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URS 686-5

STRUCTURAL DEBRIS AND BUILDING DAMAGE PREDICTION METHODS

FINAL REPORT

June 1968

OCD Work Unit 3312B

Contract Number 12471 (6300A-310)

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URS SYSTEMS CORPORATION

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by

James E. Edmunds

URS RESEARCH COMPANY
1811 Trousdale Drive
Burlingame, California 94010

Prepared for

OFFICE OF CIVIL DEFENSE
Office of the Secretary of the Army
Washington, D.C. 20310

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Summary
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Summary Report

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STRUCTURAL DEBRIS AND BUILDING DAMAGE PREDICTION METHODS

INTRODUCTION

This report is divided into two sections. The first one summarizes ~~all of~~ the research that went into the development of the model to predict the amounts of structural debris resulting from the blast and fire effects of a nuclear weapon attack on an urban area. The second section explains how the data accumulated in the process of developing the debris prediction model can be utilized to predict damage to buildings.

DEBRIS PREDICTION MODEL

The debris prediction model consists of:

- debris charts
- volume factors for structural material
- volume factors for contents

The Japanese experiences at Hiroshima and Nagasaki, and the weapons tests in Nevada and in the Pacific, as well as structural dynamics calculations were the basis for the debris charts. The charts predict the percent of the structure becoming debris as a function of the incident overpressure, and may be used for buildings subjected to the effects of blast alone, or to the combined effects of blast and fire. There are debris charts for twenty structure categories. Factors have been developed to determine the quantities of material in each structure category. These factors are multiplied by the contained volume of the structure to give cubic yards of material. No characteristics of the material are obtained by use of these factors, other than combustibility or noncombustibility. Factors have also been developed to determine the quantities of contents present in eighteen different occupancy categories.

Once the amount of debris is known, it is distributed over an area to determine the depth. An assumption of even distribution is made, and no differentiation is made between on-site and off-site debris. It is desirable to include a number of buildings, usually an entire block, in an area for the purposes of calculating debris depths.

The debris charts and tables of structural and contents volume factors are included in the report.

GENERAL BUILDING DAMAGE PREDICTIONS

In the process of developing the debris prediction methods, a large amount of information concerning building damage was collected. With this information, URS has been able to predict building damage in terms of the percent of the various building components becoming debris, as distinct from predicting precisely which wall or which partition will be blown in. Great care must be taken not to make the damage predictions more detailed than is justified.

The more information that is known about a building, the more confidence one can have in the damage prediction process. The information contained on a Sanborn Map is the minimum amount necessary to predict damage. Photographs of the building are desirable to ascertain the locations and sizes of windows, which have a great effect on the loading of the building.

The process of predicting building damage is as follows. Once the building details and incident overpressure are determined, the debris charts are used to get an overall estimate of damage. Then a table of damage to building elements is referred to in order to determine the damage to specific elements. The damage to interior elements is determined by considering how their loading is affected by the presence or absence of the exterior walls. By means of this procedure, an estimate of the overall damage may be made.

To assist in the application of the damage prediction method the report presents: (1) a table of damage to various building elements (e.g., 8-in. brick walls, 6-in. reinforced concrete wall, etc.), (2) a table that narratively describes the debris charts, and (3) descriptions of light, moderate, and severe damage to the categories of buildings covered by the debris charts. In addition, some examples are given that show the level of detail obtainable with the damage description method described herein.

ABSTRACT

This report is a compilation and summary of the efforts of the URS Corporation to develop a method to predict the amounts of structural debris that would result from the blast and fire effects of a nuclear weapon attack upon an urban area. The report is divided into two sections, the first dealing with the development of the debris prediction model and its use. The second section sets forth a method to predict building damage using the information accumulated during the development of the debris model.

CONTENTS

CONTENTS, cont.

ILLUSTRATIONS

ILLUSTRATIONS, cont.

