judgment to establish the most likely, lowest reasonable, and highest reasonable failure criteria for a given structural type or component. A beta distribution function is constructed from these values, and other probabilities are calculated therefrom by either manual or computer methods.

Results are presented in graphic form for each of 17 structural types of interest and their components.

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Final Report *November 1971*

Detachable Summary

PROBABILISTIC AIR BLAST FAILURE CRITERIA FOR URBAN STRUCTURES

By: E. E. PICKERING
J. L. BOCKHOLT
Facilities and Housing Research

Prepared for:

OFFICE OF CIVIL DEFENSE
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SUMMARY

Background

Civil defense planners require reliable criteria for the estimation of nuclear weapons air blast damage to a wide variety of urban structures for use in strike damage analyses, damage limiting studies, shelter cost effectiveness studies and for other purposes. Such criteria, to be of maximum use, should be available in numerical probabilistic form.

Currently, available structural damage information is limited to (1) generalized information, (2) structural damage criteria prepared for offensive planning purposes, (3) reports of full scale experiments involving exposure of very limited structural types to low yield weapons, and (4) laboratory and analytical work relating to specific structural designs. Because of the very wide variability of strengths of existing structures and components within a given defined type, the available information is considered to be severely limited, particularly from a probabilistic standpoint.

Objective

The objectives of this work were: (1) to develop a probabilistic system of describing the variability of structural failure criteria as functions of nuclear explosion air blast parameters, (2) to construct a preliminary set of air blast failure criteria distribution functions for a cross section of urban structural types and components, and (3) to present failure criteria probability statements, derived from the distribution functions, in a readily usable numerical form for use by civil defense planners.

An associated objective was to develop definitions of failure for building components and complete buildings which are meaningful for civil defense casualty estimation, physical damage estimation and recovery planning.

Failure Variability

Many factors serve to produce a relatively wide variability in the free field air blast environment at which a given structural type will collapse or fail. The factors include:

Structural Variability

Apparent identical structures will exhibit a wide range of resistance to air blast loads due to design differences, differences in material strengths, age, quality of workmanship, previous loading experience, etc.

Air Blast Loading Variability

Considerable variabilities also exist in the air blast loading experienced by similar structures located at equal distances from a nuclear explosion but in different atmospheric, topographical, and urban environments. The variations of size, shape, and degree of openings also cause variabilities in loading. The yield of an explosion also affects loading at given air blast parameter locations.

Failure Definitions

The concept of failure utilized herein is one of "incipient failure or collapse" which signifies that a structure or component has been loaded just to the point where it will fail or collapse without further additions of load. Occupants of the various structures are expected to undergo substantial translation, to be subject to impact of high-velocity debris, collapsing structural components and other processes resulting in a high degree of casualties.

Probabilistic Concept

In order to develop structural failure criteria in probabilistic form for the population of a given structural type, it was first necessary to determine the form of the statistical distribution as a function of an air blast parameter for the range of structural strengths represented by the structural type as defined.

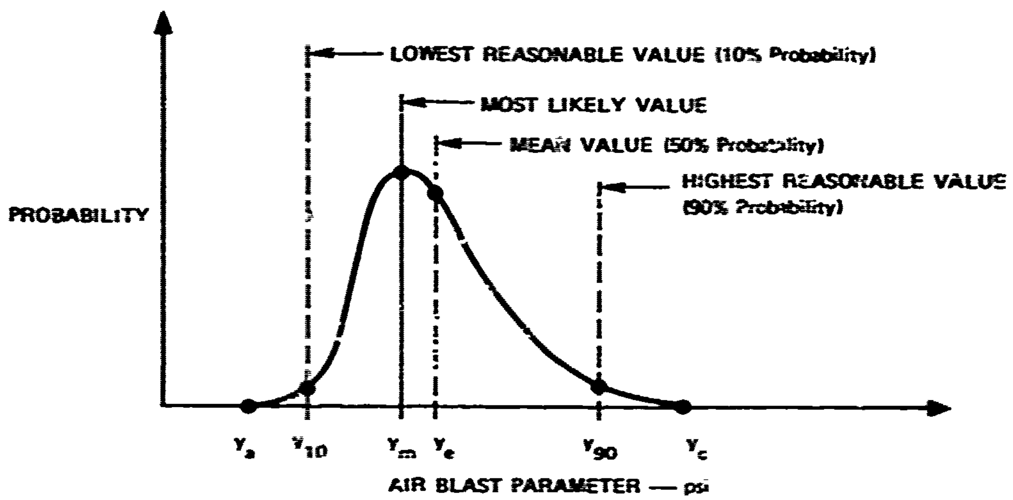
Since very little empirical evidence is available to support the determination of forms of distribution by regular statistical methods, a subjective method was developed. This method is analogous to that used in the Program Evaluation and Review Technique (PERT), where experienced judgment is used to estimate the most likely, optimistic and pessimistic times (or costs, or resources) for accomplishment of tasks for which past experience is lacking. In the present application, experienced judgment is utilized to determine the most likely, highest reasonable, and lowest reasonable value of the air blast parameter causing failure, taking into account all of the pertinent variabilities. The three values are used to develop the approximate form of the distribution as illustrated in Figure S-1.

The form of distribution developed from the above process is of the approximate Beta type which possesses considerable flexibility as regards skewness, peakedness, etc.

Through utilization of the mathematical characteristics of the Beta distribution it becomes possible to describe the range of probabilities of failure as functions of an air blast parameter. The main report illustrates this process in detail and presents manual and computerized methods.

Air Blast Parameters

Since some structures (diffraction sensitive) are primarily sensitive to the overpressure characteristic of the blast wave, some (drag sensitive) to the dynamic pressure, and others to combinations, there



APPROXIMATE EXPECTED MEAN VALUE = $y_e = \frac{y_a + 4y_m + y_c}{6}$ (3)

APPROXIMATE STANDARD DEVIATION = $\sigma_{y_e} = \frac{y_c - y_a}{6}$ (4)

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FIGURE S1 DISTRIBUTION FUNCTION FOR FAILURE CRITERIA

can be no one air blast parameter that will serve as a unique measure for the establishment of failure criteria.

The concept followed herein is to use peak free field air blast overpressure as an index measure. The "index free field peak overpressure" is that overpressure where the defined degree of failure occurs even though failure may result from dynamic pressure forces or from combinations of overpressure and dynamic pressure forces.

Air blast parameter charts for a 5 megaton surface burst and for a 5 megaton air burst at 14,500 feet height of burst have been furnished for ready conversion of air blast parameter values to distance from the burst.

Building Types Considered

It was necessary to establish a relatively limited set of structural types which are representative of all structures of interest to civil defense planners. The types to be evaluated were developed in coordination with OCD staff and include:

TYPE	DESCRIPTION
1	Single-story frame residence with or without basement.
2	Single-story masonry, load-bearing wall residence with or without basement.
3	Two- or three-story frame single residences, row houses, apartments, and motels with or without basements.
4	Two- or three-story masonry, load-bearing wall single residences, row houses, apartments, and motels with or without basements.
5	Mixed one- and two-story "store front" and light commercial masonry, load-bearing wall buildings.
6	Mixed two- to four-story commercial, residential, and office, masonry, load-bearing wall buildings.
7	Multistory, steel frame apartment buildings, four to ten stories. Light and heavy wall covering variations.
8	Multistory, reinforced concrete frame apartment buildings, four to ten stories. Light and heavy wall covering variations.
9	Multistory, steel frame office and institutional buildings, four to ten stories. Light and heavy wall covering variations.
10	Multistory, reinforced concrete frame office and institutional buildings, four to ten stories. Light and heavy wall covering variations.
11	Tall steel frame office buildings, more than ten stories. Light and heavy wall covering variations.
12	Tall reinforced concrete frame office buildings, more than ten stories. Light and heavy wall covering variations.
13	One-story masonry, load-bearing wall school and institutional buildings.
14	Monumental masonry buildings, two to five stories, with and without frames.

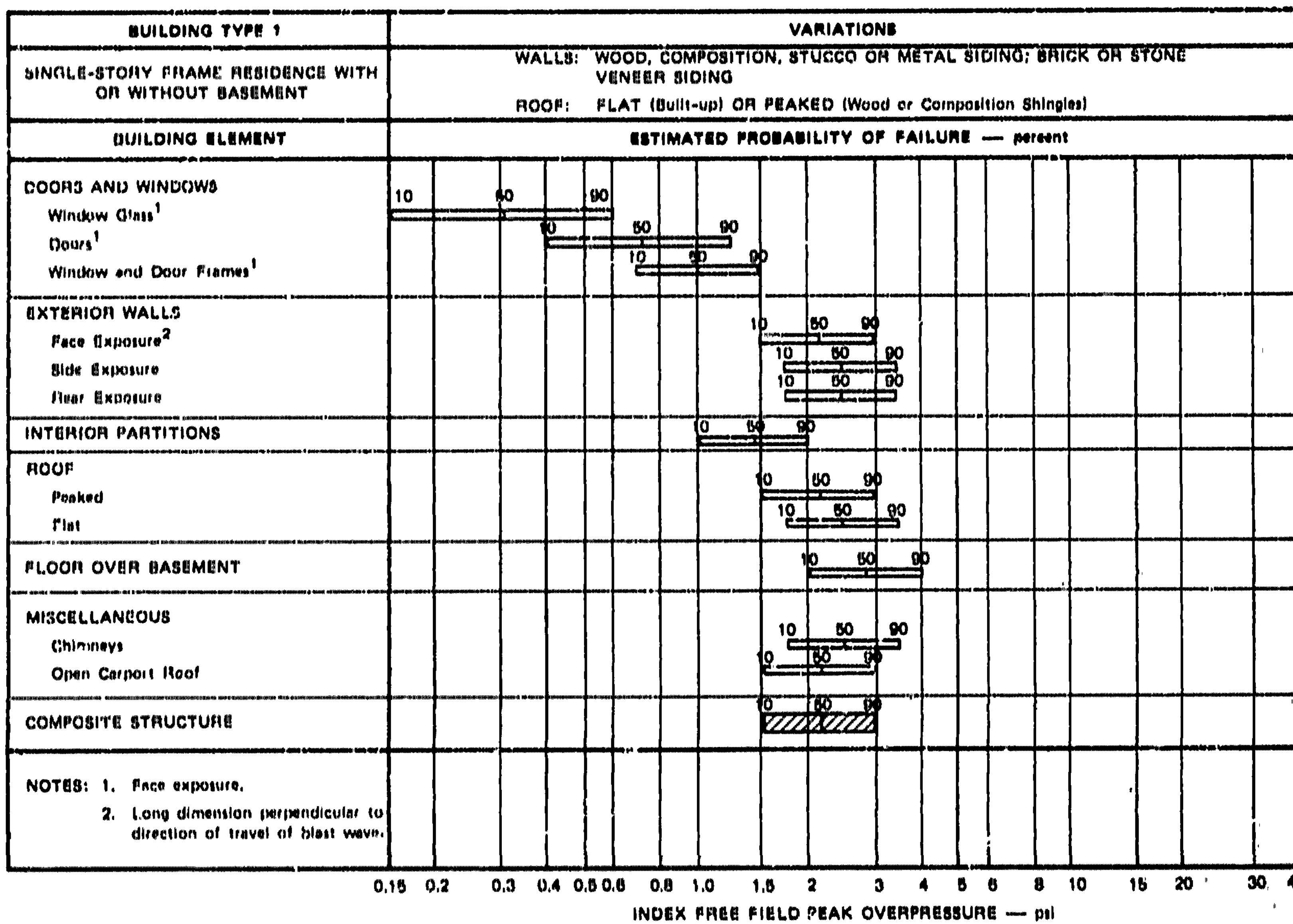
TYPE	DESCRIPTION
15	Masonry, load-bearing wall industrial buildings, one-story.
16	Light steel frame industrial buildings, one-story.
17	Heavy steel frame industrial buildings, one-story.

For each of the building types listed, complete descriptions have been prepared and are presented in the main report. Definitions of failure for the components of each type and for the composite structure are also presented.

Probability of Failure Estimating Charts

A separate Estimated Probability of Failure chart was prepared for each of the building types listed previously. The charts permit the estimating of the probability of failure of a component or the composite structure at a given index overpressure value, or conversely, the index overpressure value can be determined for a given probability of failure.

A representative chart appears hereafter.


BUILDING TYPE 1
VARIATIONS
SINGLE-STORY FRAME RESIDENCE WITH OR WITHOUT BASEMENT
WALLS: WOOD, COMPOSITION, STUCCO OR METAL SIDING; BRICK OR STONE VENEER SIDING
ROOF: FLAT (Built-up) OR PEAKED (Wood or Composition Shingles)
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Window and Door Frames[1]
EXTERIOR WALLS
Face Exposure[2]
Side Exposure
Rear Exposure
INTERIOR PARTITIONS
ROOF
Peaked
Flat
FLOOR OVER BASEMENT
MISCELLANEOUS
Chimneys
Open Carport Roof
COMPOSITE STRUCTURE
NOTES: 1. Face exposure.
2. Long dimension perpendicular to direction of travel of blast wave.
10
50
90
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD PEAK OVERPRESSURE — psi

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The problem to be solved is one of describing the strength variability and the form of its distribution function for the various building types and their components in the light of almost complete absence of experimental evidence, particularly exposure to high yield weapons.

The approach used is based on an analogy of the Program Evaluation and Review Technique (PERT) method of establishing the frequency distribution of completion times for work elements. In the PERT application, experienced judgment is used to establish most likely, optimistic, and pessimistic completion times. An approximate beta distribution function is defined from these three values from which a range of probabilities of completion time may be calculated. The application of the technique to the present problem uses the best available experienced judgment to establish the most likely, lowest reasonable, and highest reasonable

failure c· .·a for a given structural type or component. A beta distribution function is constructed from these values, and other probabilities are calculated therefrom by either manual or computer methods.

Results are presented in graphic form for each of 17 structural types of interest and their components.

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CONTENTS

ILLUSTRATIONS

I INTRODUCTION

Background

Civil defense planners require reliable criteria for the estimation of nuclear weapons air blast damage to a wide variety of structures for use in strike damage analyses, damage limiting studies, shelter cost-effectiveness studies and numerous other purposes. As the nature of such studies becomes more and more complex and as they incorporate sophisticated electronic computer processes, it becomes imperative that the soundest possible damage criteria be available in numerical form.

Structural damage information for civil defense planners is limited essentially to the following sources, all of which have limitations for civil defense planning use:

1. Generalized structural damage information as contained in "The Effects of Nuclear Weapons."[1*] Structural damage data contained in this document are limited[†] by the types of structures covered, by the lack of variability information from which numerical probability-of-damage relationships can be derived, and by the weakness of experimental evidence, particularly from high-yield weapons.

2. Structural damage criteria prepared for offensive planning purposes. Such criteria necessarily tend to provide for a high probability of damage to ensure attainment of damage objectives.

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* Superscripts refer to numbered references contained in Appendix A, References.

† This is not to say the the "Effects of Nuclear Weapons" is not a useful document. On the contrary, it is an extremely comprehensive and useful document for general civil defense planning purposes.

3. Reports of full scale experiments in which a few structural types were exposed to low-yield explosions.

4. Results of laboratory experiments and analytical work relating to a limited number of building types and components.

An associated problem is in the area of definition of damage or failure. offensive planners are generally interested in total destruction of structural targets to provide assurance against functional use, whereas civil defense planners are more interested in determining the threshold of structural failure and the effect on occupants.

The classes of structures of primary interest to civil defense planners are those associated with people, including structures in which people live and work. They also include structures in which people are expected to take shelter under threat of nuclear attack. This latter category relates primarily to the designated shelter structures of the National Fallout Shelter Survey (NFSS). Since the major portion of the population of the United States is located in urban areas, a cross section of urban structures ranging from the single family residence of suburbia to the high-rise commercial and office buildings of central business districts must be evaluated.

Although most structures are designed in accordance with building codes, there remains a wide variability in both static and dynamic strengths of given structural types and components. The variabilities result from many factors including load assumptions, design methods, basic variabilities in the strength of construction materials, workmanship, age of structures, and other factors.

The development of precise descriptions of the variability of failure criteria for given structural types and compon s would require a statistical quantity of structures exposed to actual nuclear blast situations. Obviously, this situation will not result and reliance must therefore be placed on the information that is available, no matter how limited, including:

1. Information from the Nagasaki and Hiroshima events.

2. Data from limited exposure of a few building types and components in planned nuclear weapon experiments.

3. Laboratory scale experiments.

4. Analytical work.

However, these sources of failure criteria have severe limitations in application to present problems, for example:

1. The Nagasaki and Hiroshima events involved low yield weapons against nontypical targets compared with U.S. urban areas.

2. Nuclear test exposures have been limited to a few structural types, and they have mostly been exposed to low yield explosions.

3. Laboratory scale experiments have been limited to model structures, or at the maximum scale, to structural components.

4. Analytical work has for the most part been limited to deterministic solutions for individual structural designs.*

In view of the limited experimental and analytical evidence, the development of probability estimates must rely on a subjective approach using the judgment of engineers experienced in nuclear air blast damage experiments and analysis to establish the range of failure criteria and to develop numerical failure probabilities through use of simplified statistical techniques.

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* At the present time, another portion of this program is concerned with the development of analytical procedures to predict the collapse of structures from air blast of nuclear weapons.

Objectives

The objectives of this work are to:

1. Develop a probabilistic system of describing the variability of structural failure criteria as functions of nuclear explosion air blast parameters.

2. Construct a preliminary set of air blast failure criteria distribution functions for a cross section of urban building types and components.

3. Present failure criteria probability statements derived from such distribution functions in a readily usable numerical form for use by civil defense planners.

In meeting the above objectives, it is necessary to establish definitions of failure that are meaningful in terms of civil defense casualty estimation, physical damage estimation, and recovery planning. Also, it is necessary to establish a relatively limited set of structural types that will be representative of all structures of interest to civil defense planners.

A limiting objective, or constraint, is that the above objectives are to be met with available information and without resort to additional analytical or experimental structural failure analysis. As a result, the criteria presented must be considered to be of a preliminary nature, subject to refinement on further study.

Scope of Work

The research work performed under this project consisted of the following substantive items:

1. Identification, selection, and description of a cross section of urban building types of interest to civil defense planners and investigators.

2. Review of the air blast structural damage literature and assembly of failure criteria information as a function of air blast parameters.

3. Review of practical statistical methods and development of a method for describing the variability and distribution functions of air blast failure criteria for structural components and systems.

4. Development of a system of numerical presentation of probabilistic estimates of failure criteria for selected structures and components.

5. Establishment of judgments of the range and most likely values of air blast failure criteria and, based on these judgments, development of failure criteria distribution functions.

6. Presentation of data for each building type and component in the format developed under 4 above.

7. Preparation and presentation, in readily usable form, of a set of air blast parameter data as a function of ground distance to serve as a basis for conversion of damage criteria from an air blast parameter base to a distance base.

Method of Approach

Structural types to be included in the analysis were selected after discussions with OCD staff and a review of a cross section of the NFSS list and other urban structural types. An attempt was made to include a general cross section of all urban types with the highest degree of association with people.

Structural damage criteria were developed for each structural type and component through a system including the following steps:

1. Review of the literature pertaining to the structure or component of interest.*

* Representative sources are indicated by references 6 through 18 in Appendix A.

2. Development of preliminary values of failure criteria and variability.

3. Review of preliminary values by associated engineers possessing comprehensive and extensive experience in nuclear air blast structural analysis and full scale structural test design and evaluation.

4. Adoption of reported values through discussions among authors and reviewers.

A concept entitled "Index Free Field Overpressure" was used to present the air blast variable in a uniform manner in cases where drag loading was either contributing or dominant.

The system describing variability and probability of failure criteria was based on approximate methods used in the Program Evaluation and Review Technique (PERT).[2] A more rigorous procedure was developed to describe the beta distribution function characteristics to account for unbalanced (skewed) distributions. Both manual and computer analytical systems were developed and presented.

A simplified, uniform system of graphical presentation of probability of failure criteria was developed to include major building components and a composite type for each structure.

Descriptions of each building type, its variations, and its components were developed and presented for the guidance of users.

The most up-to-date air blast parameter data were obtained, and a graphic system that is easy to use was developed for presentation. Data were presented for a 5-Mt surface burst and a 5-Mt air burst at 14,500 ft height of burst.

Acknowledgments

The work reported in this document was performed in the Facilities Engineering Group of Stanford Research Institute. H. L. Murphy and Carl K. Wiehle, senior civil engineers, reviewed the preliminary criteria and took part in the judgments leading to reported values. John R. Rempel, physicist, prepared the air blast parameter charts in Appendix C.

The work was initiated and monitored by N. E. Landdeck, N. A. Meador, and G. N. Sisson of the Research Directorate, Office of Civil Defense, whose guidance and assistance are appreciated.

II FAILURE VARIABILITY AND FAILURE DEFINITIONS

Introduction

Apparent identical structures will exhibit a wide range of resistance to both static and dynamic loading. This range of variability results from many factors including variability in the strength of component materials, the quality of workmanship, small differences in design, foundation differences, and previous loading experience. Age, design loads and criteria, and alteration history also produce widely ranging variables for populations of given structural types.

In the case of loading resulting from nuclear air blast, an additional set of variables is present. This set includes the yield of the explosion, the orientation of the structure to the direction of the blast wave, topography, proximity to other structures, and the nature of the structure itself.

In combination, the foregoing sets of variables produce a situation in which a given structural type or component will exhibit a considerable range of failure criteria as related to air blast parameters.

Structural Variability

Basic structural materials possess inherent variability in strength as variously defined (elastic limit, yield point, rupture). Metallic materials such as structural steel are generally relatively narrow in variability, with concrete, wood, and masonry exhibiting considerably wider strength characteristics.

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The basic variability of strength of structural materials is further affected by the variability resulting from the construction process. Potential strengths are strongly affected by the degree of attention paid to proper construction practices. Typical practices adversely affecting the strength of construction materials include:

1. Excess water in concrete.
2. Failure to consolidate concrete properly.
3. Failure to cure concrete properly.
4. Use of poorer quality timber than specified.
5. Failure to nail timber members properly.
6. Gross reduction of timber sections by the electrical and mechanical trades.
7. Lack of proper penetration in welding structural steel members.
8. Lack of proper steel placement in reinforced concrete.

Failures of structures from conventional loads are not common, however, since design methods include a sufficient factor of safety to offset the variabilities of basic materials and the construction process. On the other hand, the population of a given structural type could exhibit a wide range of failure criteria if loaded to the ultimate by conventional methods.

An additional set of variables results from the design process. Different designers use different methods resulting in selections of different structural systems. The behavior of bolted or riveted joints will be different from that of welded joints. Different static load assumptions will produce different structural member sizes. A considerable amount of design is based on readily available stock materials, thus a stock member that is barely adequate in one case may be substantially stronger than necessary in another.

Building codes also have a strong influence on design and loading, and allowable stress criteria vary widely among various codes. In some areas, special loading conditions (e.g., lateral loading from earthquakes and hurricanes) are specified in building codes. This results in stronger buildings than those elsewhere.

Air Blast Loading Variability

The variabilities included in air blast loading are of three general types: (1) those associated with basic air blast phenomena; (2) those resulting from the structural environment; and (3) those caused by the size, shape, and configuration of the structure.

Air Blast Variabilities

For an explosion of the given yield, many factors affect the value of an air blast parameter observed at a given distance. Together these factors can result in a rather wide variability. They include:

1. Meteorological conditions.
2. Ground surface conditions
3. Topography.
4. Height of explosion above ground.

Structure Environment Variabilities

The immediate environment of a structure has a definite effect on the air blast. Variabilities may be caused by:

1. Other structures in close proximity.
2. Topographic features in the vicinity.

Structure Configuration Variabilities

The structural loading resulting from a given air blast wave depends strongly on the characteristics of the structure itself and its configurations. Variabilities result from:

1. Orientation of the structure to the direction of the blast wave.

2. Variations in openings (doors and windows).

3. Strength of wall coverings (strong wall coverings will translate heavier loadings to frame members).

4. Interior contents.

Yield Considerations

The yield of the explosion influences the relationship between the value of peak overpressure/peak dynamic pressure and the duration of the blast wave. The higher the yield the longer the duration for a given value of peak ovepressure or peak dynamic pressure. This factor is of considerable importance in the failure criteria of certain structures that are termed "drag sensitive" (i.e., affected by the drag or dynamic pressure feature of the blast wave).