TABLES

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Section 1
INTRODUCTION

BACKGROUND

URS Corporation has been studying the effects of nuclear weapons on buildings since 1963 under the sponsorship of the Office of Civil Defense (Refs. 1-4). The goal of this effort is to develop methodology which will enable prediction of the amount of debris that would be produced in an urban area by a nuclear attack. Charts showing the per cent of building material becoming debris as a function of incident overpressure have been developed. These charts are for either air blast only or for blast combined with fire effects. Using these charts, together with methods for estimating the volumes of potential debris (both structural and contents), one is able to predict debris depths for an area of interest.

Sufficient information on building damage was gathered during the development of these debris charts to permit qualitative damage predictions to be made for individual buildings.

NEED FOR HANDBOOK

Many of the contractors doing research for the Office of Civil Defense (OCD) have need for damage and/or debris predictions. Although URS has supplied some of the predictions in the past, it would often be much more efficient if each contractor could make his own predictions, as they are the ones who are most familiar with their requirements. It is hoped that this handbook will enable them to do this. It will also allow the predictions to be made as the contractors need them.

Another benefit of presenting URS' prediction methods in detail is that they likely will be more widely read and understood in a separate document than they are buried within the pages of a report. And, hopefully, this will stimulate constructive criticism, resulting in improved prediction methodology.

It is realized that this handbook will not solve all of the problems involved in predicting damage and debris. However, it will provide familiarity with current URS prediction techniques and enable those with a limited engineering background who have debris or damage prediction problems to effectively communicate with others who have the ability to assist them.

INTENDED USES

It is intended that the primary users of this document will be OCD contractors having need of debris or damage predictions in their research. General usage of the handbook will insure a degree of comparability of their predictions. The methods presented herein have numerous shortcomings. These shortcomings will be pointed out in some detail when the methodology is presented.

Section 2
PREDICTION OF DEBRIS

GENERAL

Ideally, debris is defined as the material contained in those portions of buildings that have undergone complete failure due to air blast and/or fire, and, thus, impede access to or through an area. For damage less than total collapse, access through an area can be greatly affected by the distribution of debris. In the total collapse case, there may be no difference between traveling through the site itself or going through what was originally the street. In examining the Japanese experiences, which were the primary data sources for the debris charts, it was not possible to distinguish between on-site and off-site debris.* Consequently, the definition of debris applicable to this study is the material contained in those portions of buildings that have undergone complete failure due to air blast, including fire effects if present.

The ability to predict debris depths depends upon the knowledge of how a building interacts with the air blast wave (and fire, if present), the amount of the debris produced, and how this amount is distributed. Methods to determine all of these unknowns have been developed by URS and will be presented in the following paragraphs. A distribution scheme assuming uniform distribution of the total debris volume has been adopted. Tables have been developed which relate the volume of structural material contained in a structure to specific structural categories, and the volume of contents has been related to the building's usage. Charts showing the per cent of structural material becoming debris as a function of overpressure have been constructed. With this information, the debris depth for any area of interest may be calculated.

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* On-site debris is defined as that which remains within the building. Off-site debris is that which is ejected from the building.

DEBRIS CHART DEVELOPMENT

Much of the existing information concerning building response to blast is in terms of light, moderate, and severe damage. These damage categories, while useful, do not directly relate to the debris production characteristics of a building. This is a very important point — structural debris and structural damage are not synonymous. For example, light damage occurs before any significant structural debris is produced, and severe damage generally does not correspond to 100 per cent debris. A reinforced concrete floor slab may be greatly deflected and severely cracked and would be considered severely damaged, but would produce virtually 0 per cent debris. A steel frame may be distorted, but it is not 100 percent debris until it has collapsed. However, these damage categories have been developed using information from the weapons tests as well as theoretical considerations, and were used to aid in constructing the debris production curves.

The concept behind the development of the debris charts was to utilize as much as possible the data gathered in actual experiences rather than use theoretical considerations. Thus the basis for the debris charts was the information contained in the United States Strategic Bombing Survey (USSBS) reports on Hiroshima and Nagasaki (Refs. 5 and 6). Gaps in the data were filled as much as possible by using information from the nuclear weapons tests in Nevada and the Pacific (Refs. 7-23). Since the basic data mostly came from low yield weapons, extrapolation to megaton yield weapons necessitated theoretical calculations.