Summary of Variability Considerations

The foregoing discussion of the several sets of variabilities may be summarized as being a situation of a highly variable blast wave producing highly variable loading on a structure with highly variable strength. The situation requires a probabilistic approach to air blast structural vulnerability programs such as that presented herein.

Failure Definitions

As stated in the introduction, different definitions of structural failure are used by different investigators depending on their interests. The concept of failure used herein for both structural components and composite structures is related to civil defense problems of injury and death and to the problems of reconstruction. The concept of "incipient failure or collapse" is used which means that a structure or component has been loaded just to the point where it will fail or collapse without further additions of load. Occupants of the structures are expected to undergo substantial translation and to be subject to impact of high velocity debris, collapsing structural components, and other processes resulting in a high degree of casualties.

The concept also implies that a structure that has "failed" is damaged to the point where repair is either impossible or grossly uneconomical. In another view, reconstruction, if attempted, would be essentially on a "brick-by-brick" basis.

This concept is also reflected in the definitions of failure contained in the narrative material for each building type.

III PROBABILISTIC BASIS OF ESTIMATES

Introduction

Although there are large uncertainties and variables, civil defense planners must be provided with the most accurate failure criteria prediction method available. To be of value, this information should also be presented in probability distribution form as a function of some air blast parameter. These circumstances require that the most experienced judgment be used, taking into account the analytical and empirical data available.

The situation is similar to that facing managers of complex new enterprises who must make predictions as to activity duration (or costs or required efforts) and to determine the probability of achieving those predictions. Under PERT,[2] most likely, optimistic, and pessimistic times (or costs or efforts) are established by judgment based on experience. Ordinarily, the most likely value is considered to be the mode, and the optimistic and pessimistic values are assumed to have probabilities of 1% and 99%, respectively. It is necessary to assume a probability distribution function since no information exists as to the actual form of the function. The three time (or cost or effort) values (most likely, optimistic, and pessimistic) are used to establish the approximate form of the distribution function and from this, other approximate parameters (mean, standard deviation, and variance) can be calculated.

The probability distribution function that results in the PERT situation is of an approximate beta form. The features of this distribution as it applies to the PERT process are illustrated in Figure 1.

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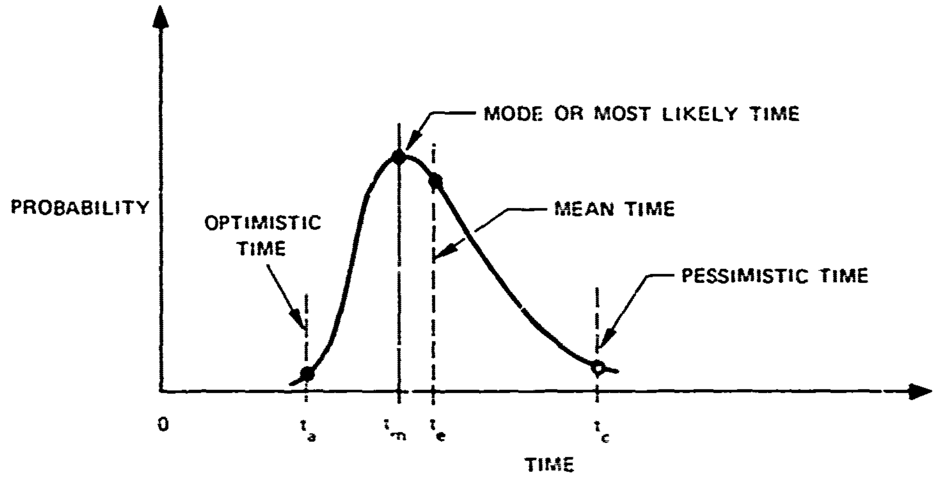

APPROXIMATE EXPECTED MEAN TIME $= t_e = \dfrac{t_a + 4_m + t_c}{6}$ (1)

APPROXIMATE STANDARD DEVIATION $= \sigma_{t_e} = \dfrac{t_c - t_a}{6}$ (2)

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FIGURE 1 PERT PROBABILITY DISTRIBUTION FUNCTION

In the PERT process, other probability values (in addition to the 1%, median, and 99% are calculated under the assumption that the distribution is normal. In the case of structural failure, it is known that distributions are more likely to be skewed mean to the right or left of the mode), and the assumption of a normal distribution for calculation of other probability values is not realistic. Also, with the normal distribution, low and high probabilities approach infinity, whereas the beta distribution possesses discrete end points related more to the structural failure situation. It is therefore advantageous to apply the characteristics of the beta distribution to the present problem.

In applying the PERT-beta distribution analogy to the present problem of failure criteria prediction, the fundamental features of the former system can be retained with some change in nomenclature and notation. These changes include:

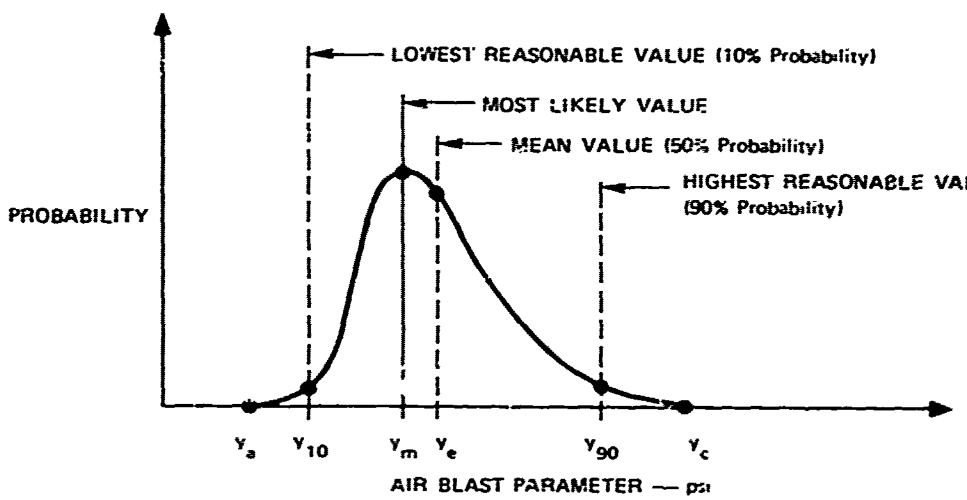
1. The <u>Most Likely Time</u> becomes the <u>Most Likely Value</u> (y_m) for incipient failure based on judgment and analytical and experimental evidence.

2. The <u>Optimistic Time</u> becomes the <u>Lowest Reasonable Value</u> (y_a) for incipient failure.

3. The <u>Pessimistic Time</u> becomes the <u>Highest Reasonable Value</u> (y_c) for incipient failure.

In the probability of failure case, it is more useful to establish values corresponding to probabilities of failure of 10% (y_{10}) and 90% (y_{90}) for the lowest and highest reasonable values rather than the usual 1% and 99% used in the PERT process, since the latter values are more difficult to establish in the absence of empirical evidence.

The distribution function as it applies to the probability of failure case will then appear as shown in Figure 2.



APPROXIMATE EXPECTED MEAN VALUE = $y_e = \dfrac{y_a + 4y_m + y_c}{6}$ * (3)

APPROXIMATE STANDARD DEVIATION = $\sigma_{y_e} = \dfrac{y_c - y_a}{6}$ (4)

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* Not used in the following analysis

FIGURE 2 DISTRIBUTION FUNCTION FOR FAILURE CRITERIA

Development of Beta Distribution Function Parameters

Although the approximate beta distribution function analysis is a useful tool, it possesses some limitations and a more rigorous system is desirable. Such a system is developed in the paragraphs below.

The approximate beta distribution process discussed earlier does not consider discrete end points and thus differs from a true beta function, which possesses such points. In the discussion that follows, y_a and y_c refer to the 0% and the 100% end points, and y_{10} and y_{90} refer to the probabilities at the lowest and highest reasonable failure criteria values, respectively.

The beta distribution is generally defined in the range 0 to 1. However, it can be generalized to the range y_a to y_c by normalizing the variable y to

$$y_o = \frac{y - y_a}{y_c - y_a} . \qquad (5)$$

The beta distribution on the range y_a to y_c is now given by the density function

$$f(y_o) = \frac{1}{\beta}\left(\frac{y - y_a}{y_c - y_a}\right)^{r-1}\left(1 - \frac{y - y_a}{y_c - y_a}\right)^{t-r-1}$$

or

$$f(y_o) = \frac{1}{\beta(y_c - y_a)^{t-2}} (y - y_a)^{r-1}(y_c - y)^{t-r-1} \qquad (6)$$

where β (known as the beta function) is given by

$$\beta = \frac{\Gamma(r)\Gamma(t - r)}{\Gamma(t)} \quad , \quad \text{where } \Gamma \text{ is the gamma function} \tag{7a}$$

If t and r are integers, this reduces to

$$\beta = \frac{(r - 1)!(t - r - 1)!}{(t - 1)!} \tag{7b}$$

As can be seen, four parameters are required to define the beta function—lower and upper end points y_a and y_c and shape parameters r and t. Three of these parameters can be derived from the values of y_{10}, y_{90}, and y_m. However, this still leaves the value of the fourth parameter undefined. One approach to this problem, and the one used herein, is to select the value of the fourth parameter arbitrarily. For this study, the value of t was selected by judgment as

$$t = 8 \quad . \tag{8}$$

The value of the parameter t essentially controls the concentration of the beta distribution about the mode, i.e., the higher the value of t, the more concentrated, or peaked, the distribution becomes. The selected value of t = 8 represents a moderate concentration of the distribution about the mode.

Values of the ratios $(y_m - y_{10})/(y_{90} - y_{10})$ determined from standard tables of the beta distribution function are plotted in Figure 3 for t = 8 and values of r from 1.5 to 6.5. This figure can be used to find the value of the parameter r by entering the chart at the bottom with the value of the $(y_m - y_{10})/(y_{90} - y_{10})$ and reading the corresponding value of r along the side.

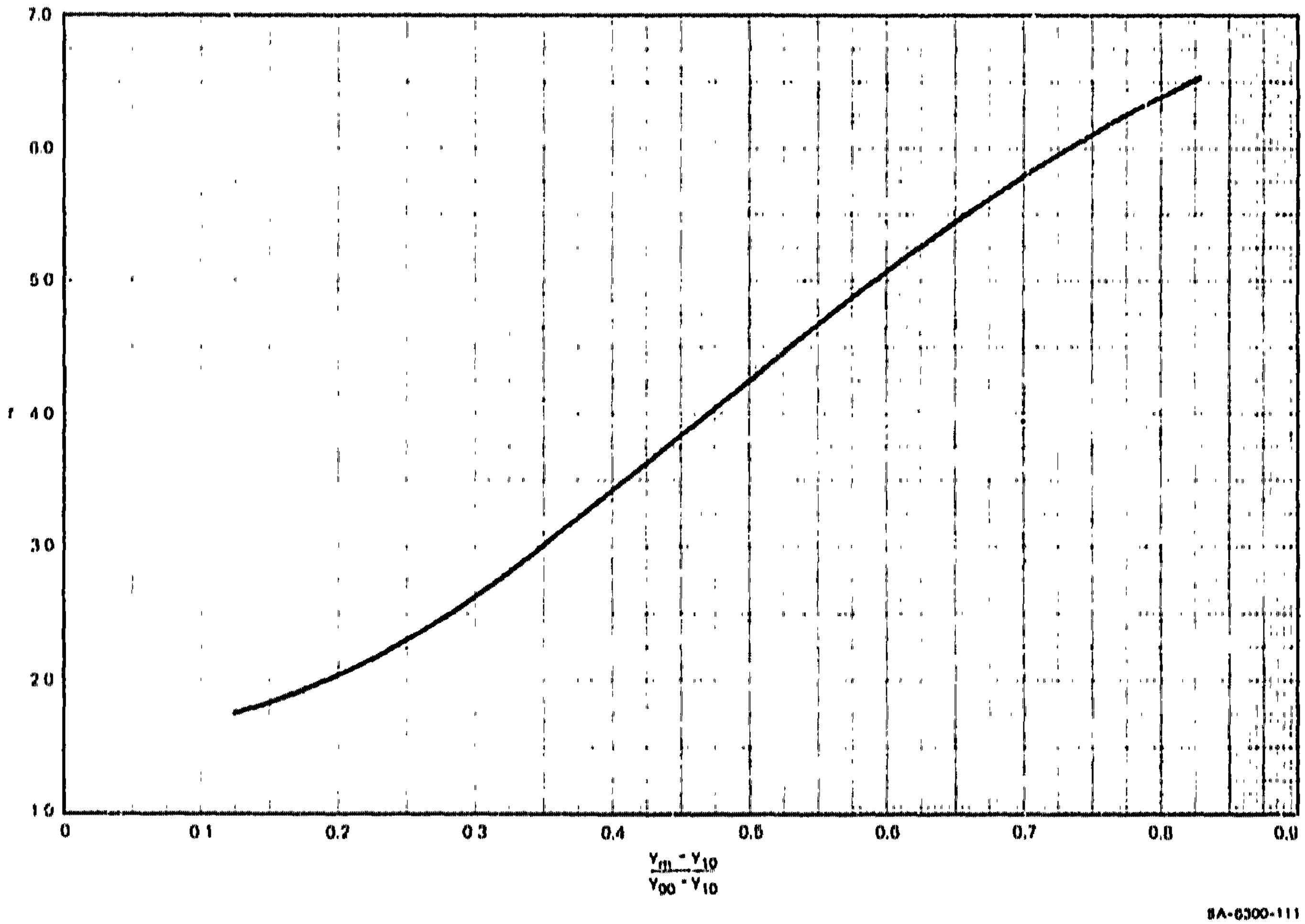

FIGURE 3 $\frac{Y_m - Y_{10}}{Y_{90} - Y_{10}}$ VERSUS r FOR A BETA DISTRIBUTION FUNCTION WITH t = 8

The mode for this beta distribution is given by

$$\text{Mode} = y_m = y_a + \frac{(r-1)}{(t-2)}(y_c - y_a) \quad . \tag{9}$$

The value of $y_c - y_a$ can be expressed in terms of the known parameters y_{10} and y_{90} by means of the following approximate relationships, the first of which is analogous to Equation (2), used in the PERT procedure,

$$y_c - y_a = 6\sigma_y \tag{10}$$

$$y_{90} - y_{10} = 2.57\sigma_y \tag{11}$$

Thus,

$$y_c - y_a = 2.33(y_{90} - y_{10}) \quad . \tag{12}$$

Substituting this expression, along with $t = 8$, into Equation (9) and solving for y_a yields

$$y_a = y_m - 0.388(r-1)(y_{90} - y_{10}) \quad . \tag{13}$$

The value of y_c, although not required for this analysis, can now be determined from Equation (12).

Values of the cumulative probability distribution, in terms of the standardized variable x, are given in Figure 4 for the beta function with values of $t = 8$ and $1.5 \leq r \leq 6.5$. These values were derived from standard

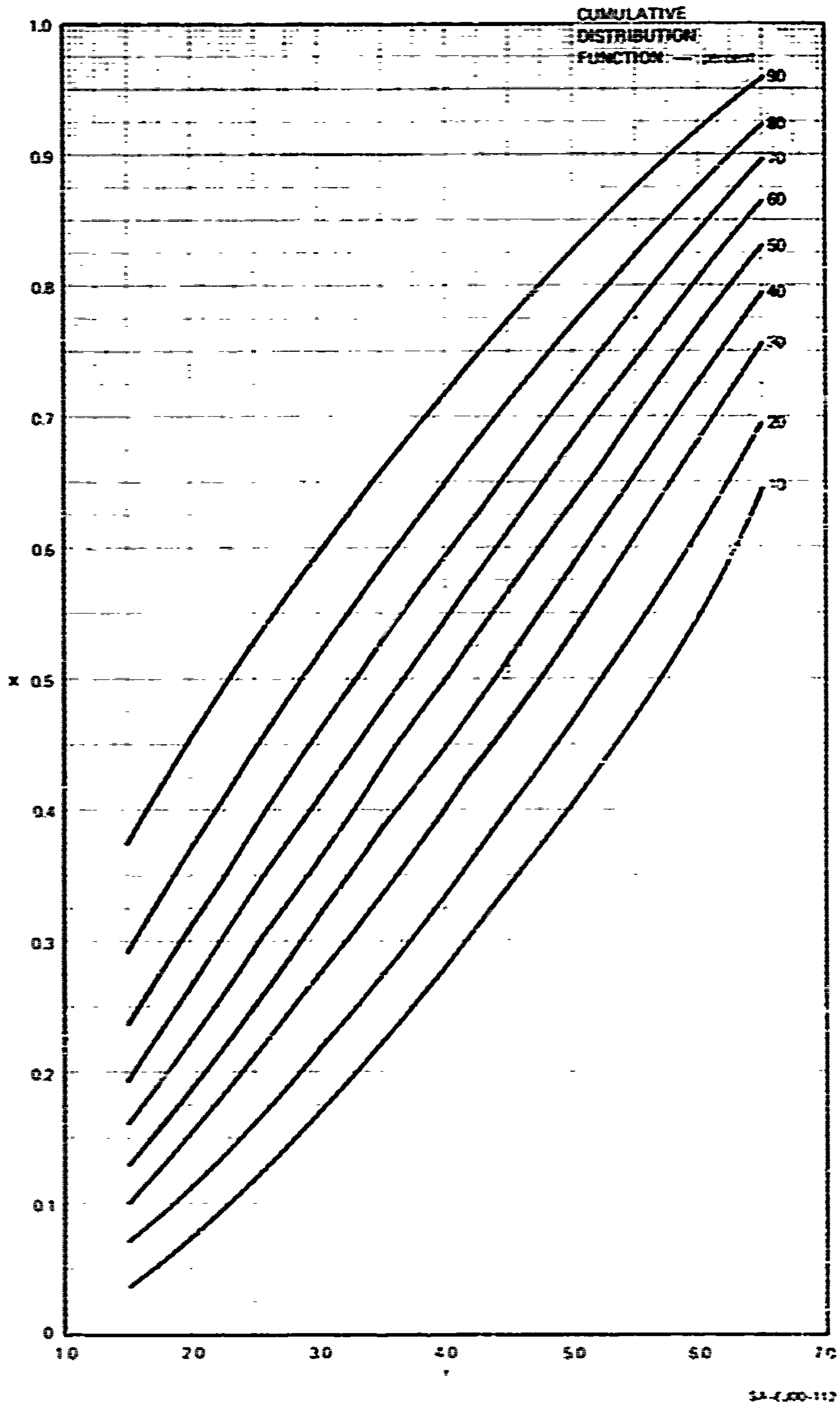

FIGURE 4 CUMULATIVE DISTRIBUTION FUNCTION VALUES FOR A BETA DISTRIBUTION FUNCTION WITH t = 8

tables of the beta distribution.* These tables are expressed in terms of the variable x, where $0 \le x \le 1$. Transformation of the variable $y(y_a \le y \le y_c)$ is accomplished by the following relationship

$$y = y_a + (y_c - y_a)x \quad . \tag{14}$$

Substituting Equation (12), this can be rewritten as

$$y = y_a + 2.33(y_{90} - y_{10})x \quad . \tag{15}$$

Method of Application

In applying the foregoing concepts to the development of failure probability estimates, the following steps are taken:

1. The most likely value of the incipient failure blast parameter (y_m) is established by judgment and a review of experimental and analytical evidence.

2. The values corresponding to the 10% (y_{10}) and 90% (y_{90}) probabilities of failure are chosen by the same means.

3. The ratio $(y_m - y_{10})/y_{90} - y_{10})$ is calculated, and the corresponding value of r is determined from Figure 3.

4. The value of y_a is calculated from Equation (13).

5. The 50% probability of failure (y_{50}) is determined from Figure 4 and Equation (15).

* Tables of the beta distribution may be found in:
J. R. Benjamin and M. F. Nelson, Tables of the Standardized Beta Distribution, Stanford University Department of Civil Engineering, Report No. 59, January 1966[3] and
Karl Pearson, Tables of the Incomplete Beta-Function, Biometrika Office, London, 1934.[4]

Additional probability of failure values can be determined in the same manner as indicated in step 5.

The above procedure is illustrated by the example below.

The failure of a structure subjected to a blast is predicted to occur at the following peak overpressures:

1. Failure is estimated as most likely to occur at 4.0 psi, thus $y_m = 4.0$ (most likely value).

2. Failure is estimated to occur in 1 out of 10 cases at 2.5 psi, thus $y_{10} = 2.5$ (lowest reasonable value). Similarly, in 1 out of 10 cases, the structure is estimated to be able to withstand an overpressure of 6.5 psi, thus $y_{90} = 6.5$ (highest reasonable value).

3. $(y_m - y_{10})/(y_{90} - y_{10}) = (4.0 - 2.5)/(6.5 - 2.5) = 0.375$

   From Figure 3, $r = 2.94$.

4. From Equation (13)

   $y_a = 4.0 - 0.388(2.94 - 1.00)(6.5 - 2.5) = 0.99.$

5. From Figure 4, $x_{50} = 0.357$

   $y_{50} = 0.99 + 2.33(6.5 - 2.5)(0.357) = 4.32.$

6. Other probability values are calculated in the same manner as in step 5 with the following results:

   $y_0 = 1.0$ $\qquad$ $y_{60} = 4.8$

   $y_{10} = 2.5$ $\qquad$ $y_{70} = 5.2$

   $y_{20} = 3.0$ $\qquad$ $y_{80} = 5.8$

   $y_{30} = 3.5$ $\qquad$ $y_{90} = 6.5$

   $y_{40} = 3.9$ $\qquad$ $y_{100} = 10.3$

   $y_{50} = 4.3$

The above values are plotted in the example cumulative distribution function shown in Figure 5. The example probability of failure data ploted in the linear graphic form used for presentation in this report appear in Figure 6.

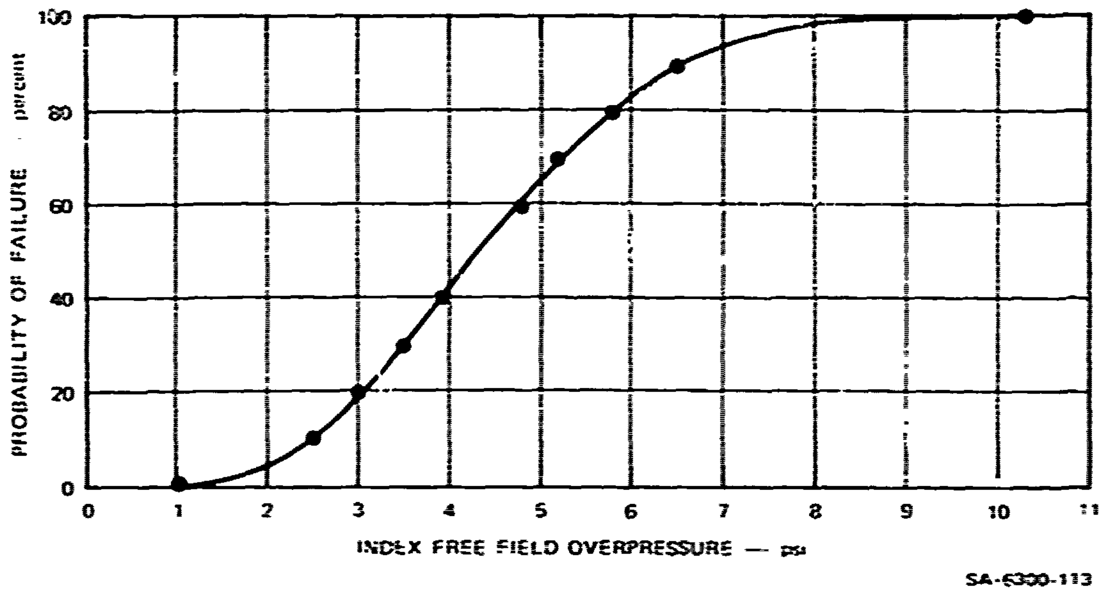

FIGURE 5 EXAMPLE CUMULATIVE PROBABILITY DISTRIBUTION FUNCTION

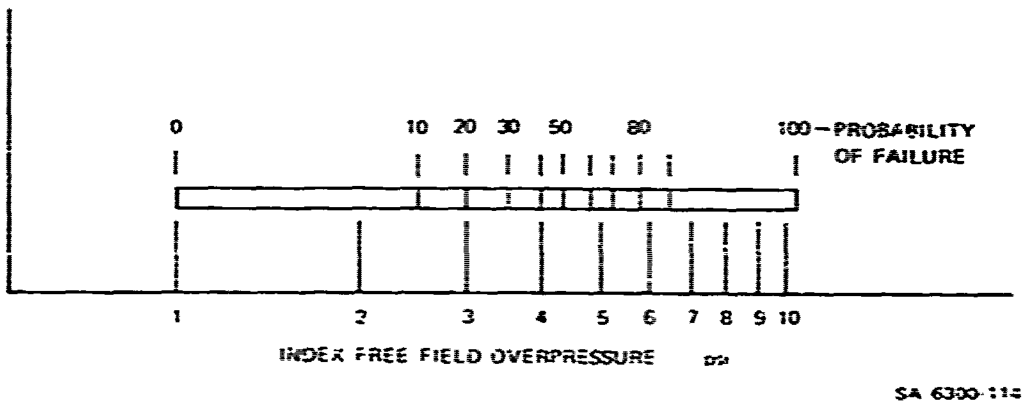

FIGURE 6 LINEAR FORM OF PROBABILITY OF FAILURE CRITERIA

Extension of the Method

The Bayesian Approach

The probabilistic basis described earlier is closely associated in an elementary way with an applied statistical philosophy introduced by Thomas Bayes and known as the Bayesian Theory. The Bayesian approach combines subjective and objective elements of statistical analysis. The approach is to incorporate empirically observed data into a previously developed (prior) distribution to achieve a new (posterior) distribution.

In the Bayesian approach the prior distribution may be based on previous empirical data or may be developed by judgment from related processes. The distribution is then altered in the light of future observations.

In the present case, the prior distribution is based largely on judgment and could therefore be classed as the initial step of a Bayesian approach. As future failure data become available, the distributions developed herein may be refined.

The mathematics of the Bayesian Theory are beyond the scope of the present study but may be found in several advanced statistical texts, such as Reference 5.

Computer Applications

Electronic computer processes are easily applied to the approach discussed. Inputs would include the y_{10}, y_{90}, and y_m values, a value of t, and elements of beta function tables in either tabular or algorithmic form. The output would consist of tabular or graphic presentations of the failure criteria values for designated probability steps. An example of such an application is given in Appendix B, which uses the same initial values as in the previous example.

Other Shape Characteristics

The beta process developed herein uses only one value of the shape parameter t relating to the "peakedness" of the distribution. The value of 8 was chosen as representative of average structural situations. The range of structural situations would no doubt require the introduction of other values.

IV AIR BLAST PHENOMENA DATA

Introduction

An earlier section discussed the yield-dependent phenomena (blast wave duration) that contribute to the overall variability in structural vulnerability problems. The presentation of failure criteria for a wide range of yields is beyond the scope of this study; furthermore, they would not be useful to civil defense planners. The civil defense problem is generally oriented to urban areas where large yield strikes would be expected. The yield, however, should be large enough to cause sufficient blast durations to fully influence structures with long period fundamental modes of vibration; these are generally tall framed buildings. Yields of the order of 5 Mt are sufficient to accomplish this and are the basis of the estimates given here. The 5-Mt yield is also sufficiently representative of a range of yields from 1 to 10 Mt as related to blast wave duration.

Index Free Field Peak Overpressure

Since some structures (diffraction sensitive) are primarily sensitive to the overpressure characteristic of the blast wave, some (drag sensitive) to the dynamic pressure, and others (most) to combinations, there can be no one air blast parameter that will serve as a unique measure for the establishment of failure criteria.

The concept followed here is to use peak free field air blast overpressure as an index measure. The index free field peak overpressure is that overpressure where the defined degree of failure occurs even though

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failure results primarily from dynamic pressure or from combinations of overpressure and dynamic pressure.

Air Blast Parameter Data

The failure criteria presented herein use index free field peak overpressure values as indicators of probability of failure for various structural types and their components. Civil defense planners will frequently require the measure to be stated in terms of distance from a given explosion. For this reason, charts of all required air blast parameters as functions of distance for both a 5-Mt surface burst and a 5-Mt air burst at 14,000 feet HOB have been prepared and are presented in Appendix C. Data from the charts can be "scaled" to other yields through the use of procedures outlined in Reference 1.

V PROBABILITY OF FAILURE ESTIMATES

Introduction and Use

The probability of failure estimates presented hereafter in chart form have been developed by the methods described in the preceding sections. Each chart (which applies to one building type) is preceded by a narrative description of the building type and definitions of failure. Failure definitions are supplied for components as well as for the composite structure.

The information supplied on the charts permits estimation of the probability of failure at various index free field overpressure values for each structural component (e.g., window glass) separately and for a composite structure including all components.

The charts may be used in two ways:

1. The probability of failure of a component or the composite structure at a given index overpressure value may be read by projecting a vertical line from the overpressure value upwards until it intersects the probability bar for the desired component. The point of the intersection represents the estimated probability of failure of all structures in the population of that overpressure. For example, from the chart of Building Type 1, 90% of all windows in the buildings of this type would be expected to fail at 0.6 psi index free field overpressure, while 10% would not.

2. The index free field overpressure value for a given probability of failure can be determined by reversing the above procedure. For example, 50% of the composite of all Type 1 structures would be expected to fail at 2.2 psi while 50% would not reach the state of failure as defined.

Building Types

The page locations of building descriptions, failure definitions, and estimated probability of failure charts for each building type are listed below.

Type	Description	Page Number
11	Tall steel frame office buildings, more than ten stories. Light and heavy wall covering variations.	75
12	Tall reinforced concrete frame office buildings, more than ten stories. Light and heavy wall covering variations.	79
13	One-story masonry, load-bearing wall school and institutional buildings.	83
14	Monumental masonry buildings, two to five stories, with and without frames.	87
15	Masonry, load-bearing wall industrial buildings, one story.	91
16	Light steel frame industrial-type buildings, one story.	95
17	Heavy steel frame industrial-type buildings, one story.	99

TYPE 1

Building Description and Failure Definitions

Building Type

Single-story, wood-frame residence with or without basement.

General Description and Variations

This building type includes all one-story, single-family or duplex residences with or without basements constructed with wood stud walls, wood joist floors and ceilings, and wood rafter roofs. Various types of post and beam and panel construction are included.

Structural, space, and wall opening configurations are considered to be in general accord with municipal building codes.

Variations in size range from 1,000 to 2,000 square feet, or from two to five bedrooms.

Exterior wall coverings include wood, composition, stucco or metal siding over insulation board, and brick or stone veneer over insulation board.

Roof variations include different slopes and shapes of peaked roofs with wood or composition shingles and flat roofs of asphalt and felt built-up construction with gravel topping.

Interior walls are primarily wood stud with gypsum board or plaster coverings.

Foundation variations include slab-on-grade, footing and foundation wall with crawl space and partial or full basements.

This type also includes one and one-half story and split-level residences and different types of prefabricated designs.

The large bulk of single-family wood frame residences built since World War II fall in this category, as do many residences built earlier.

Because hurricane-reinforced residences are more resistant than those described here, they are not included in this category; however, they are not too prevalent.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Window and door frames--split, shattered, or substantially removed from walls.

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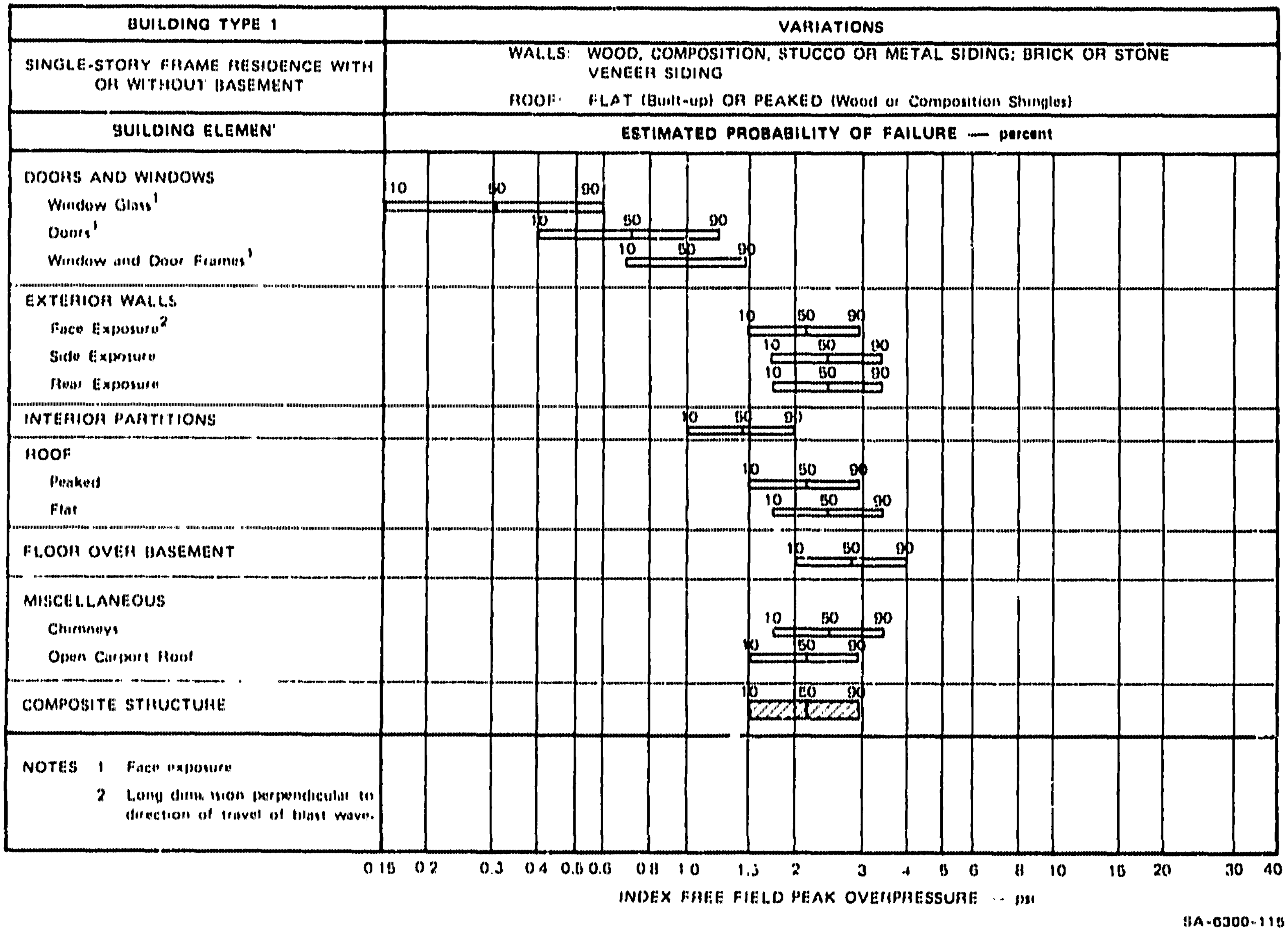
BUILDING TYPE 1
VARIATIONS
SINGLE-STORY FRAME RESIDENCE WITH OR WITHOUT BASEMENT
WALLS: WOOD, COMPOSITION, STUCCO OR METAL SIDING; BRICK OR STONE VENEER SIDING
ROOF: FLAT (Built-up) OR PEAKED (Wood or Composition Shingles)
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Window and Door Frames[1]
EXTERIOR WALLS
Face Exposure[2]
Side Exposure
Rear Exposure
INTERIOR PARTITIONS
ROOF
Peaked
Flat
FLOOR OVER BASEMENT
MISCELLANEOUS
Chimneys
Open Carport Roof
COMPOSITE STRUCTURE
NOTES 1 Face exposure
2 Long dimension perpendicular to direction of travel of blast wave.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.3 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD PEAK OVERPRESSURE — psi
SA-6300-115

Exterior Walls

Face exposure—foundation anchorage sheared and wall displaced or collapsed; 75% of siding removed.
Side exposure—same as for face exposure. Front wall failure will contribute to failure of side walls.
Rear exposure—same as for face and side walls.

Interior Partitions

50% or more covering removed from majority of walls.

Roof

75% or more of rafters failed for peaked roofs, and same for joists of flat roofs; gross displacement of roof system.

Floor over basement

75% or more of floor joists failed; collapse of floor system amounting to one half of basement height.

Miscellaneous

Chimneys—blown over; major shear and displacement.
Open carport roof—collapse or major displacement.

Composite Structure

The composite structure is defined as the average structure among the various types of residences included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage that precludes use for residential purposes without major reconstruction. Salvage and reconstruction would be on a board-by-board basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes any one or combinations of the following:

1. Roof collapse or gross displacement.

2. Collapse of walls.

3. 75% or more of siding removed.

TYPE 2

Building Description and Failure Definitions

Building Type

Single-story masonry, load-bearing wall residence with or without basement.

General Description and Variations

This building type includes all one-story, single-family or duplex residences with or without basements constructed with brick, stone, concrete block, or combination walls. The masonry wall supports all vertical loads without the assistance of studs or other framing.

Structural, space, and wall opening configurations are considered to be in general accord with municipal building codes.

Variations in size range from 1,000 to 2,000 square feet, or from two to five bedrooms.

Exterior wall variations include: (1) solid brick; (2) brick cavity wall; (3) brick facing on concrete block, with or without cavity; (4) stone facing on brick or concrete block; and (5) solid stone.

Roof variations include different slopes and shapes of peaked roofs with wood, composition, slate, or tile coverings and flat roofs of asphalt and felt built-up construction with gravel topping.

Interior walls may be either stud frame with gypsum board or plaster covering or masonry with plaster covering. The inside finish of exterior walls may be either directly plastered or furred with gypsum board.

Foundation variations include slab-on-grade, footing and foundation wall with crawl space and partial or full basements.

Floor and ceiling joist systems are usually of normal wood construction.

This type also includes one- and one-half story and split level designs.

The large bulk of single family masonry, load-bearing wall residences built since World War II fall in this category as well as many residences built earlier.

This type does not include reinforced brick or reinforced concrete block residences, which are generally more resistant.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Window and door frames--split, shattered, or substantially removed from walls.

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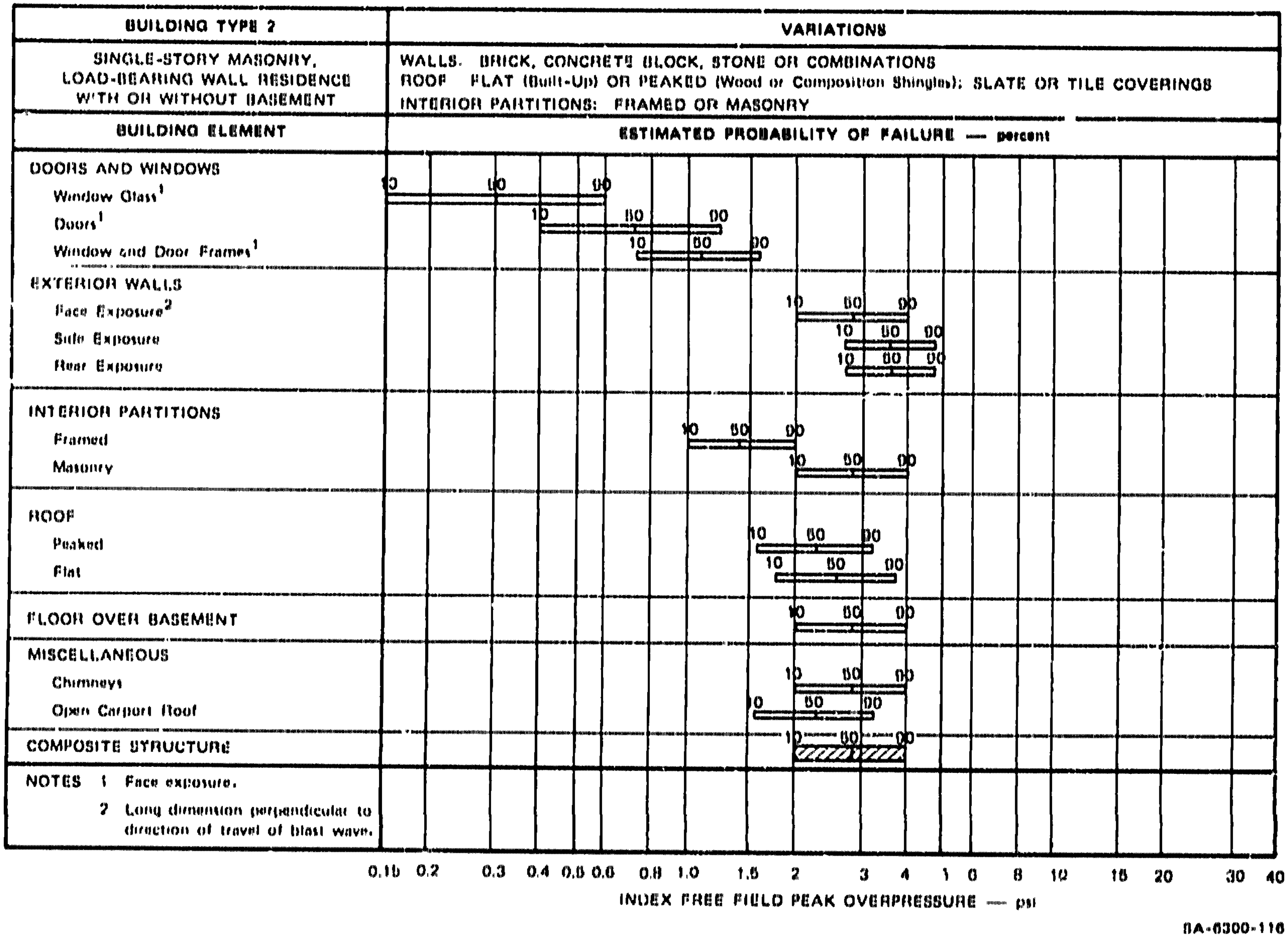
BUILDING TYPE 2
VARIATIONS
SINGLE-STORY MASONRY, LOAD-BEARING WALL RESIDENCE WITH OR WITHOUT BASEMENT
WALLS. BRICK, CONCRETE BLOCK, STONE OR COMBINATIONS
ROOF FLAT (Built-Up) OR PEAKED (Wood or Composition Shingles); SLATE OR TILE COVERINGS
INTERIOR PARTITIONS: FRAMED OR MASONRY
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Window and Door Frames[1]
EXTERIOR WALLS
Face Exposure[2]
Side Exposure
Rear Exposure
INTERIOR PARTITIONS
Framed
Masonry
ROOF
Peaked
Flat
FLOOR OVER BASEMENT
MISCELLANEOUS
Chimneys
Open Carport Roof
COMPOSITE STRUCTURE
NOTES 1 Face exposure.
2 Long dimension perpendicular to direction of travel of blast wave.
0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 8 10 15 20 30 40
INDEX FREE FIELD PEAK OVERPRESSURE — psi
SA-6300-116

Exterior Walls

Face exposure--wall shattered or at least 75% collapsed.
Side exposure--same as for face exposure; front wall failure will contribute to failure of side walls.
Rear exposure--same as for face and side walls.

Interior Partitions

50% or more covering removed for majority of walls.

Roof

75% or more of rafters failed for peaked roofs and same for joists of flat roofs; gross displacement of roof system.

Floor over Basement

75% or more of floor joists failed; collapse of floor system amounting to one-half of basement height.

Miscellaneous

Chimneys--blown over; major shear and displacement.
Open carport roof--collapse or major displacement.

Composite Structure

The composite structure is defined as the average structure among the various types of residences included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for residential purposes without major reconstruction. Salvage and reconstruction would be on a brick-by-brick basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes either one or a combination of the following:

1. Roof collapse or gross displacement.

2. Collapse of walls.

TYPE 3

Building Description and Failure Definitions

Building Type

Two- or three-story wood frame single residences, row houses, apartments, and motels, with or without basements.

General Description and Variations

This building type includes all two- or three-story residential structures, with or without basements, constructed with wood stud walls, wood joist floors and ceilings, and wood rafter or wood truss roof framing. The framing system may be either "balloon" or "platform" or any variation.

Structural, space, and wall opening configurations are considered to be in general accord with municipal building codes.

Size variations range up to 3,000 square feet for single residences and from 800 to 1,500 square feet in multiple residences.

Exterior wall covering variations include wood, composition, stucco or metal siding over insulation board, and brick or stone veneer over insulation board.

Roof variations include different slopes and shapes of peaked roofs with wood or composition shingles and flat roofs of asphalt and felt built-up construction with gravel topping.

Interior walls are primarily wood stud with gypsum board or plaster covering.

Foundation variations include slab-on-grade, footing and foundation wall with crawl space and partial or full basements. Where the basement is used for parking, the first floor will be of reinforced concrete.

This type of building includes "duplexes," "row houses," and "garden apartments."

Hurricane reinforced residences are more resistant and are not included in this category.

Failure Definitions

Doors and Windows

Window glass—cracked, holed, or shattered.
Doors—blown off hinges or panels shattered.
Window and door frames—split, shattered, or substantially removed from walls.

Exterior Walls

Face exposure—f[illegible]ation anchorage sheared and walls displaced or collapsed; 75% of [illegible] removed.
Side exposure—same as for face exposure. Front wall failure will contribute to failure of side walls.
Rear exposure—same as for face and side walls.