In the USSBS report on Hiroshima, 173 individual buildings were surveyed, and the report contains, for most of the 173, information on floor plans, construction materials, amount and type of damage, and photographs from several vantage points. At Nagasaki, although a greater number of individual buildings were surveyed, the information gathered was much less detailed than at Hiroshima, and therefore was not as useful.

The data from the Nevada weapons tests were quite useful in the construction of the debris charts. Information was obtained concerning residential structures, industrial steel frame structures, and structure elements (such as wall panels). The Pacific tests did not give as much useable data, which is unfortunate, as some of the weapons were of megaton yields.

Six structure categories were distinguishable for debris prediction purposes from the USSBS reports on Hiroshima and Nagasaki.

- Wood frame (residential type)
- Masonry load-bearing wall (unreinforced)
- Light steel frame covered with lightweight walls and roof (industrial structure)
- Heavy steel frame (used to support a heavy crane) covered with lightweight walls and roof (industrial structure)
- Multistory steel or reinforced concrete frame structures designed to withstand earthquake loadings.
- Multistory steel or reinforced concrete frame structures not designed to withstand earthquake loadings

In general, structures may be classified (insofar as their response to a nuclear blast is concerned) as being either diffraction-sensitive or drag-sensitive. A diffraction-sensitive structure is one for which the primary cause of damage is overpressure (and the associated reflected pressure). This overpressure causes unbalanced forces during the time it takes the blast wave to travel from one side of the building (or element) to the other and become equalized. A drag-sensitive structure is one for which the differential pressure becomes equalized very rapidly, and the loading is primarily due to dynamic pressure (blast wind forces). An example of a purely diffraction-sensitive structure would be a low building without any openings, while a purely drag-sensitive structure would be a utility pole. Damage to a drag-sensitive structure is related to weapon yield, since the damage is dependent upon the duration of the positive phase as well as upon the magnitude of the dynamic pressure. Therefore, a given level of damage can be caused by either a short duration pulse with high dynamic pressure, or a long duration pulse with low dynamic pressure. On the other hand, a diffraction-sensitive structure undergoes its damaging loading for only as long as it takes the blast wave to travel from one side of the structure to the other, and this travel time is essentially the same for all yields for a given overpressure, so that damage is independent of yield. In actuality, structures are neither strictly drag nor diffraction-sensitive, but some combination of both.*

In the USSBS reports, each building was arranged by its major components, with before and after-damage presented for each component. The components were roof, exterior walls, framing, interior partitions, and floor. This breakdown enabled debris percentages to be estimated more accurately than if the building was considered as a whole. The per cent debris of each component was estimated, then multiplied times the component's volume. All of the debris volumes were added together, and compared to the undamaged volume giving the overall percentage of structural material that became debris.

The approach that was used to predict fire-caused debris was similar to that used to predict air-blast caused debris. This is, information from past events was used as much as possible. Of course, the Hiroshima and Nagasaki reports were quite useful, and these experiences were the only ones which included the combined effects of blast and fire. Other events which were used were the Chicago fire of 1871, the Baltimore fire of 1904, the Toronto fire of 1904, the San Francisco earthquake and fire of 1906, and the Hamburg, Germany attack and fire storm in 1943 (Refs. 25-31). In addition, various publications of the National Board of Fire Underwriters and of Underwriters Laboratories, Inc., giving fire resistance ratings and results of fire tests on various types of construction, were used (Refs. 32-34). The fire results were based upon the assumption of an uncontrolled mass fire which consumes all of the combustible material. No attempt was made to determine the redistribution of the combustible debris due to blast effects. It is possible that a structure severely damaged by air blast will have most of its contents ejected from the building and therefore have very little combustible material remaining. However, it is also possible in this case that the lower stories of the

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* A very good explanation of air-blast loading is contained in Chapter IV of Ref. 25, The Effects of Nuclear Weapons (ENW).

building and the streets around the building will be filled with combustible debris transported there from other buildings, and an uncontrolled fire will be sufficiently intense to cause building collapse.