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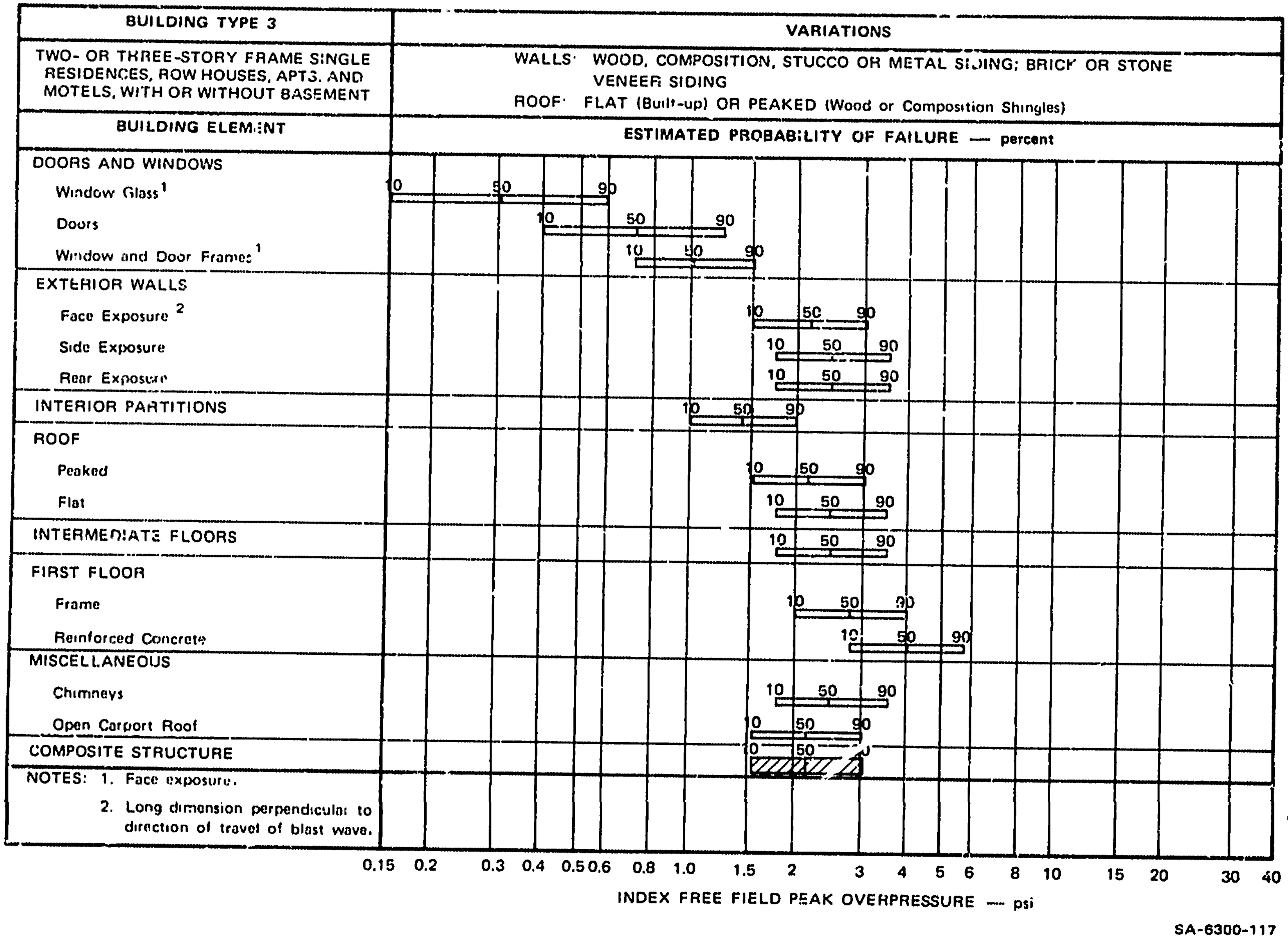
BUILDING TYPE 3
VARIATIONS
TWO- OR THREE-STORY FRAME SINGLE RESIDENCES, ROW HOUSES, APTS. AND MOTELS, WITH OR WITHOUT BASEMENT
WALLS: WOOD, COMPOSITION, STUCCO OR METAL SIDING; BRICK OR STONE VENEER SIDING
ROOF: FLAT (Built-up) OR PEAKED (Wood or Composition Shingles)
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors
Window and Door Frames[1]
EXTERIOR WALLS
Face Exposure[2]
Side Exposure
Rear Exposure
INTERIOR PARTITIONS
ROOF
Peaked
Flat
INTERMEDIATE FLOORS
FIRST FLOOR
Frame
Reinforced Concrete
MISCELLANEOUS
Chimneys
Open Carport Roof
COMPOSITE STRUCTURE
NOTES: 1. Face exposure.
2. Long dimension perpendicular to direction of travel of blast wave.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD PEAK OVERPRESSURE — psi
SA-6300-117

Interior Partitions

50% or more covering removed for majority of walls.

Roof

75% or more of rafters failed for peaked roofs and same for joists of flat roofs; gross displacement of roof system.

Floors

Upper floors--failure generally depends on wall failure. If two walls collapse the floors will drop.
Floor over basement--75% or more of floor joists failed or collapse of floor system amounting to one-half of basement height for wood joist floors. For reinforced concrete floor, failure is defined as any deflection amounting to 1/20 of longest span.

Miscellaneous

Chimneys--blown over; major shear or displacement.

Composition Structure

The composite structure is defined as the average structure among the various types of buildings included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for residential purposes without major reconstruction. Salvage and reconstruction would be on a board-by-board basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes any one or combinations of the following:

1. Roof collapse or gross displacement.

2. Collapse of walls.

3. 75% or more of siding removed.

4. Gross deflection from the vertical.

TYPE 4

Building Description and Failure Definitions

Building Type.

Two- or three-story masonry load-bearing wall single residences, row houses, apartments, and motels, with or without basement.

General Description and Variations

This building type includes all two- or three-story residential structures with or without basement, constructed of brick, stone, concrete block, or combination walls. The masonry wall supports all vertical loads without the assistance of wood, steel, or concrete framing.

Structural space and wall opening configurations are considered to be in general accord with municipal building codes.

Size variations range up to 3,000 square feet for single residences and from 800 to 1,500 square feet in multiples.

Exterior wall variations include: (1) solid brick; (2) brick cavity wall; (3) brick facing on concrete block, with or without cavity; (4) stone facing on brick or concrete block; and (5) solid stone.

Roof variations include different slopes and shapes of peaked roofs with wood or composition shingles and clay tile or slate and flat roofs of asphalt and felt built-up construction with gravel topping.

Interior walls may be either stud frame with gypsum board or plaster covering or masonry with plaster covering. The inside finish of exterior walls may be either directly plastered or furred with gypsum board.

Foundation variations include slab-on-grade, footing and foundation wall with crawl space and partial or full basements. Where the basement is used for parking, the first floor will be of reinforced concrete.

This type of building includes "duplexes," "row houses," and "garden apartments." It also includes some older four-story structures not now generally permitted by building codes.

It does not include reinforced brick or reinforced concrete block structures, which are generally more resistant.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Windows and door frames--split, shattered, or substantially removed from walls.

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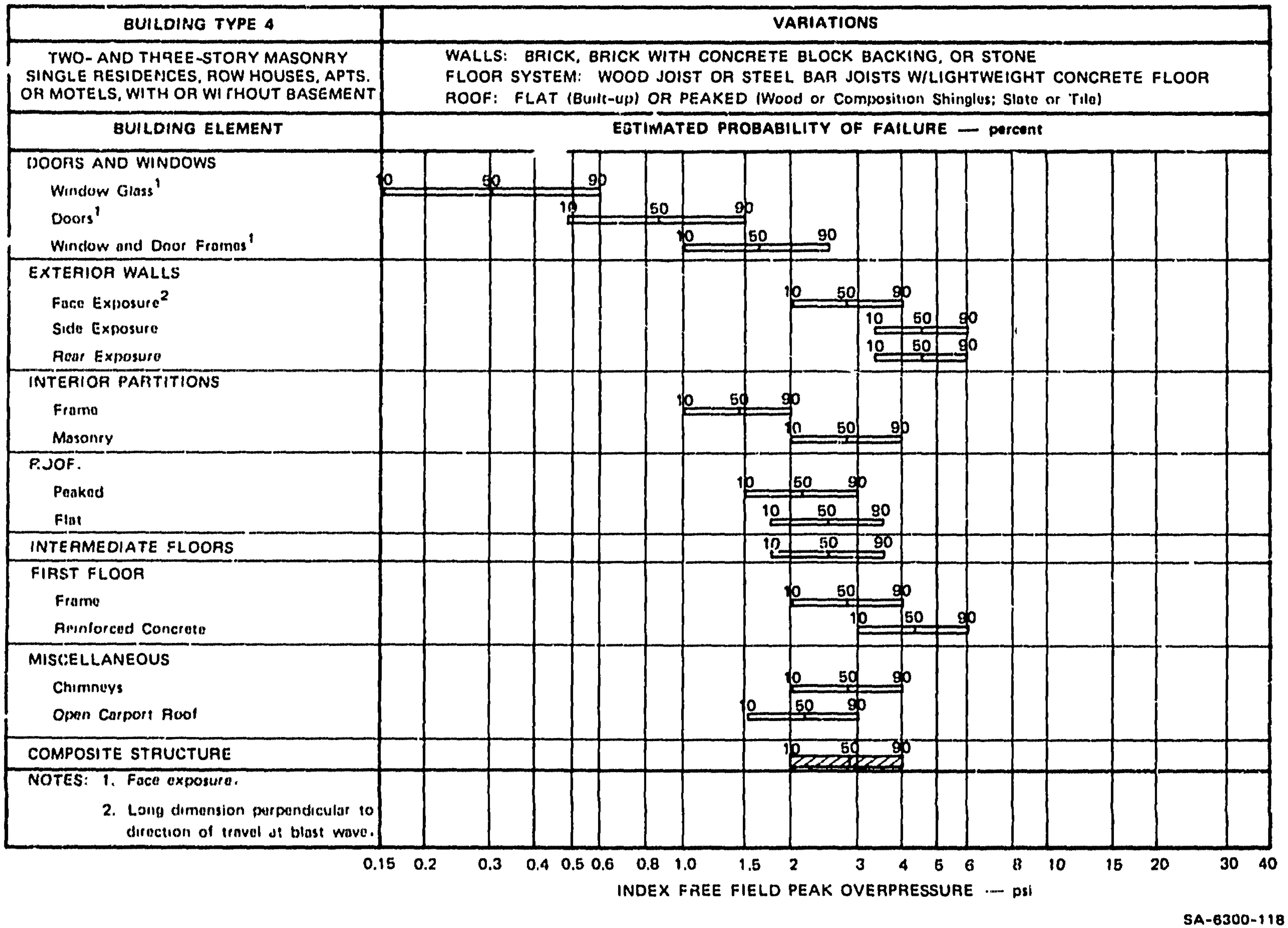

BUILDING TYPE 4
VARIATIONS
TWO- AND THREE-STORY MASONRY SINGLE RESIDENCES, ROW HOUSES, APTS. OR MOTELS, WITH OR WITHOUT BASEMENT
WALLS: BRICK, BRICK WITH CONCRETE BLOCK BACKING, OR STONE
FLOOR SYSTEM: WOOD JOIST OR STEEL BAR JOISTS W/LIGHTWEIGHT CONCRETE FLOOR
ROOF: FLAT (Built-up) OR PEAKED (Wood or Composition Shingles; Slate or Tile)
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Window and Door Frames[1]
EXTERIOR WALLS
Face Exposure[2]
Side Exposure
Rear Exposure
INTERIOR PARTITIONS
Frame
Masonry
ROOF.
Peaked
Flat
INTERMEDIATE FLOORS
FIRST FLOOR
Frame
Reinforced Concrete
MISCELLANEOUS
Chimneys
Open Carport Roof
COMPOSITE STRUCTURE
NOTES: 1. Face exposure.
2. Long dimension perpendicular to direction of travel of blast wave.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD PEAK OVERPRESSURE — psi
SA-6300-118

Exterior Walls

Face exposure--wall shattered or at least 75% collapsed.
Side exposure--same as for face exposure. Front wall failure will contribute to failure of side walls.
Rear exposure--same as for face and side walls.

Interior Partitions

50% or more covering removed for majority of walls.

Roof

75% or more of rafters failed for peaked roofs and same for joists of flat roofs; gross displacement of roof system.

Floors

Upper floors--failure generally depends on wall failure. If the walls collapse the floors will drop.

Floor over Basement

75% or more of floor joists failed or collapse of floor system amounting to one-half of basement height for wood joist floors. For reinforced concrete floor, failure is defined as any deflection amounting to 1/20 of longest span.

Miscellaneous

Chimneys--blown over; major shear or displacement.

Composite Structure

The composite structure is defined as the average structure among the various types of buildings included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for residential purposes without major reconstruction. Salvage and reconstruction would be on a brick-by-brick basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes either one or a combination of the following:

1. Roof collapse or gross displacement.

2. Collapse of walls.

TYPE 5

Building Description and Failure Definitions

Building Type

Mixed one- and two-story "store front" and light commercial masonry, load-bearing wall buildings.

General Description and Variations

This building type includes the large variety of small to medium structures found in light "strip" and neighborhood retail and commercial districts. Typical locations are in the urban fringe, suburban areas, "strips" along major highways, and smaller towns.

The type is characterized by rather narrow frontages, more or less continuous structures with occasional service alleys, common walls in some cases, flat roofs, and decorative "store fronts," usually with a large glass area. A typical size would be 40-foot frontage by 80-foot depth with 12- to 15-foot ceiling height.

Wall variations include solid brick, solid concrete block, or concrete block with brick, stone, or tile facings.

"Store front" variations include various configurations and combinations of plate glass, structural glass, metal panels, and decorative brick and tile. The typical structure has a large expanse of glass on its front face.

Roofs are generally flat with "built-up" coverings supported by joists or light trusses.

Second floors, if they exist, are used for store purposes, offices, or apartment-type residences. Wall openings tend to be smaller than those on street floors.

This type does not include large "shopping center" buildings or older two- to four-story, heavy masonry, mixed commercial, office and residential structures found in older commercial fringes of larger cities.

Failure Definitions

"Store fronts"

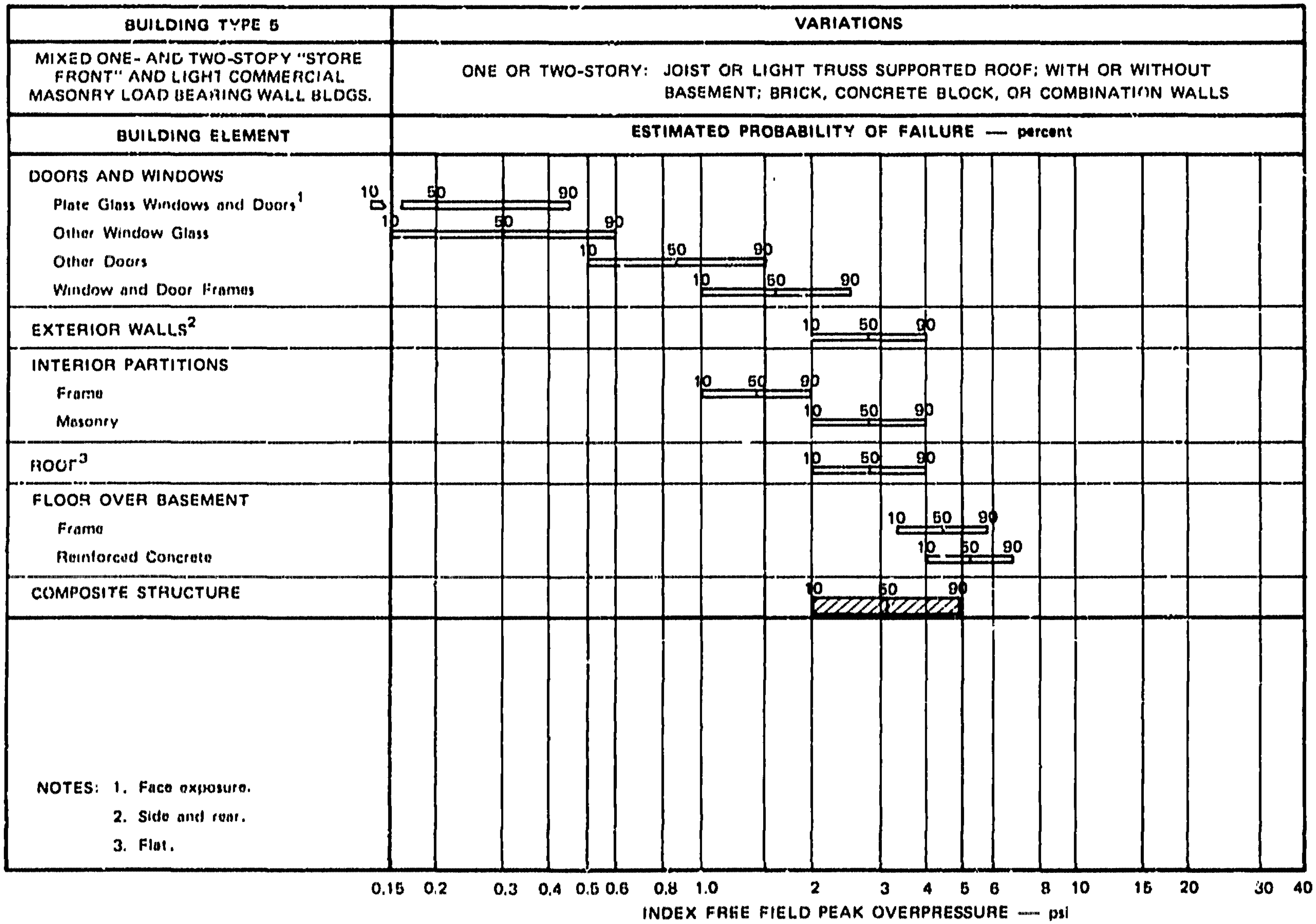
Glass holed or shattered; other panels substantially displaced.

Side and Rear Walls

Walls shattered or at least 75% collapsed.

Roof

75% or more of rafters or roof trusses failed; gross displacement of roof system.


BUILDING TYPE 5
VARIATIONS
MIXED ONE- AND TWO-STORY "STORE FRONT" AND LIGHT COMMERCIAL MASONRY LOAD BEARING WALL BLDGS.
ONE OR TWO-STORY: JOIST OR LIGHT TRUSS SUPPORTED ROOF; WITH OR WITHOUT BASEMENT; BRICK, CONCRETE BLOCK, OR COMBINATION WALLS
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Plate Glass Windows and Doors[1]
Other Window Glass
Other Doors
Window and Door Frames
EXTERIOR WALLS[2]
INTERIOR PARTITIONS
Frame
Masonry
ROOF[3]
FLOOR OVER BASEMENT
Frame
Reinforced Concrete
COMPOSITE STRUCTURE
NOTES: 1. Face exposure.
2. Side and rear.
3. Flat.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD PEAK OVERPRESSURE — psi

SA-6300-119

Interior Partitions

Frame--50% or more of covering removed.
Masonry--shattered or at least 75% collapsed.

Floor over basement

75% or more of floor joists failed or collapse of floor system amounting to one-half of basement height for wood joist floors. For reinforced concrete floor, failure is defined as any deflection amounting to 1/20 of longest span.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would be on a brick-by-brick basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes either one or a combination of the following:

1. Roof collapse or gross displacement.

2. Collapse of walls.

TYPE 6

Building Description and Failure Definitions

Building Type

Mixed two- to four-story commercial, residential, and office, masonry load-bearing wall buildings.

General Description and Variations

This building type includes a wide variety of two- to four-story masonry load-bearing wall structures found in the area between the downtown and residential districts of larger cities. Typical uses include small stores, professional offices (such as physicians, dentists, and lawyers), and apartment-type residences. The stores usually occupy the lower floor, and offices and apartments occupy the upper floors. The period of construction for this building type is before World War II.

This type is characterized by rather narrow frontages, more or less continuous structures with occasional service alleys, common walls in some cases, and flat roofs. The front of the building usually has fairly large window areas, particularly on the ground floor, while the sides and rear have only small window areas. A typical individual size would be 40-foot frontage by 80-foot depth with 12- to 15-foot ceiling height on the ground floor and 8 to 10 feet for upper floors.

Wall variations include solid brick, cut or artificial stone, concrete block, structural clay tile, or concrete block or structural clay tile with brick or stone facing.

Interior walls are generally masonry: brick, concrete block, or structural clay tile, with plaster covering.

Floors are typically wood decking supported on wood beams and joists, although, in some instances, masonry flat-arch floors or concrete beam and slab floors may be used.

Roofs are generally flat with "built-up" coverings. Construction is similar to that for the floors.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Window and door frames--split, shattered, or substantially removed from walls.

Exterior Walls

Walls shattered or at least 75% collapsed.

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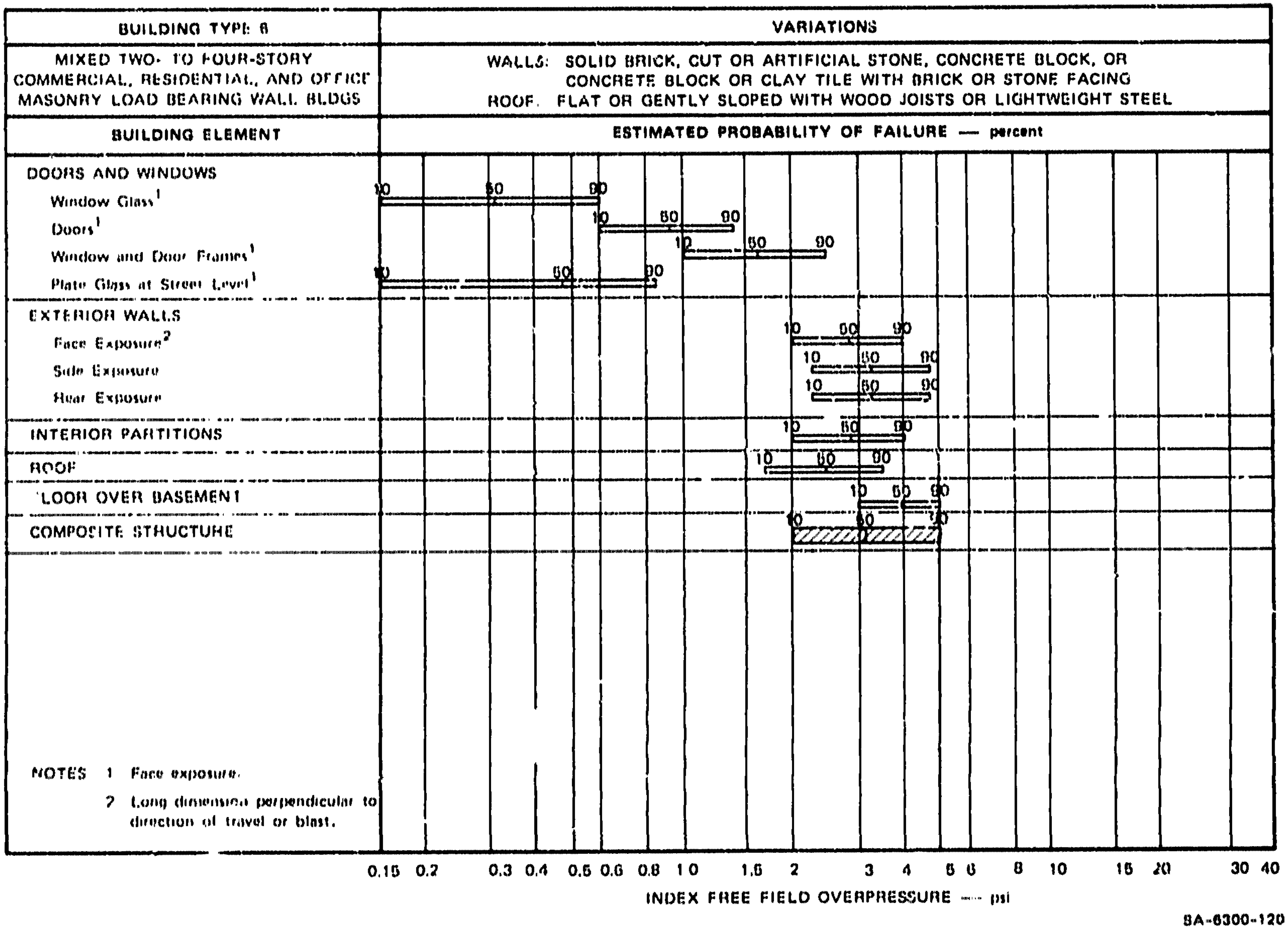
BUILDING TYPE 6
VARIATIONS
MIXED TWO- TO FOUR-STORY COMMERCIAL, RESIDENTIAL, AND OFFICE MASONRY LOAD BEARING WALL BLDGS
WALLS: SOLID BRICK, CUT OR ARTIFICIAL STONE, CONCRETE BLOCK, OR CONCRETE BLOCK OR CLAY TILE WITH BRICK OR STONE FACING
ROOF. FLAT OR GENTLY SLOPED WITH WOOD JOISTS OR LIGHTWEIGHT STEEL
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Window and Door Frames[1]
Plate Glass at Street Level[1]
EXTERIOR WALLS
Face Exposure[2]
Side Exposure
Rear Exposure
INTERIOR PARTITIONS
ROOF
FLOOR OVER BASEMENT
COMPOSITE STRUCTURE
NOTES 1 Face exposure.
2 Long dimension perpendicular to direction of travel or blast.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE — psi
SA-6300-120

Interior Partitions

Shattered or at least 75% collapsed.

Roof

75% or more of joists failed: gross displacement of roof system.

Floor over Basement

75% or more of floor joists failed or collapse of floor system amounting to one-half of basement height for wood joist floors. Collapse of floor for masonry flat-arch floors. For reinforced concrete floor, failure is defined as any deflection amounting to 1/20 of longest span.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would be on a brick-by-brick basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes either one or a combination of the following:

1. Roof collapse or gross displacement.

2. Collapse of walls.

TYPE 7

Building Description and Failure Definitions

Building Type

Multistory, steel frame apartment building, four to ten stories. Light and heavy wall covering variations.

General Description and Variations

This building type includes all four- to ten-story apartment buildings, dormitories, and hotels of steel frame construction. The elevator and stairwell core, generally of reinforced concrete or masonry construction, is assumed to help carry the vertical and lateral load.

The primary period of steel frame construction in multistory apartment buildings is before World War II, with reinforced concrete frame construction coming into prevalence since that time.

A typical layout consists of a room-corridor-room type of arrangement. Column spacing is generally about 20 feet in the long direction, while in the short direction spacing depends on the length of the building.

Exterior wall variations include both light and heavy coverings. Light wall coverings consist primarily of aluminum or steel panels. Heavy wall coverings include masonry curtain or panel walls, with or without veneer. These may be constructed with or without a cavity. Precast concrete elements are gaining in popularity.

Interior partitions are primarily (1) wood or steel studs with plaster or gypsum wallboard, (2) gypsum block, and (3) clay tile or concrete block with plaster.

Floor construction includes (1) open web joists with steel decking and a thin (2- to 3-inches thick) concrete covering and (2) reinforced concrete slabs with or without support beams.

Roofs are flat with "built-up" coverings, usually of the same type of construction as the floors.

Failure Definitions

Glass Doors and Windows

Cracked, holed, or shattered.

Exterior Walls

At least 75% of wall blown out or collapsed.

Interior Partitions

Frame--50% or more of covering removed.
Masonry--collapsed or at least 75% blown out.

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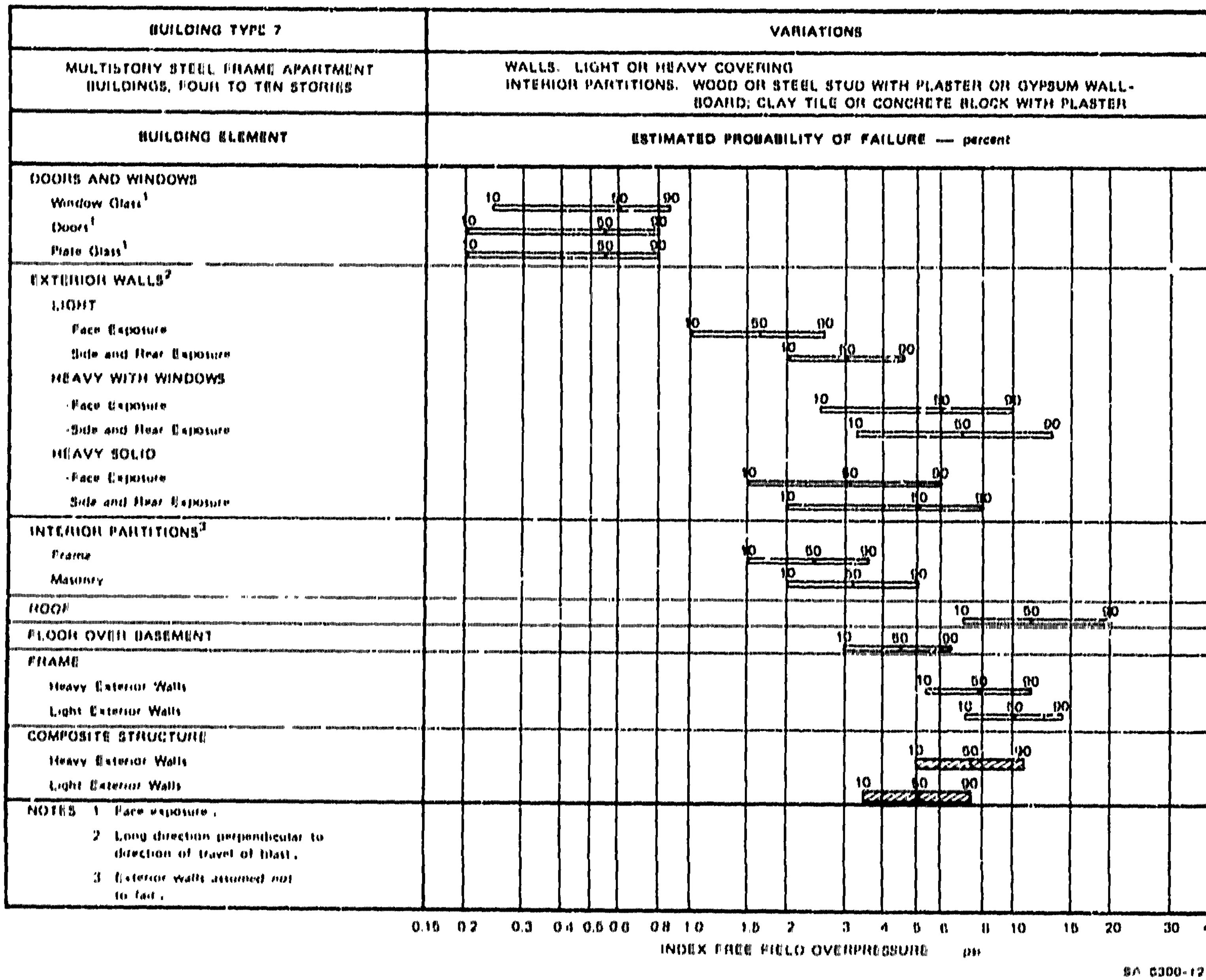
BUILDING TYPE 7
VARIATIONS
MULTISTORY STEEL FRAME APARTMENT BUILDINGS, FOUR TO TEN STORIES
WALLS. LIGHT OR HEAVY COVERING
INTERIOR PARTITIONS. WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALL-BOARD; CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Plate Glass[1]
EXTERIOR WALLS[2]
LIGHT
Face Exposure
Side and Rear Exposure
HEAVY WITH WINDOWS
Face Exposure
Side and Rear Exposure
HEAVY SOLID
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS[3]
Frame
Masonry
ROOF
FLOOR OVER BASEMENT
FRAME
Heavy Exterior Walls
Light Exterior Walls
COMPOSITE STRUCTURE
Heavy Exterior Walls
Light Exterior Walls
NOTES 1 Face exposure.
2 Long direction perpendicular to direction of travel of blast.
3 Exterior walls assumed not to fail.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE psi
SA 6300-121

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

Floor over Basement

Failure is defined as any deflection amounting to 1/20 of longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor displacements amounting to 1/20 of the story height. Collapse of the frame is imminent.

Vertical Core

Severe cracking and distortion of walls. Collapse is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times, but might be necessary because of a lack of new materials in the recovery period.

Because of differences in the resulting load on the frame, two categories of composite structure are defined:

1. Steel frame with light wall coverings.
2. Steel frame with heavy wall coverings.

Failure in either of these categories is defined as the occurrence of any or combinations of the following:

1. All exterior walls and interior partitions blown out.
2. Severe distortion or collapse of the frame.
3. Severe cracking and distortion of vertical core walls.

It is expected that failure of the light wall composite structure will be controlled by the first of the above criteria, while failure of the heavy wall composite structure will be controlled by the last two criteria.

TYPE 8

BUILDING DESCRIPTION AND FAILURE DEFINITIONS

Building Type

Multistory, reinforced concrete frame apartment building, four to ten stories. Light and heavy wall covering variations.

General Description and Variations

This building type includes all four- to ten-story apartment buildings, dormitories, and hotels of reinforced concrete frame construction. The elevator and stairwell core, generally of reinforced concrete or masonry construction, is assumed to help carry the vertical and lateral load.

Although some reinforced concrete frame apartment buildings were constructed before World War II, the primary period of this type of construction has been since that time.

Typical layout consists of a room-corridor-room type of arrangement. Spans may vary from 18 to 36 feet.

Exterior wall variations include both light and heavy coverings. Light wall coverings consist primarily of aluminum or steel panels. Heavy wall coverings include: (1) masonry curtain or panel walls with or without veneer and with or without a cavity, (2) precast concrete panels, and (3) reinforced concrete bearing walls.

Interior partitions include: (1) plaster or gypsum wallboard on wood or metal studs, (2) gypsum block, and (3) clay tile or concrete block with plaster. Reinforced concrete bearing walls may also serve as partitions.

Floor construction for spans up to 26 feet is primarily flat plate for the period after World War II. For longer spans and for construction before World War II, slab with beam and girder framing is prevalent. Variations of these systems include lift slabs, precast planks and channels, and "waffle" slabs. Many of the earlier waffle slabs are formed with structural clay tile, which is left in place, becoming the ceiling surface.

Roofs are flat with "built-up" coverings, usually of the same type of construction as the floors.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Window and door frames--split, shattered, or substantially removed from walls.

Exterior Walls

Walls shattered or at least 75% collapsed.

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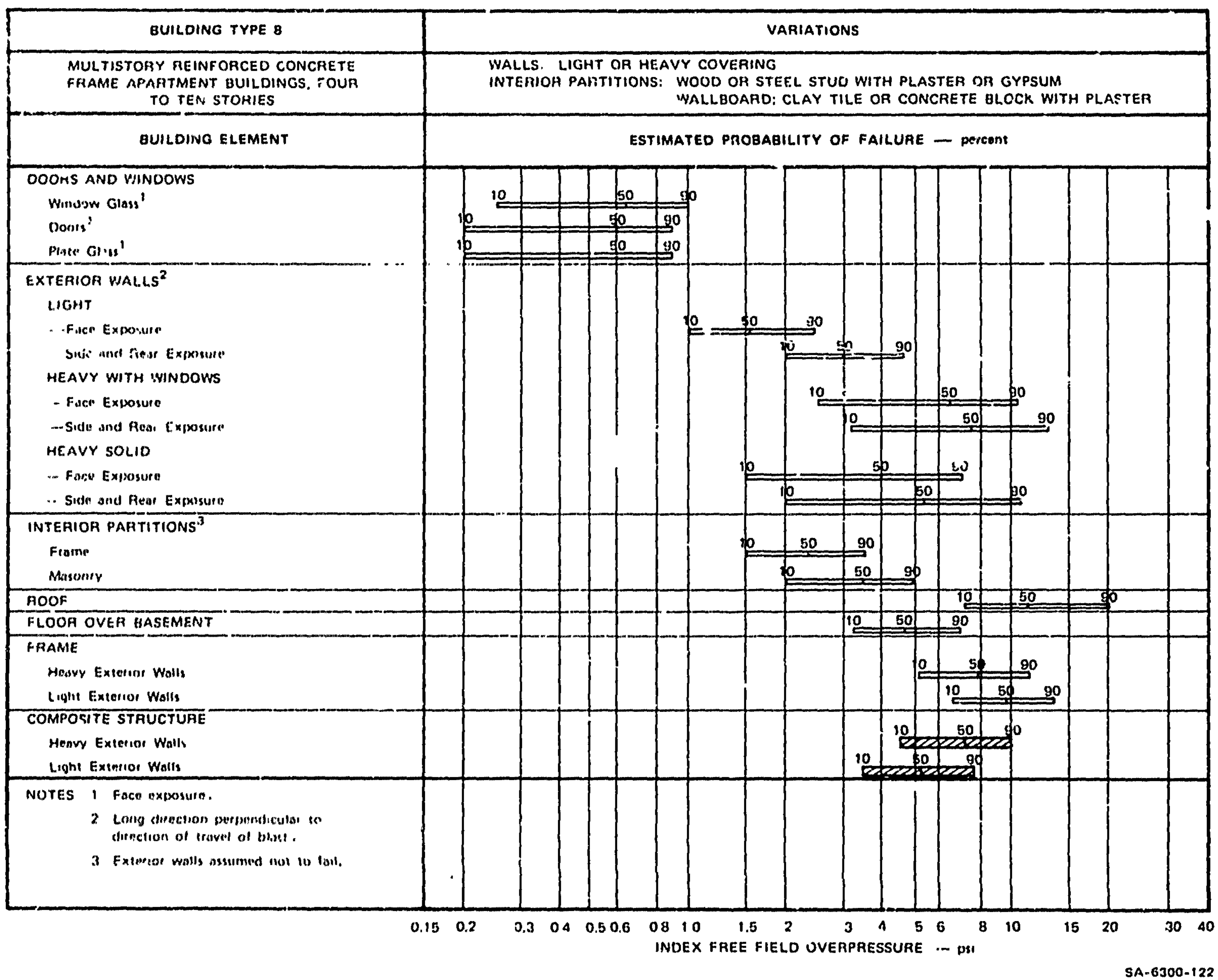
BUILDING TYPE 8
VARIATIONS
MULTISTORY REINFORCED CONCRETE FRAME APARTMENT BUILDINGS, FOUR TO TEN STORIES
WALLS. LIGHT OR HEAVY COVERING
INTERIOR PARTITIONS: WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALLBOARD; CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Plate Glass[1]
EXTERIOR WALLS[2]
LIGHT
- Face Exposure
Side and Rear Exposure
HEAVY WITH WINDOWS
- Face Exposure
—Side and Rear Exposure
HEAVY SOLID
-- Face Exposure
-- Side and Rear Exposure
INTERIOR PARTITIONS[3]
Frame
Masonry
ROOF
FLOOR OVER BASEMENT
FRAME
Heavy Exterior Walls
Light Exterior Walls
COMPOSITE STRUCTURE
Heavy Exterior Walls
Light Exterior Walls
NOTES 1 Face exposure.
2 Long direction perpendicular to direction of travel of blast.
3 Exterior walls assumed not to fail.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE — psi
SA-6300-122

Interior Partitions

Frame--50% or more of covering removed.
Masonry--shattered or at least 75% collapsed.

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

Floor Over Basement

Failure is defined as any deflection amounting to 1/20 of longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor deflections amounting to 1/20 of the story height. Collapse of the frame is imminent.

Vertical Core

Severe cracking and distortion of walls. Collapse is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period.

Because of differences in the resulting load on the frame, two categories of composite structure are required:

1. Reinforced concrete frame with light wall coverings.
2. Reinforced concrete frame with heavy wall coverings.

Failure in each of these categories includes any or combinations of the following:

1. All exterior walls and interior partitions blown out.
2. Severe distortion or collapse of the frame.
3. Severe cracking and distortion of vertical core walls.

TYPE 9

Building Description and Failure Definitions

Building Type

Multistory, steel frame office and institutional buildings, four to ten stories. Light and heavy wall covering variations.

General Description and Variations

This building type includes all four- to ten-story office and institutional buildings of steel frame construction. Institutional uses include schools and hospitals. The frame is generally of fireproof construction, with masonry, concrete, or more recently, sprayed asbestos plaster being used as the fire proofing medium. The elevator and stairwell core, generally of reinforced concrete or masonry construction, is assumed to help carry the vertical and lateral load.

Interior layouts are varied with much more open space than in residential structures.

Exterior wall variations include both light and heavy wall coverings. Light wall coverings consist primarily of metal panels or curtain walls, often containing large window areas. Heavy wall coverings consist primarily of masonry curtain or panel walls with brick or stone veneer, constructed with or without a cavity. Precast concrete wall and window units are becoming popular. The height of the first floor is generally greater than that of the upper stories, and the walls often consist of large areas of glass.

Interior partitions are generally of light construction, consisting of: (1) plaster or gypsum wallboard on wood or steel studs, (2) gypsum block, (3) metal or wood movable partitions, and (4) clay tile or concrete block with plaster.

Floor construction includes: (1) open web joists with steel decking and concrete covering and (2) reinforced concrete slabs with or without support beams. Suspended ceilings are generally used in conjunction with these systems to provide a flat ceiling and to hide lighting and ventilation systems.

Roofs are flat with "built-up" coverings and are usually the same type of construction as the floors.

Failure Definitions

Glass Doors and Windows

Cracked, holed, or shattered.

Exterior Walls

At least 75% of wall blown out or collapsed.

Interior Partitions

Frame--50% or more of covering removed.
Masonry--collapsed or at least 75% blown out.

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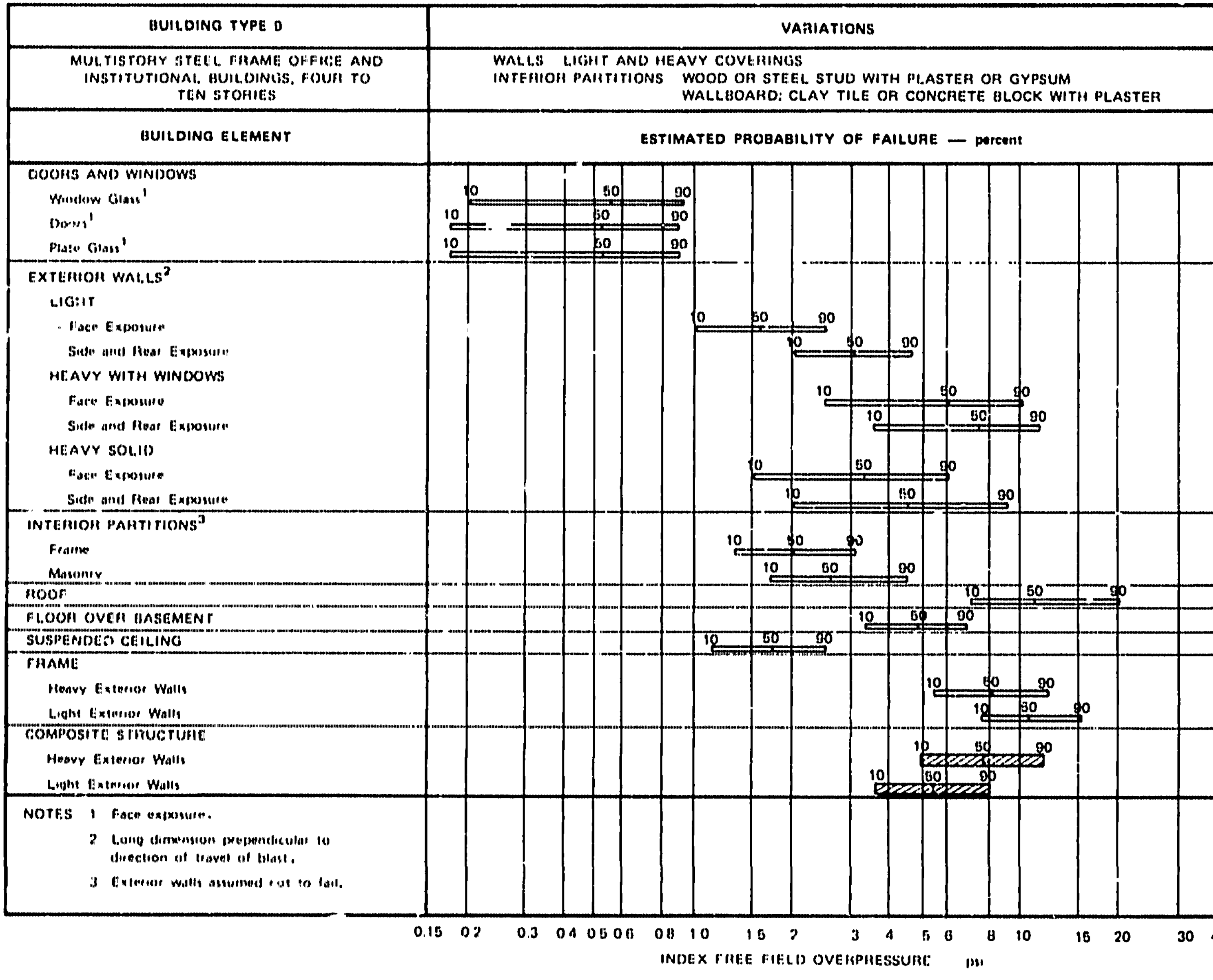
BUILDING TYPE D
VARIATIONS
MULTISTORY STEEL FRAME OFFICE AND INSTITUTIONAL BUILDINGS, FOUR TO TEN STORIES
WALLS LIGHT AND HEAVY COVERINGS
INTERIOR PARTITIONS WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALLBOARD; CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Plate Glass[1]
EXTERIOR WALLS[2]
LIGHT
Face Exposure
Side and Rear Exposure
HEAVY WITH WINDOWS
Face Exposure
Side and Rear Exposure
HEAVY SOLID
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS[3]
Frame
Masonry
ROOF
FLOOR OVER BASEMENT
SUSPENDED CEILING
FRAME
Heavy Exterior Walls
Light Exterior Walls
COMPOSITE STRUCTURE
Heavy Exterior Walls
Light Exterior Walls
NOTES 1 Face exposure.
2 Long dimension perpendicular to direction of travel of blast.
3 Exterior walls assumed not to fail.
10 50 90
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE psi
SA-6300-123

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

Floor over Basement

Failure is defined as any deflection amounting to 1/20 of longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor displacements amounting to 1/20 of the story height. Collapse of the frame is imminent.

Vertical Core

. cracking and distortion of walls. Collapse is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times, but might be necessary because of a lack of new materials in the recovery period.

Because of differences in the resulting load on the frame, two categories of composite structure are defined:

1. Steel frame with light wall coverings.
2. Steel frame with heavy wall coverings.

Failure in either of these categories is defined as the occurrence of any or combinations of the following:

1. All exterior walls and interior partitions blown out.
2. Severe distortion or collapse of the frame.
3. Severe cracking and distortion of vertical core walls.

It is expected that failure of the light wall composite structure will be controlled by the first of the above criteria, while failure of the heavy wall composite structure will be controlled by the last two criteria.

TYPE 10

Building Description and Failure Definitions

Building Type

Multistory, reinforced concrete frame office and institutional buildings, four to ten stories. Light and heavy wall covering variations.

General Description and Variations

This building type includes all four- to ten-story office and institutional buildings of reinforced concrete frame construction. Institutional uses include hospitals and schools. The elevator and stairwell core, generally of reinforced concrete or masonry construction, is assumed to carry part of the vertical and lateral load.

Interior layouts are varied with much more open space than in residential structures.

Exterior wall variations include both light and heavy wall coverings. Light wall coverings consist primarily of metal panels or curtain walls often containing large window areas. Heavy wall coverings include: (1) masonry curtain and panel walls, with and without masonry veneer and with and without a cavity; (2) precast concrete panels; and (3) reinforced concrete curtain or bearing walls. The height of the first story is generally greater than that of the upper stories, with the walls often containing large areas of glass.

Interior partitions include: (1) plaster or gypsum wallboard on wood or metal studs, (2) gypsum block, (3) movable wood or metal partitions, and (4) clay tile or concrete block with plaster.

Floor construction is reinforced concrete of one of the following types: (1) flat plate, (2) one-way joists, (3) two-way grids or "waffle slabs," (4) lift slabs, and (5) precast slabs. Suspended ceilings are generally used in conjunction with these systems to provide a flat ceiling.

Roofs are flat with "built-up" coverings, usually of the same type of construction as the floors.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Window and door frames--split, shattered, or substantially removed from walls.

Exterior Walls

Walls shattered or at least 75% collapsed.

Interior Partitions

Frame--50% or more of covering removed.