WOOD FRAME STRUCTURES

This category refers to that type of construction generally found in residential buildings. The debris production starts at 2 psi and a building will be 100 per cent debris by 5 psi (Fig. 1). The reduction in debris due to fire will vary according to the type of exterior, and interior wall and ceiling construction. Accordingly, three horizonal lines representing the different constructions are shown, indicating the amount of incombustible material remaining after a fire.* Whether blast damage was sustained prior to burning would make little difference in the per cent of debris produced, since the blast effects would be essentially obliterated by the fire.

This type of building is quite diffraction sensitive, so no distinction is made in the amount of debris produced by either megaton or kiloton yield weapons.

LOAD-BEARING MASONRY STRUCTURES

This category includes all those buildings that have either brick or masonry block walls with no frame. This type of construction is very common in residences, one- to four-story apartment buildings, small retail stores, and industrial buildings. From the Japanese and weapons test data, the onset of debris production was set at 4 psi, and complete destruction at 9.5 psi (Fig. 2).

Damage and debris production due to fire are dependent upon the construction of interior floors and roof. If these are combustible so that the fire destroys them, then the incombustible walls lose their lateral support, and

* The results of fire (for every building type) are assumed to be for an uncontrolled fire that consumes all of the combustible material.

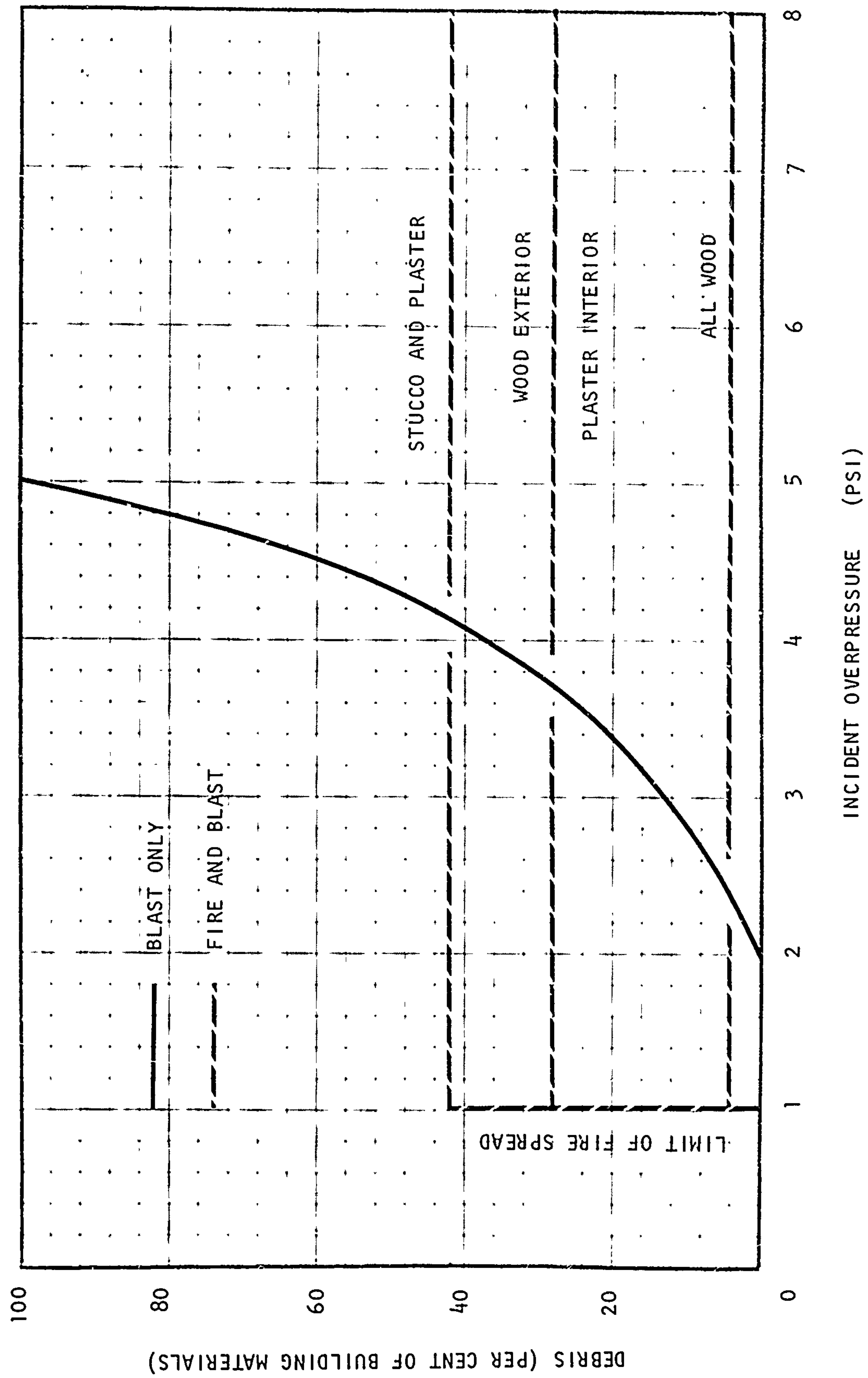

Fig. 1. Percent Debris vs Overpressure — Wood Frame Building

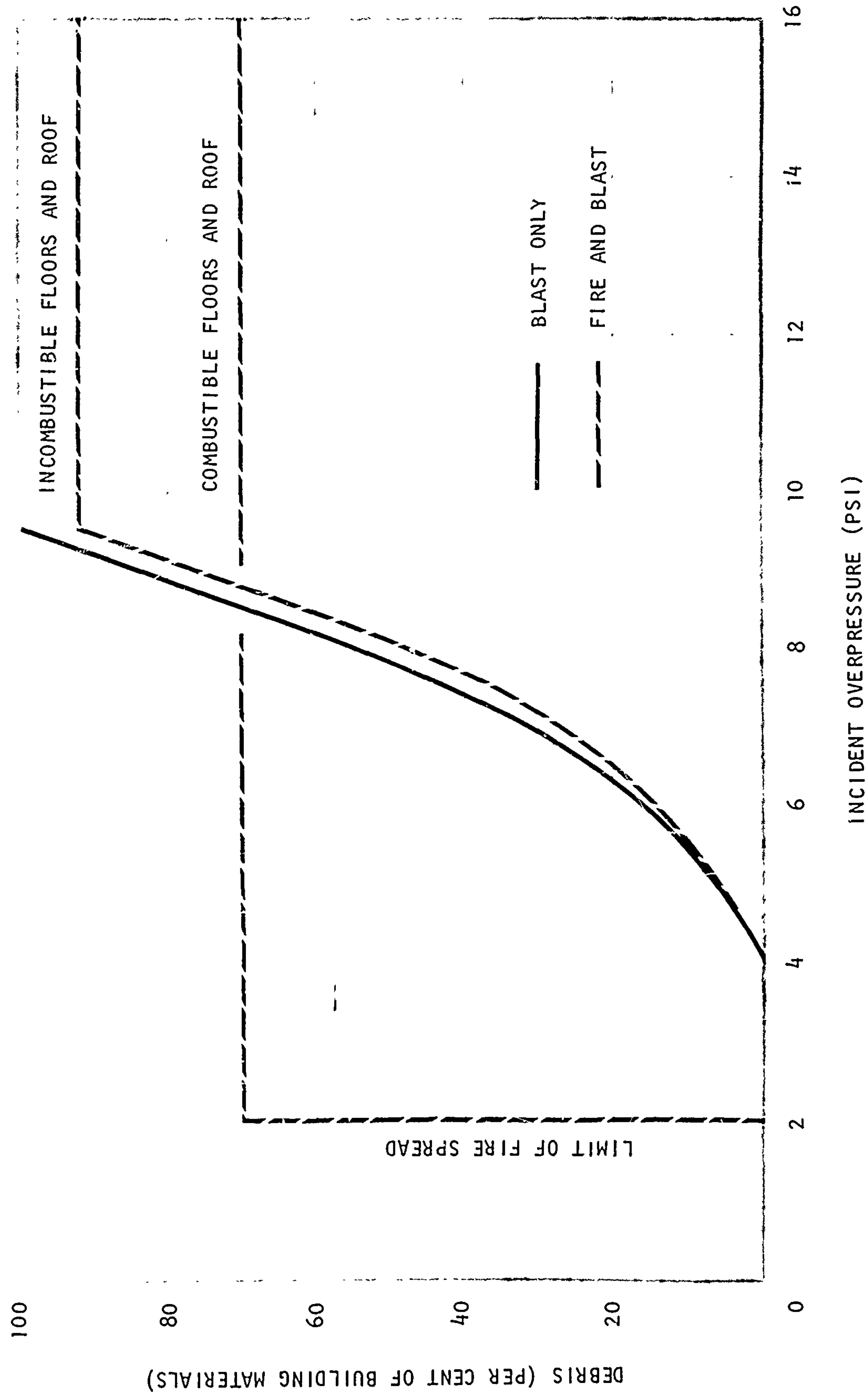