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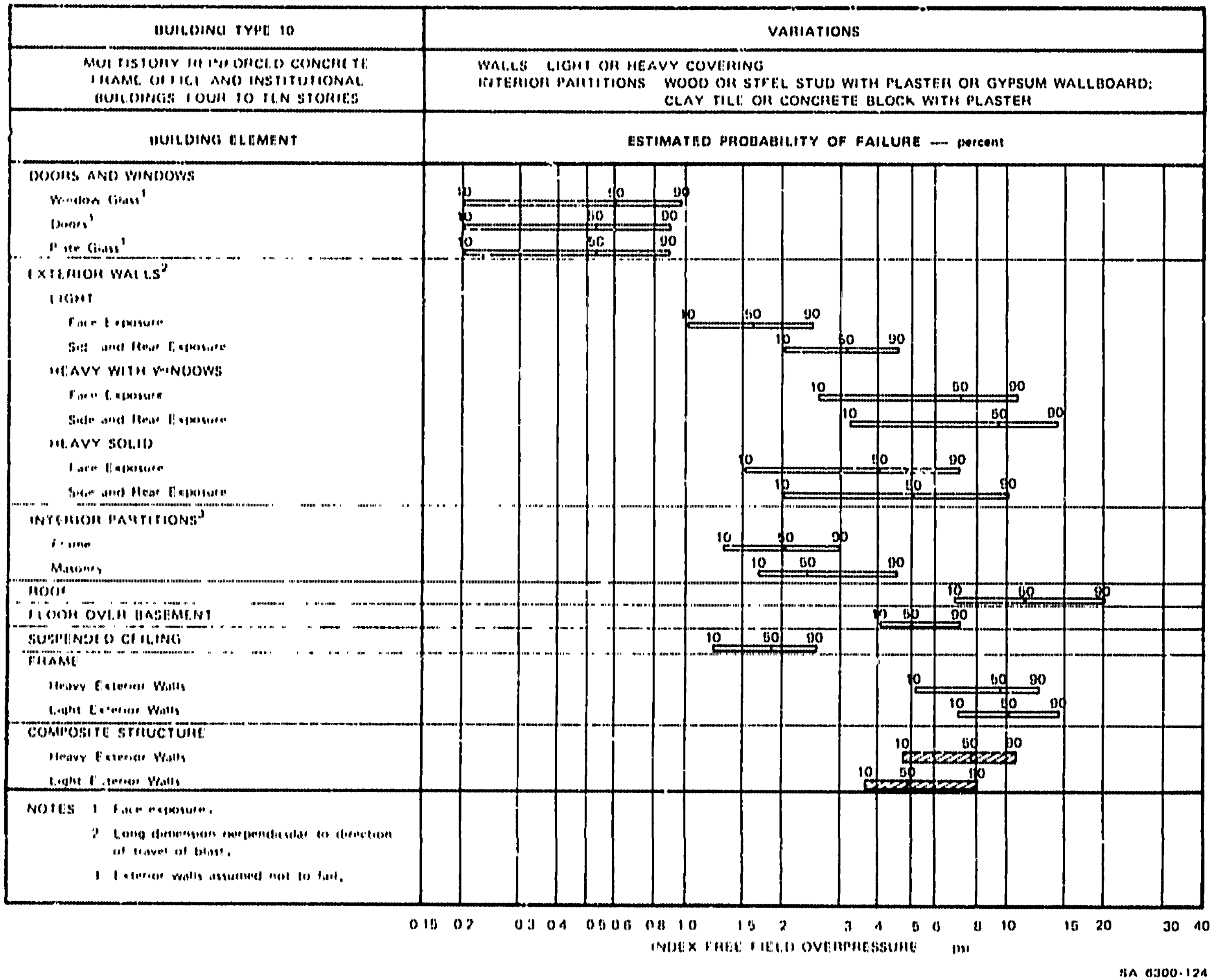
BUILDING TYPE 10
VARIATIONS
MULTISTORY REINFORCED CONCRETE FRAME OFFICE AND INSTITUTIONAL BUILDINGS FOUR TO TEN STORIES
WALLS LIGHT OR HEAVY COVERING
INTERIOR PARTITIONS WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALLBOARD; CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Plate Glass[1]
EXTERIOR WALLS[2]
LIGHT
Face Exposure
Side and Rear Exposure
HEAVY WITH WINDOWS
Face Exposure
Side and Rear Exposure
HEAVY SOLID
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS[3]
Frame
Masonry
ROOF
FLOOR OVER BASEMENT
SUSPENDED CEILING
FRAME
Heavy Exterior Walls
Light Exterior Walls
COMPOSITE STRUCTURE
Heavy Exterior Walls
Light Exterior Walls
NOTES 1 Face exposure.
2 Long dimension perpendicular to direction of travel of blast.
3 Exterior walls assumed not to fail.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE psi
SA 6300-124

Masonry--shattered or at least 75% collapsed.

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

Floor over Basement

Failure is defined as any deflection amounting to 1/20 of longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor deflections amounting to 1/20 of the story height. Collapse of the frame is imminent.

Vertical Core

Severe cracking and distortion of walls. Collapse is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period.

Because of differences in the resulting load on the frame, two categories of composite structure are required:

1. Reinforced concrete frame with light wall coverings.
2. Reinforced concrete frame with heavy wall coverings.

Failure in each of these categories includes any or combinations of the following:

1. All exterior walls and interior partitions blown out.
2. Severe distortion or collapse of the frame.
3. Severe cracking and distortion of vertical core walls.

It is expected that failure of the light wall composite structure will be controlled by the first of the above criteria, while failure of the heavy wall composite structure will be controlled by the last two criteria.

TYPE 11

Building Description and Failure Definitions

Building Type

Tall steel frame office buildings, more than ten stories. Light and heavy wall covering variations.

General Description and Variations

This building type includes all steel frame office buildings of more than ten stories. These are generally found only in the downtown areas of large cities. The frame is of fireproof construction, with masonry, concrete, and, more recently, sprayed asbestos plaster being used as the fireproofing medium. The elevator and stairwell core, generally of reinforced concrete, is assumed to help carry the vertical and lateral load.

Interior layouts are varied with relatively large open spaces.

Because of the height of the building, exterior walls are usually of lightweight construction, such as aluminum or stainless steel panels or curtain walls. Large window areas are usually prevalent. In some cases, relatively heavy coverings, primarily masonry or precast concrete units, may be used.

Interior partitions are also generally of lightweight construction, including: (1) plaster of gypsum wallboard on steel studs, (2) gypsum block, and (3) metal or wood movable partitions.

Floor construction includes: (1) open web joists with steel decking and a lightweight concrete covering and (2) reinforced concrete slabs, with or without support beams. Suspended ceilings are generally used to provide a flat ceiling and to hide lighting and ventilation systems.

Roofs are flat with "built-up" coverings and are usually of the same type of construction as the floors.

Failure Definitions

Glass Doors and Windows

Cracked, holed, or shattered.

Exterior Walls

At least 75% of wall blown out or collapsed.

Interior Partitions

Frame--50% or more of covering removed.
Masonry--collapsed or at least 75% blown out.

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

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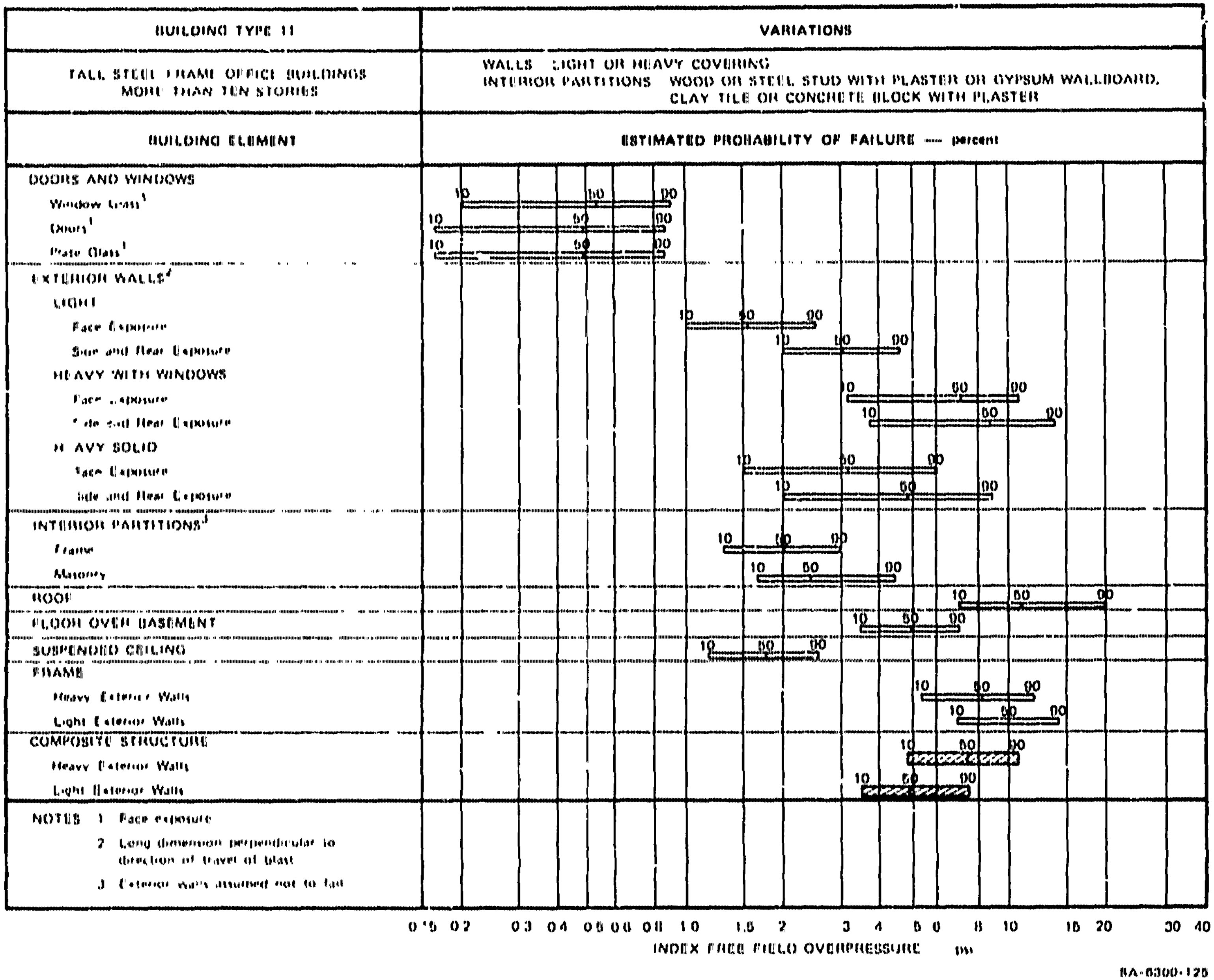

BUILDING TYPE 11
VARIATIONS
TALL STEEL FRAME OFFICE BUILDINGS MORE THAN TEN STORIES
WALLS LIGHT OR HEAVY COVERING
INTERIOR PARTITIONS WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALLBOARD, CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Plate Glass[1]
EXTERIOR WALLS[2]
LIGHT
Face Exposure
Side and Rear Exposure
HEAVY WITH WINDOWS
Face Exposure
Side and Rear Exposure
HEAVY SOLID
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS[3]
Frame
Masonry
ROOF
FLOOR OVER BASEMENT
SUSPENDED CEILING
FRAME
Heavy Exterior Walls
Light Exterior Walls
COMPOSITE STRUCTURE
Heavy Exterior Walls
Light Exterior Walls
NOTES 1 Face exposure
2 Long dimension perpendicular to direction of travel of blast
3 Exterior walls assumed not to fail
10
50
90
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE psi
RA-6300-125

Floor over Basement

Failure is defined as any deflection amounting to 1/20 of longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor displacements amounting to 1/20 of the story height. Collapse of the frame is imminent.

Vertical Core

Severe cracking and distortion of walls. Collapse is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times, but might be necessary because of a lack of new materials in the recovery period.

Because of differences in the resulting load on the frame, two categories of composite structure are defined:

1. Steel frame with light wall coverings.

2. Steel frame with heavy wall coverings.

Failure in either of these categories is defined as the occurrence of any or combinations of the following:

1. All exterior walls and interior partitions blown out.

2. Severe distortion or collapse of the frame.

3. Severe cracking and distortion of vertical core walls.

It is expected that failure of the light wall composite structure will be controlled by the first of the above criteria, while failure of the heavy wall composite structure will be controlled by the last two criteria.

TYPE 12

Building Description and Failure Definitions

Building Type

Tall reinforced concrete frame office buildings, more than ten stories. Light and heavy wall covering variations.

General Description and Variations

This building type includes all reinforced concrete frame office buildings of more than ten stories. These are generally found only in the downtown areas of large cities. The elevator and stairwell core, generally of reinforced concrete, is assumed to help carry the vertical and lateral load.

Interior layouts are varied with relatively large open spaces.

Exterior wall coverings include both light and heavy coverings. Light wall coverings consist primarily of metal panels or curtain walls often containing large window areas. Heavy wall coverings include: (1) masonry curtain or panel walls, with or without veneer and with or without a cavity; (2) precast concrete panels; and (3) reinforced concrete curtain or bearing walls. The height of the first story is generally greater than that of the upper stories, with the walls often consisting of large areas of glass.

Interior partitions include: (1) plaster or gypsum wallboard on wood or metal studs, (2) gypsum block, (3) movable wood or metal partitions, and (4) clay tile or concrete block with plaster.

Floor construction is generally reinforced concrete of one of the following types: (1) flat plate, (2) one-way joists, (3) two-way grids or "waffle" slabs, and (4) precast slabs. Composite steel and concrete slabs may also be used. Suspended ceilings are generally used in conjunction with these systems.

Roofs are flat with "built-up" coverings, usually of the same type of construction as the floors.

Failure Definitions

Doors and Windows

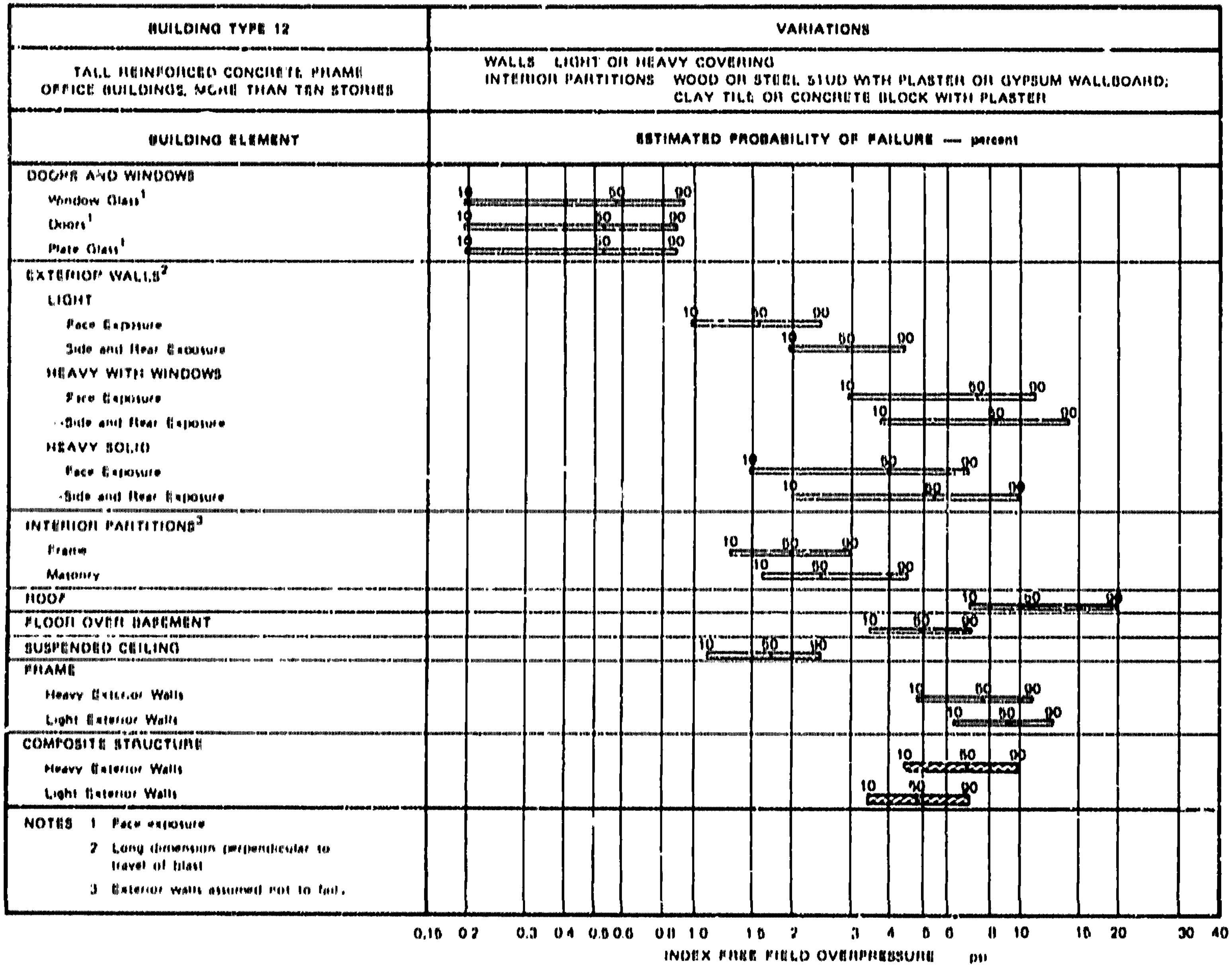
Window glass--cracked, holed, or shattered.
Doors--blown off hinges or panels shattered.
Window and door frames--split, shattered, or substantially removed from walls.

Exterior Walls

Walls shattered or at least 75% collapsed.

Interior Partitions

Frame--50% or more of covering removed.
Masonry--shattered or at least 75% collapsed.


BUILDING TYPE 12
TALL REINFORCED CONCRETE FRAME
OFFICE BUILDINGS, MORE THAN TEN STORIES
VARIATIONS
WALLS LIGHT OR HEAVY COVERING
INTERIOR PARTITIONS WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALLBOARD; CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Plate Glass[1]
EXTERIOR WALLS[2]
LIGHT
Face Exposure
Side and Rear Exposure
HEAVY WITH WINDOWS
Face Exposure
Side and Rear Exposure
HEAVY SOLID
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS[3]
Frame
Masonry
ROOF
FLOOR OVER BASEMENT
SUSPENDED CEILING
FRAME
Heavy Exterior Walls
Light Exterior Walls
COMPOSITE STRUCTURE
Heavy Exterior Walls
Light Exterior Walls
NOTES 1 Face exposure
2 Long dimension perpendicular to travel of blast
3 Exterior walls assumed not to fail.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE psi

SA-6300-126

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

Floor over Basement

Failure is defined as any deflection amounting to 1/20 of longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor deflections amounting to 1/20 of the story height. Collapse of the frame is imminent.

Ve[illegible]

[illegible]king and distortion of walls. Collapse is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period.

Because of differences in the resulting load on the frame, two categories of composite structure are required:

1. Reinforced concrete frame with light wall coverings.

2. Reinforced concrete frame with heavy wall coverings.

Failure in each of these categories includes any or combinations of the following:

1. All exterior walls and interior partitions blown out.

2. Severe distortion or collapse of the frame.

3. Severe cracking and distortion of vertical core walls.

It is expected that failure of the light wall composite structure will be controlled by the first of the above criteria, while failure of the heavy wall composite structure will be controlled by the last two criteria.

TYPE 13

Building Description and Failure Definitions

Building Type

One-story masonry, load-bearing wall school and institutional buildings.

General Description and Variations

This building type includes all one-story masonry, load-bearing wall schools and institutional buildings, such as hospitals and rest homes. Construction of this building type has been primarily since World War II, with the large bulk of schools constructed during this period falling in this category. Exceptions to this might be schools built in congested areas of large cities, where shortage of space may make construction of one-story structures impractical.

Typical layouts include both single and double rows of classrooms, with or without a corridor. Typical room sizes are 30 by 35 feet, with 10-foot ceilings. Large window areas are usually prevalent at least on one side of the classroom.

Exterior wall variations include: (1) solid brick, (2) brick facing on concrete block, (3) brick facing on structural clay tile, and (4) stucco on wood frame. Pilasters are often used at points where the roof framing bears on the exterior walls. These also provide lateral support for the walls.

Interior partitions include: (1) stud frame with gypsum board or plaster covering and (2) concrete block or structural clay tile with plaster covering.

Roofs are generally relatively flat, and consist of a concrete, gypsum plank or wood decking supported on concrete steel, or wood beams or steel joists or light trusses. Roof covering is generally of the "built-up" type.

Schools designed for earthquake or hurricane forces are not included in this building type. These structures, which are of similar construction but are prevalent only in certain areas of the country, are more resistant. Also not included are auditoriums or gymnasiums that may be adjacent to the above schools.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or shattered.
Window and door frames--substantially removed from walls.

Exterior Walls

At least 75% of wall collapsed.

Interior Partitions

Frame--50% or more of covering removed.
Masonry--collapsed or at least 75% blown out.

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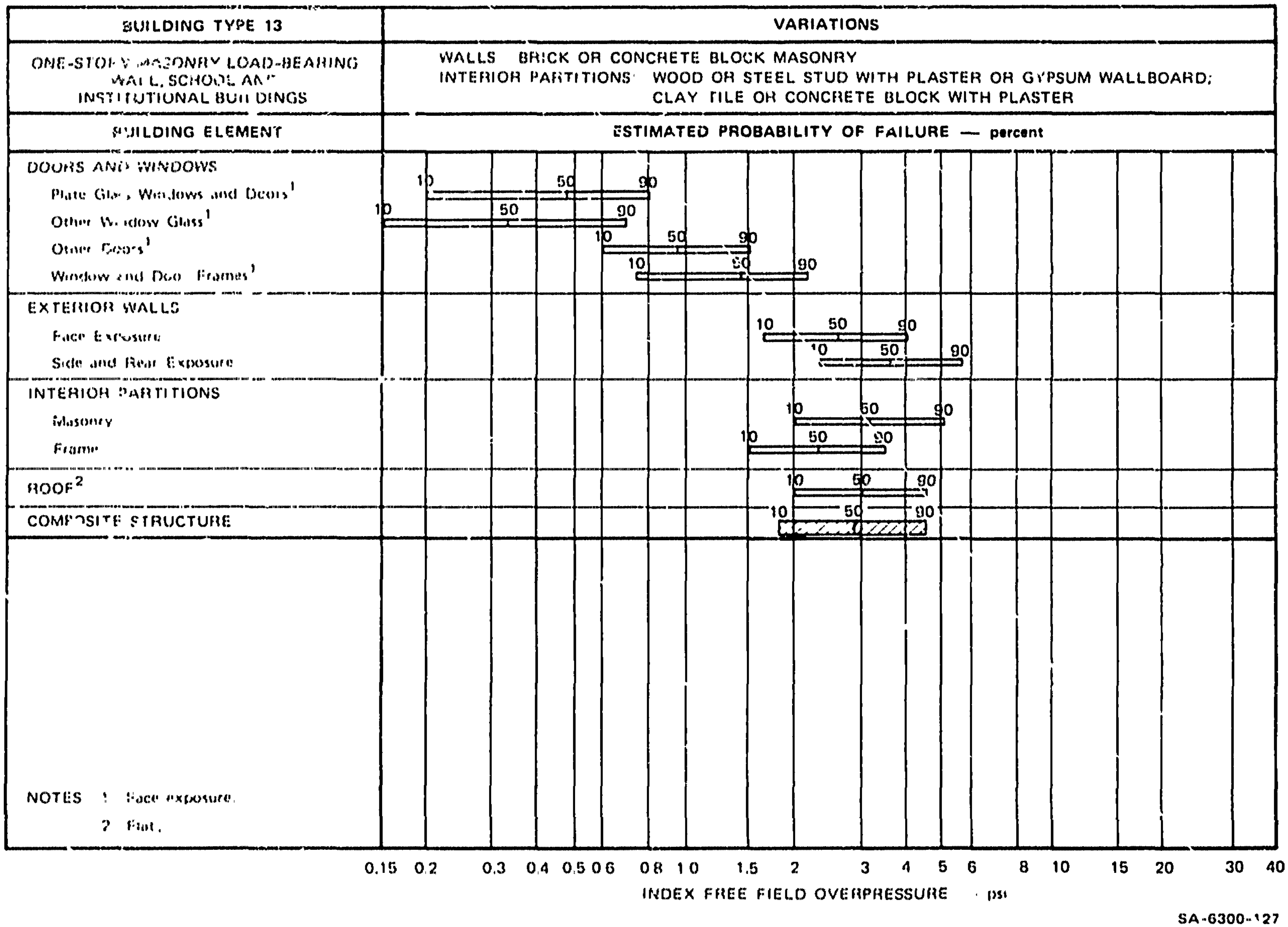
BUILDING TYPE 13
VARIATIONS
ONE-STORY MASONRY LOAD-BEARING WALL, SCHOOL AND INSTITUTIONAL BUILDINGS
WALLS BRICK OR CONCRETE BLOCK MASONRY
INTERIOR PARTITIONS WOOD OR STEEL STUD WITH PLASTER OR GYPSUM WALLBOARD; CLAY TILE OR CONCRETE BLOCK WITH PLASTER
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Plate Glass Windows and Doors1
Other Window Glass1
Other Doors1
Window and Door Frames1
EXTERIOR WALLS
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS
Masonry
Frame
ROOF2
COMPOSITE STRUCTURE
NOTES 1 Face exposure.
2 Flat.
10
50
90
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE — psi
SA-6300-127

Roof

Failure is defined as any deflection amounting to 1/20 of longest span.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would be on a brick-by-brick basis and would probably not be economical in ordinary times but might be necessary because of a lack of new materials in the recovery period. Failure includes either one or a combination of the following:

1. Roof collapse or gross displacement.
2. Collapse of the walls.

TYPE 14

Building Description and Failure Definitions

Building Type

Monumental masonry buildings, two to five stories, with and without frames.

General Description

This building type includes the large variety of monumental buildings, such as courthouses, government buildings, and banks. They are of two to five stories, and generally were constructed before World War II.

This type is characterized by very thick masonry load-bearing walls. A frame, the exterior columns of which are often imbedded in the exterior walls, may also be present. Floors and interior walls are similarly of massive construction. Often the buildings are ornate in appearance.

Exterior wall variations include: (1) brick, (2) varieties of stone, (3) stone facing on brick, (4) reinforced concrete, and (5) artificial stone.

Interior walls are generally of construction similar to that of exterior walls, although they are not often as thick.

Types of floor construction vary widely. Variations include brick and terr cotta flat-arch floors with concrete fill and concrete slabs on reinforced concrete or steel beam girders.

Roofs may be either flat or sloped. Flat roofs are generally of construction similar to that of the floors. Sloped roofs generally consist of a wood, steel, or concrete decking supported by wood or steel trusses. In some instances, domes made of wood, concrete, tile, or steel may also be present.

Structural frames are often used in conjunction with the lo d-bearing walls as interior supports for the floors and roof. These consist of wrought iron and cast iron members in many of the buildings constructed before 1900, with steel members generally used in the remainder of the buildings. Exterior columns are generally imbedded in the exterior masonry walls, with the interior columns fireproofed with masonry or concrete.

Failure Definitions

Doors and Windows

Window glass--cracked, holed, or shattered.
Doors--blown off hinges or shattered.
Window and door frames--substantially removed from walls.

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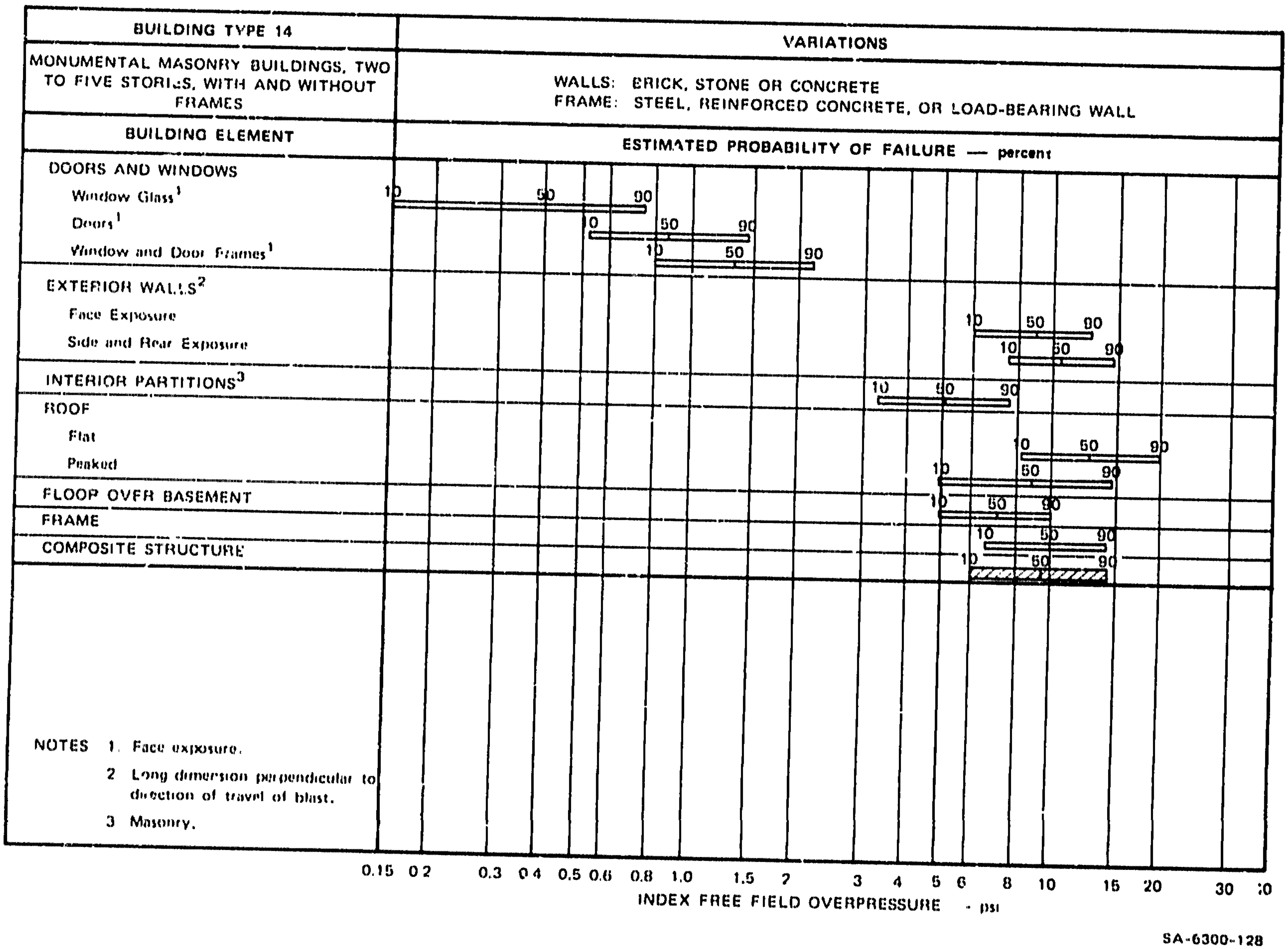

BUILDING TYPE 14
VARIATIONS
MONUMENTAL MASONRY BUILDINGS, TWO TO FIVE STORIES, WITH AND WITHOUT FRAMES
WALLS: BRICK, STONE OR CONCRETE
FRAME: STEEL, REINFORCED CONCRETE, OR LOAD-BEARING WALL
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
DOORS AND WINDOWS
Window Glass[1]
Doors[1]
Window and Door Frames[1]
EXTERIOR WALLS[2]
Face Exposure
Side and Rear Exposure
INTERIOR PARTITIONS[3]
ROOF
Flat
Peaked
FLOOR OVER BASEMENT
FRAME
COMPOSITE STRUCTURE
NOTES 1. Face exposure.
2 Long dimension perpendicular to direction of travel of blast.
3 Masonry.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 50
INDEX FREE FIELD OVERPRESSURE - psi
SA-6300-128

Exterior Walls

At least 75% of wall collapsed.

Interior Partitions

Collapsed or at least 75% blown out.

Roof

Flat--failure is defined as any deflection amounting to 1/20 of longest span.
Sloped--75% or more of roof trusses failed; gross displacement of roof system.

Floor over Basement

Failure is defined as any deflection amounting to 1/20 of the longest span.

Structural Frame

Severe distortion of the frame, with floor-to-floor displacements amounting to 1/20 of the story height. Collapse of the frame is imminent.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical because of outmoded type of construction. Failure includes any or combinations of the following:

1. Roof collapse or gross displacement.
2. Collapse of exterior walls.
3. Severe distortion or collapse of the frame.

TYPE 15

Building Description and Failure Definitions

Building Type

Masonry, load-bearing wall industrial type buildings, one story.

General Description and Variations

This building type includes all one-story industrial type of buildings of masonry, load-bearing wall construction. Typical uses include small manufacturing companies, warehouses, and some retail stores. Included in this category are the "tilt-up" wall types of buildings.

This type is characterized by large open areas. Typical bay widths are 20 feet, with span lengths of about 60 feet being common. Story heights range from about 11 to 20 feet.

Exterior wall variations include: (1) brick, (2) brick facing on concrete block, (3) concrete block, and (4) lightly reinforced concrete, primarily used for tilt-up walls.

Masonry pilasters or light steel columns are used in conjunction with the masonry walls to provide lateral support for the walls and also to provide additional bearing area for the roof framing. Light steel columns may be used in conjunction with the tilt-up wall type of construction.

Roofs are flat with "built-up" coverings. Roof deckings include: (1) corrugated metal panels attached to purlins spanning between deep steel beams or trusses; (2) concrete decking, with or without filler or wood decking supported on wood beams.

Partitions are generally not used, except in some cases to provide a small area for offices.

This type does not include buildings of more than two spans, which are more resistant, but not prevalent.

Failure Definitions

Exterior Walls

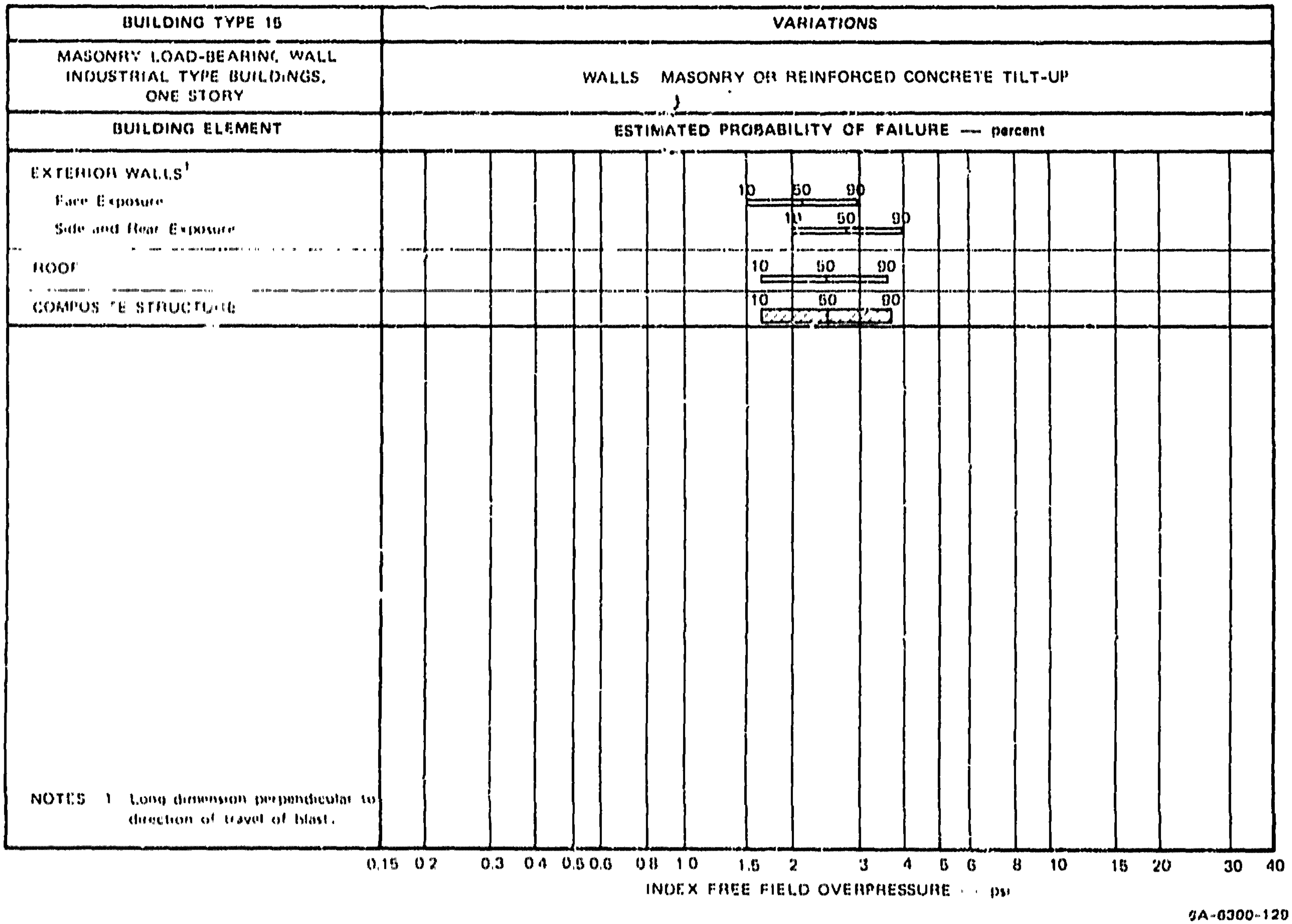
At least 75% of wall collapsed, including supporting pilasters or columns.

Roof

75% of decking removed for metal panel or wood roofs; gross displacement of roof system. For reinforced concrete roofs, failure is defined as any deflection amounting to 1/20 of the longest span.

Composite Structure

The composite structure is defined as the average structure among the various types included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as [illegible]


BUILDING TYPE 15
VARIATIONS
MASONRY LOAD-BEARING WALL INDUSTRIAL TYPE BUILDINGS, ONE STORY
WALLS MASONRY OR REINFORCED CONCRETE TILT-UP
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
EXTERIOR WALLS[1]
Face Exposure
10 50 90
Side and Rear Exposure
10 50 90
ROOF
10 50 90
COMPOSITE STRUCTURE
10 50 90
NOTES 1 Long dimension perpendicular to direction of travel of blast.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE — psi
9A-0300-120

use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times, but might be necessary because of a lack of new materials in the recovery period. Failure includes either one or a combination of the following:

1. Roof collapse or gross displacement.

2. Collapse of the walls.

TYPE 16

Building Description and Failure Definitions

Building Type

Light steel frame industrial-type buildings, one-story.

General Description and Variations

This building type includes the large variety of small to medium size, one-story industrial type of buildings of light steel frame construction. Typical uses include light industry, repair shops, warehouses, and some types of retail stores.

This type is characterized by long spans, up to approximately 40 feet, and tall story heights, up to about 30 feet. Common among this type is the "package" building prefabricated to modular sizes.

Exterior walls are generally of lightweight construction, consisting of corrugated steel, corrugated asbestos, or aluminum sheet panels attached to steel girts spanning between exterior columns. In some cases, brick or stone facing may also be used.

Roofs are generally sloped with corrugated metal or asbestos decking attached to purlins spanning between trusses or rafters. Variations in roof shapes include sawtooth roofs and the use of monitors, primarily to provide ventilation and lighting.

The steel framing is generally of the truss-on-column type, although more recently, rigid frame construction has been gaining popularity.

Partitions are generally not used, except in some cases to provide a small area for offices.

This type does not include industrial buildings with cranes, which are included in one-story, heavy steel frame industrial buildings. It also does not include the self-framing buildings, which are generally less resistant, but are not prevalent.

Failure Definitions

Windows

Window glass-cracked, holed, or shattered.
Window frames--substantially removed from walls.

Exterior Walls

Panels disengaged from fasteners: at least 75% of wall covering blown off.

Roof Covering

Panels disengaged from fasteners: at least 75% of roof covering blown off.

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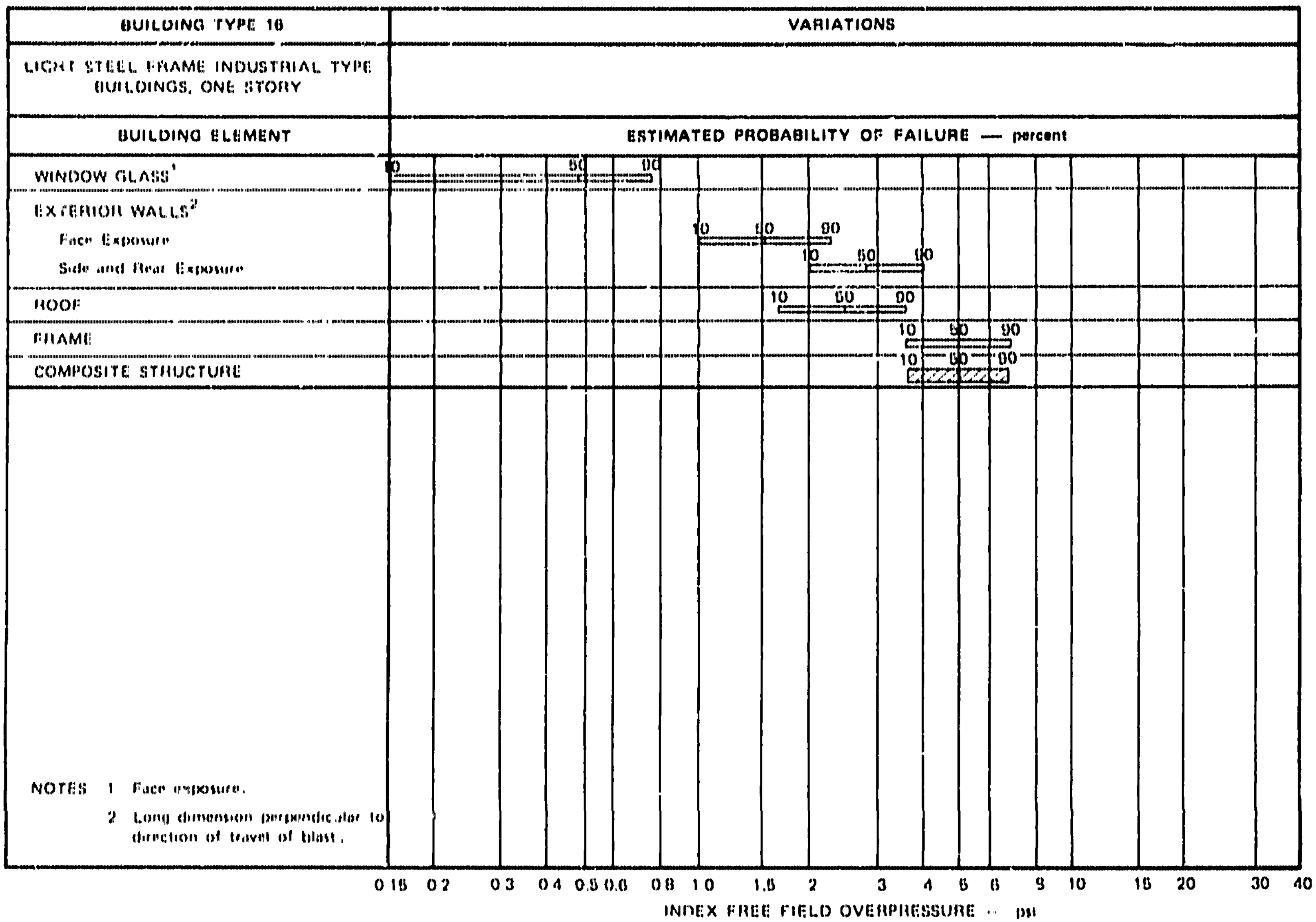
BUILDING TYPE 16
VARIATIONS
LIGHT STEEL FRAME INDUSTRIAL TYPE BUILDINGS, ONE STORY
BUILDING ELEMENT
ESTIMATED PROBABILITY OF FAILURE — percent
WINDOW GLASS[1]
EXTERIOR WALLS[2]
Face Exposure
Side and Rear Exposure
ROOF
FRAME
COMPOSITE STRUCTURE
10 50 90
NOTES 1 Face exposure.
2 Long dimension perpendicular to direction of travel of blast.
0.15 0.2 0.3 0.4 0.5 0.6 0.8 1.0 1.5 2 3 4 5 6 8 10 15 20 30 40
INDEX FREE FIELD OVERPRESSURE — psi

SA-6300-130

Structural Frame

Severe distortion of the frame, with lateral displacements of the roof on the order of 1/10 of the story height. Collapse of the frame is imminent. Failure is generally a function of the column strength, with the roof framing experiencing only minor damage until collapse occurs.

Composite Structure

The composite structure is defined as the average structure among the various types of buildings included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times, but might be necessary because of a lack of new materials in the recovery period. Because of the relatively large distinction between failure of the wall and roof coverings and the structural frame, failure of the composite structure is taken as being synonymous with failure of the structural frame.

TYPE 17

Building Description and Failure Definitions

Building Type

Heavy steel frame industrial-type buildings, one story.

General Description and Variations

This building type includes all one-story, heavy steel frame industrial buildings with up to 100-ton crane capacity and also all large multibay, multi-span, one-story, heavy steel frame industrial buildings without cranes. These buildings are primarily used in heavy manufacturing and are principally located in industrial areas of larger cities.

This type is characterized by one or more bays, each with one or more spans typically 40 feet in length, and by tall story heights, up to about 60 feet. Included among this type are the heavy framed "package" structure, prefabricated modular units, several of which may be combined in a single structure.

Exterior walls are generally of lightweight construction, consisting of corrugated steel, corrugated asbestos, or aluminum sheet panels attached to steel girts spanning between exterior columns. In some cases, brick or stone facing may also be used.

Roofs are generally sloped with corrugated metal or asbestos decking attached to purlins spanning between trusses or rafters. Variations in roof shapes include sawtooth roofs and the use of monitors, primarily to provide ventilation and lighting.

The steel framing is generally of the truss-on-column type, although more recently, rigid frame construction has been gaining popularity. Columns are used to support crane rails and are therefore very heavy.

Failure Definitions

Windows

Window glass—cracked, holed, or shattered.
Window frames--substantially removed from walls.

Exterior Walls

Panels disengaged from fasteners; at least 75% of wall covering blown off.

Roof Covering

Panels disengaged from fasteners; at least 75% of roof covering blown off.

Structural Frame

Severe distortion of the frame, with lateral displacements of the roof on the order of 1/10 of the story height. Collapse of the frame is imminent. Failure is generally a function of the column strength, with the roof framing experiencing only minor damage until collapse occurs.

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BUILDING TYPE 17	VARIATIONS
HEAVY STEEL FRAME INDUSTRIAL-TYPE BUILDINGS, ONE STORY	
BUILDING ELEMENT	ESTIMATED PROBABILITY OF FAILURE — percent

WINDOW GLASS[1]

EXTERIOR WALLS[2]

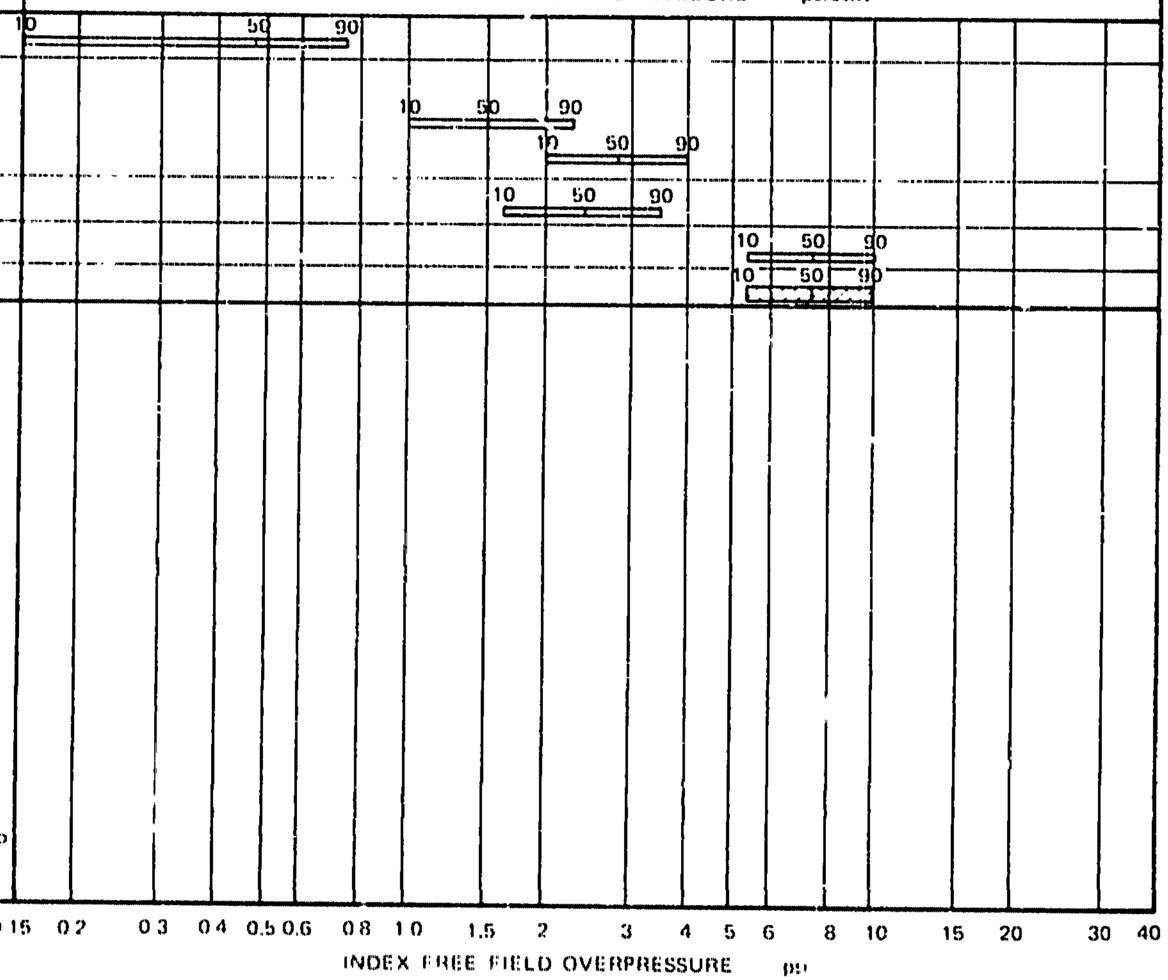
Face Exposure

Side and Rear Exposure

ROOF

FRAME

COMPOSITE STRUCTURE



NOTES 1 Face exposure.

2 Long dimension prependicular to direction of travel of blast.

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Composite Structure

The composite structure is defined as the average structure among the various types of buildings included in the general description, taking into account variances in age, orientation, and environment. Failure is defined as damage precluding use for intended purposes without major reconstruction. Salvage and reconstruction would probably not be economical in ordinary times, but might be necessary because of a lack of new materials in the recovery period. Because of the relatively large distinction between failure of the wall and roof coverings and the structural frame, failure of the composite structure is taken as being synonymous with failure of the structural frame.

Appendix A

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Appendix B

PROGRAM FOR ESTIMATING CUMULATIVE PROBABILITY OF FAILURE AS A FUNCTION OF AN AIR BLAST PARAMETER

Appendix B

PROGRAM FOR ESTIMATING CUMULATIVE PROBABILITY OF FAILURE AS A FUNCTION OF AN AIR BLAST PARAMETER

BETA

```
100  REM*************************************************************
102  REM
104  REM  BETA -- PRØGRAM FØR ESTIMATING CUMULATIVE PRØBABILITY
106  REM          ØF FAILURE VALUES USING THE BETA PRØBABILITY
108  REM          DISTRIBUTIØN FUNCTIØN (T = 8)
110  REM
112  REM          PRØGRAMMED BY JAMES L. BØCKHØLT
114  REM
116  REM          JULY 1971
118  REM
120  REM          THIS PRØGRAM IS BASED ØN THE PRØCEDURE GIVEN
122  REM          IN SECTIØN III FØR ESTIMATING THE PARAMETERS
124  REM          ØF THE BETA DISTRIBUTIØN FUNCTIØN AND CALCU-
126  REM          LATING THE CØRRESPØNDING CUMULATIVE PRØBABILITY
128  REM          ØF FAILURE VALUES.  LEAST-SQUARES PØLYNØMIALS
130  REM          WERE DETERMINED FØR THE CURVES IN FIGURES 3 AND
132  REM          4 USING STANDARD REGRESSIØN ANALYSIS PRØGRAMS.
134  REM          IN ADDITIØN, A RØUTINE WAS DEVELØPED TØ PLØT THE
136  REM          CUMULATIVE PRØBABILITY ØF FAILURE VALUES VERSUS
138  REM          THE AIR BLAST PARAMETER.
140  REM
142  REM          THIS PRØGRAM IS WRITTEN IN AN ADVANCED VERSIØN
144  REM          ØF "BASIC" TIME-SHARING LANGUAGE.  IT HAS BEEN
146  REM          CHECKED AS THØRØUGHLY AS PØSSIBLE, BUT THE USER
148  REM          ASSUMES RESPØNSIBILITY FØR ANY RESULTS ØBTAINED.
150  REM
152  REM*************************************************************
154  REM
156  DIM Y[100],T$[25]
158  REM  INPUT ESTIMATED FAILURE VALUES
160  PRINT LIN(1);"INPUT MØST LIKELY VALUE ØF FAILURE";
162  INPUT Y2
164  PRINT "INPUT LØWEST REASØNABLE VALUE (10%) ØF FAILURE";
166  INPUT Y1
168  PRINT "INPUT HIGHEST REASØNABLE VALUE (90%) ØF FAILURE";
170  INPUT Y3
172  REM
174  REM  CALCULATE VALUES ØF R (USING LEAST-SQUARES PØLYNØMIAL
176  REM  ØF CURVE IN FIGURE 3)
178  R1=Y3-Y1
180  R2=(Y2-Y1)/R1
182  IF R2>.5 THEN 188
184  R3=R2
186  GØTØ 190
188  R3=1-R2
190  R0=1.23243+.719704*R3+11.9325*R3↑2-4.60697*R3↑3
```


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```
192  IF R2>.5 THEN 198
194  R=R0
196  GØTØ 200
198  R=8-R0
200  C1=2.33*R1
202  Y0=Y2-.388*(R-1)*R1
204  REM
206  REM  CALCULATE CUMULATIVE PRØBABILITY ØF FAILURE VALUES
208  REM  (USING LEAST-SQUARES PØLYNØMIALS ØF CURVES IN FIGURE 4)
210  Y[10]=Y0+C1*(-.045705+4.46238E-02*R+9.06293E-03*R*R)
212  Y[20]=Y0+C1*(-5.91302E-02+7.73782E-02*R+6.20046E-03*R*R)
214  Y[30]=Y0+C1*(-5.83442E-02+9.90383E-02*R+4.17249E-03*R*R)
216  Y[40]=Y0+C1*(-5.44237E-02+.119168*R+1.97669E-03*R*R)
218  Y[50]=Y0+C1*(-4.26911E-02+.135673*R)
220  R4=8-R
222  Y[60]=Y0+C1*(1-(-5.44237E-02+.119168*R4+1.97669E-03*R4*R4))
224  Y[70]=Y0+C1*(1-(-5.83442E-02+9.90383E-02*R4+4.17249E-03*R4*R4))
226  Y[80]=Y0+C1*(1-(-5.91302E-02+7.73782E-02*R4+6.20046E-03*R4*R4))
228  Y[90]=Y0+C1*(1-(-.045705+4.46238E-02*R4+9.0629E-03*R4*R4))
230  Y[100]=Y0+C1
232  REM
234  REM  ØUTPUT BETA DISTRIBUTIØN FUNCTIØN PARAMETERS AND
236  REM  TABLE ØF CUMULATIVE PRØBABILITY ØF FAILURE VALUES
238  PRINT LIN(2),"BETA PRØBABILITY DISTRIBUTIØN FUNCTIØN ANALYSIS"
240  PRINT "-----------------------------------------------"
242  PRINT  USING 260;Y0
244  PRINT  USING 262;R,Y[100]
246  PRINT LIN(2),"PRØBABILITY ØF FAILURE      AIR BLAST PARAMETER"
248  PRINT SPA(9),"(%)",SPA(21),"(PSI)"
250  PRINT "----------------------      ------------------"
252  PRINT  USING 264;0,Y0
254  FØR I=10 TØ 100 STEP 10
256  PRINT  USING 264;I,Y[I]
258  NEXT I
260  IMAGE 4X,"T = 8.00",8X,"LØWER END PØINT =",DDD.DD
262  IMAGE 4X,"R =",DD.DD,8X,"UPPER END PØINT =",DDD.DD
264  IMAGE 8X,4D,21X,DDD.DD
266  REM
268  REM
270  REM  PLØT CUMULATIVE PRØBABILITY ØF FAILURE VALUES VERSUS
272  REM  AIR BLAST PARAMETER (GØØD FØR Y(100) <= 28)
274  PRINT LIN(3)
276  FØR I=1 TØ 22
278  READ T$[I]
280  NEXT I
282  DATA "P","R","Ø","B","A","B","I","L","I","T","Y"
284  DATA " ","Ø","F"," ","F","A","I","L","U","R","E"
286  Z$="."
288  REM
```

```
290 REM  CALCULATE INTERMEDIATE VALUES ØF CUMULATIVE
292 REM  PRØBABILITY ØF FAILURE USING SECØND-ØRDER
294 REM  INTERPØLATIØN FØRMULA
296 F1=Y[10]-Y0
298 F2=Y[20]-2*Y[10]-Y0
300 Y[5]=Y0+.5*F1-.125*F2
302 FØR J=10 TØ 40 STEP 10
304 F1=Y[J+10]-Y[J]
306 F2=Y[J+20]-2*Y[J+10]+Y[J]
308 Y[J+5]=Y[J]+.5*F1-.125*F2
310 NEXT J
312 FØR J=50 TØ 100 STEP 10
314 F1=Y[J-10]-Y[J]
316 F2=Y[J-20]-2*Y[J-10]+Y[J]
318 Y[J-5]=Y[J]+.5*F1-.125*F2
320 NEXT J
322 REM
324 REM  DETERMINE VALUE ØF HØRIZØNTAL INTERVAL (D1) AND
326 REM  NUMERICAL INCREMENT FØR AXIS LABEL (N)
328 IF Y[100]>2 THEN 336
330 D1=.05
332 N=1
334 GØTØ 364
336 IF Y[100]>5 THEN 344
338 D1=.1
340 N=1
342 GØTØ 364
344 IF Y[100]>11 THEN 352
346 D1=.2
348 N=1
350 GØTØ 364
352 IF Y[100]>13 THEN 360
354 D1=.25
356 N=2
358 GØTØ 364
360 D1=.5
362 N=2
364 N1=N*INT(Y[100]/N+1)
366 REM
368 REM  PLØT VERTICAL AXIS LABELS AND CUMULATIVE
370 REM  PRØBABILITY ØF FAILURE VALUES
372 S=0
374 DEF FNG(X)=INT(Y7/D1+.5)+14
376 FØR I=100 TØ 10 STEP -10
378 Y7=Y[I]
380 S=S+1
382 IF I=50 THEN 388
384 PRINT T$[S,S];TAB(8);I;TAB(14);"+";TAB(FNG(X));Z$
386 GØTØ 390
```

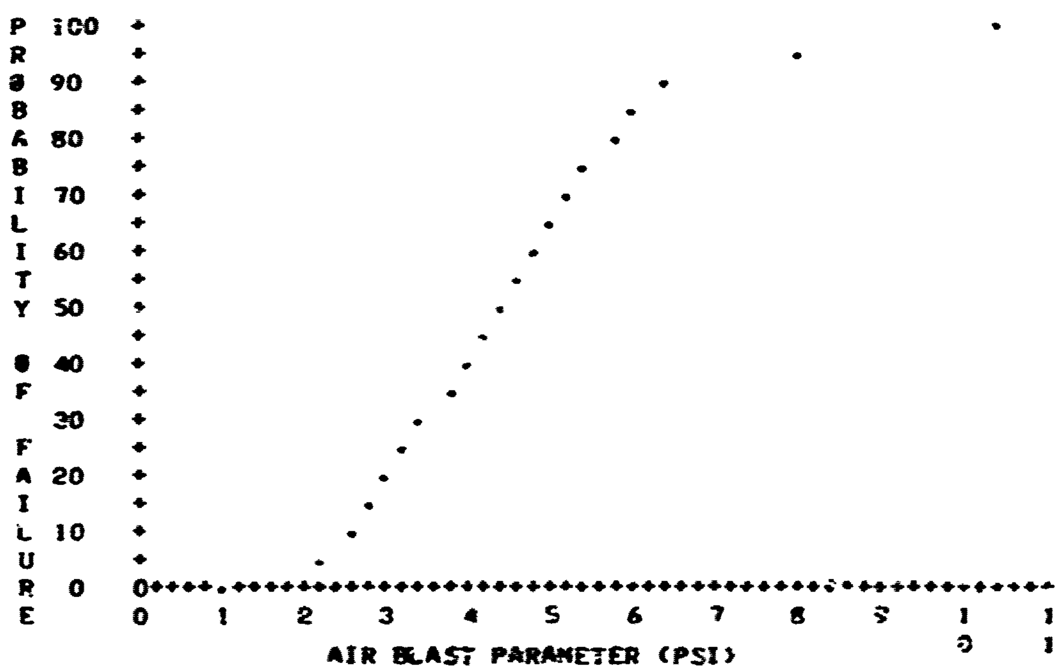
```
388  PRINT T$[S,S];" (%)";TAB(8);I;TAB(14);"+";TAB(FNG(X));Z$
390  Y7=Y[I-5]
392  S=S+1
394  IF FNG(X) <= 0 THEN 400
396  PRINT T$[S,S];TAB(14);"+";TAB(FNG(X));Z$
398  GØTØ 408
400  IF FNG(X)<0 THEN 406
402  PRINT T$[S,S];TAB(14);Z$
404  GØTØ 408
406  PRINT T$[S,S];TAB(14);"+"
408  NEXT I
410  REM
412  REM  PLØT HØRIZØNTAL AXIS LABELS
414  Y7=Y0
416  S=S+1
418  PRINT T$[S,S];TAB(10);"0";TAB(14);
420  IF FNG(X)=0 THEN 426
422  PRINT "C";
424  GØTØ 428
426  PRINT Z$;
428  N2=N1/D1
430  FØR I=1 TØ N2
432  IF FNG(X)=I+14 THEN 438
434  PRINT "+";
436  GØTØ 440
438  PRINT Z$;
440  NEXT I
442  PRINT
444  S=S+1
446  PRINT T$[S,S];
448  FØR I=0 TØ N1 STEP N
450  IF I>9 THEN 458
452  IMAGE #,D
454  PRINT  USING 452;TAB(14+I/D1),I
456  GØTØ 460
458  PRINT  USING 452;TAB(14+I/D1),INT(I/10)
460  NEXT I
462  PRINT
464  IF N1<10 THEN 474
466  FØR I=10 TØ N1 STEP N
468  PRINT  USING 452;TAB(14+I/D1),I-10*INT(I/10)
470  NEXT I
472  PRINT
474  PRINT
476  PRINT TAB(25),"AIR BLAST PARAMETER (PSI)"
478  PRINT LIN(5)
480  STØP
482  END
```

INPUT MOST LIKELY VALUE OF FAILURE?4.0
INPUT LOWEST REASONABLE VALUE (10%) OF FAILURE?2.5
INPUT HIGHEST REASONABLE VALUE (90%) OF FAILURE?6.5

BETA PROBABILITY DISTRIBUTION FUNCTION ANALYSIS

T = 8.00   LOWER END POINT = 0.99
R = 2.54   UPPER END POINT = 10.31

PROBABILITY OF FAILURE (%)	AIR BLAST PARAMETER (PSI)
0	0.99
10	2.52
20	3.06
30	3.50
40	3.91
50	4.31
60	4.73
70	5.19
80	5.73
90	6.47
100	10.31



Appendix C

AIR BLAST PARAMETER CHARTS FOR 5-Mt EXPLOSIONS

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USE OF AIR BLAST PARAMETER CHARTS

Example - 5-Mt Surface Burst

Step 1 - Select desired value of peak overpressure (p). Construct horizontal line (1) intersecting peak overpressure curve. (Example - 5 psi)

Step 2 - Construct vertical line (2) from previous intersection, intersecting other parameter curves and distance scale. Read distance to which the value of peak overpressure extends. (Example - 4.6 miles)

Step 3 - From intersection of vertical line and peak dynamic pressure curve, construct horizontal line (3) to left scale and read value of peak dynamic pressure. (Example - 0.74 psi)

Step 4 - From intersection of vertical line and peak wind velocity curve, construct horizontal line (4) to right scale and read value of peak wind velocity. (Example - 160 mph)

Step 5 - From intersection of vertical line and positive phase duration curve, construct horizontal line (5) to right scale and read value of positive phase duration. (Example - 5.4 secs)

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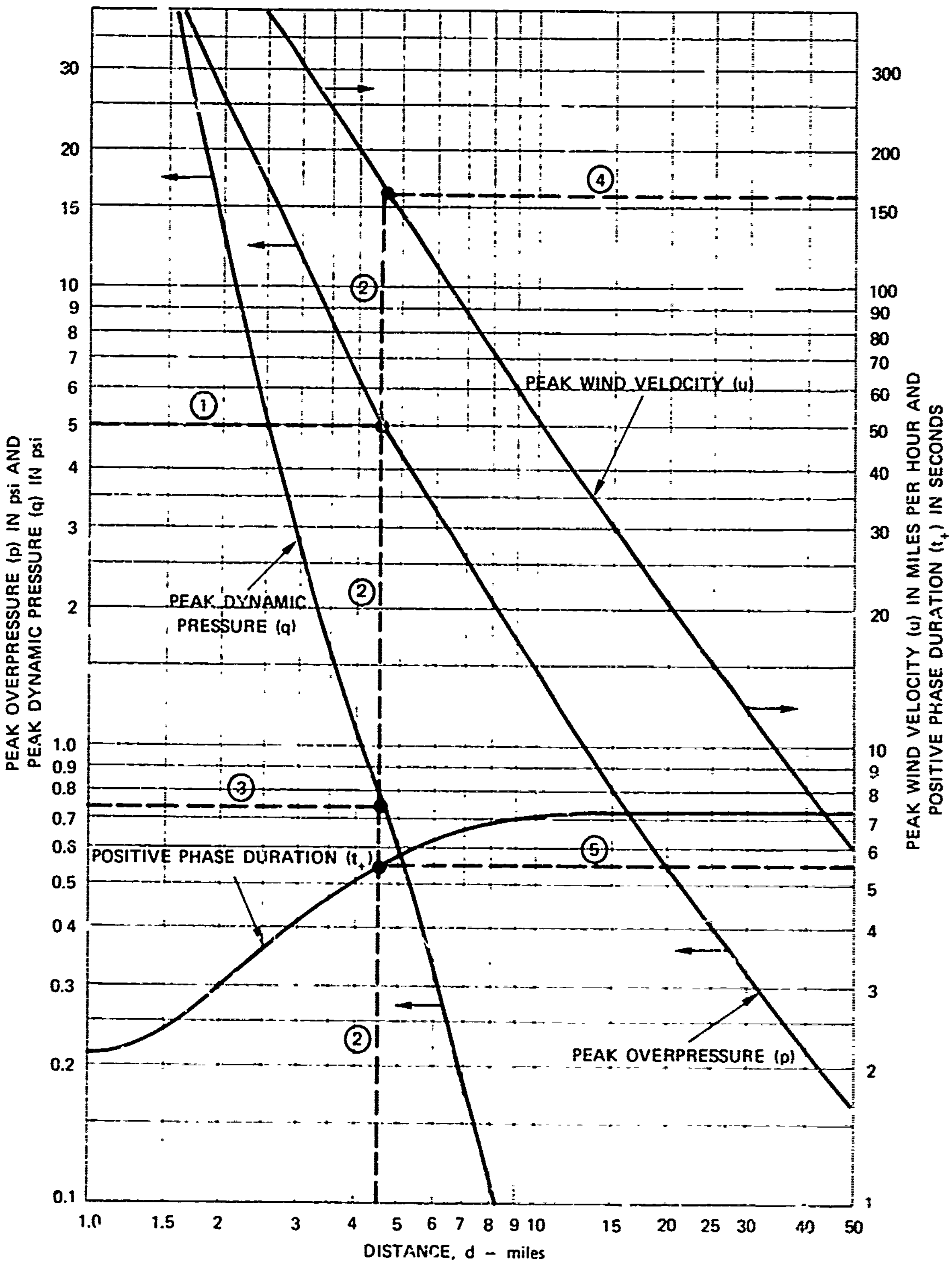

FIGURE C-1 AIR BLAST PARAMETERS VERSUS GROUND DISTANCE, 5-Mt SURFACE BURST

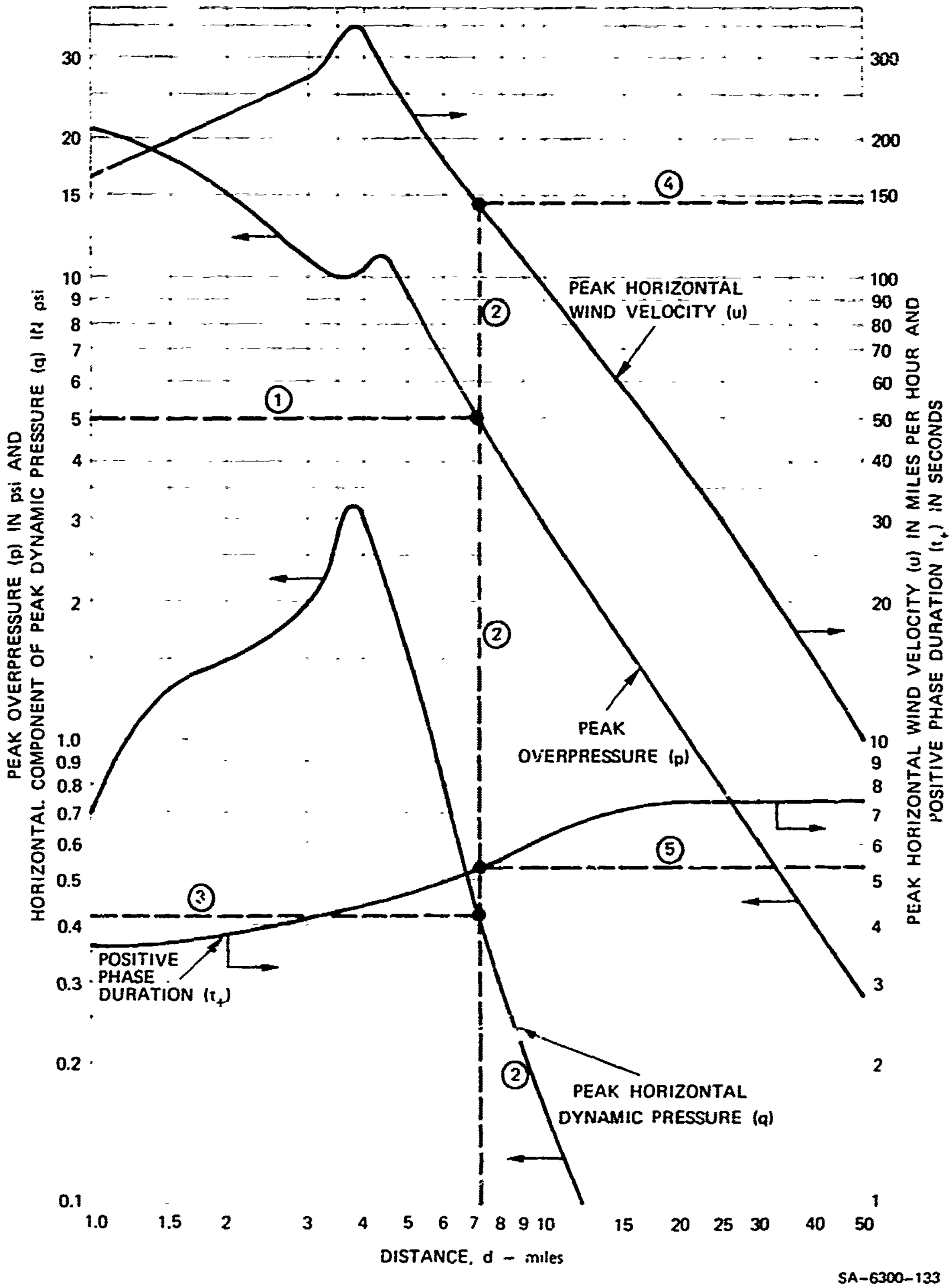

FIGURE C-2 AIR BLAST PARAMETERS VERSUS GROUND DISTANCE, 5-Mt AIR BURST AT 14,500 feet HOB