Fig. 2. Percent Debris vs Overpressure – Unreinforced Masonry Load-Bearing Wall Building

are likely to collapse. If this is the case, then blast damage would have little relationship to fire damage, and the per cent debris produced by fire would remain constant at that per cent representing the collapsed incombustible walls, regardless of the overpressure. If the floors are incombustible, then fire will only reduce the amount of blast-caused debris by the amount of combustible material present.

This type of building is essentially diffraction sensitive so the debris production curve does not change for different yield weapons.

STEEL FRAME INDUSTRIAL STRUCTURES (Light, Medium and Heavy)

Buildings in this category are typically found in industrial areas, and consist of a steel framework covered with either corrugated steel, corrugated asbestos, or flat sheet metal panels. Self-framing metal buildings, that is, those whose walls provide support for the roof without a separate frame, are also included in this category and may be compared to the structure having corrugated metal sheathing. Three separate classes of these buildings are considered. Light is without a crane, or having one with a capacity of 25 tons or less. The medium class includes all those having a 25 to 50 ton capacity crane, and the heavy class consists of all those having a crane with more than a 50 ton capacity. The columns of the medium and heavy industrial buildings are stronger and better able to withstand blast loads.

A typical failure pattern was apparent from the examination of data pertaining to this category. At a low overpressure, all of the siding and roofing failed and left only the frame standing. The frame, although distorted, remained standing unless the dynamic pressure was large enough to cause frame collapse due to drag loading. Thus if the overpressure necessary to cause failure in the covering was 2.5 psi, and that required to collapse the frame was 11 psi, for any overpressure between 2.5 and 11 psi, the debris produced by the structure would remain constant at that per cent representing the covering.

The actual curves (Figs. 3 through 8) show that the covering begins to fail at 1.5 psi, and all of it is failed by 2.5 psi. No more debris is produced until frame collapse, which cannot be set at an exact overpressure. Rather the final limb begins to rise at the point of incipient frame collapse and reaches 100 per cent debris at total collapse. Since instances of complete frame collapse were rare in the Japanese experiences, values of imminent collapse were taken from the curves predicting severe damage in TM 23-200 (Ref. 35). In this document, severe damage is defined as implying imminent collapse. To obtain some measure of the overpressure at which complete collapse occurs, the ductility* was assumed to be double that of severe damage, and the methods presented in Ref. 36 (which enable estimates to be made of the overpressure required to overcome building resistance) were applied.

Although these buildings are constructed of incombustible material, the frames are generally not fireproofed. As a result, when such a building is exposed to an intensive fire, the unprotected steel frame will usually collapse. Hence, the debris charts predict 100 per cent debris (building collapsed, no combustible material) if fire is present.

Since the frame of this structure is drag-sensitive, the increased duration of the drag loading of a megaton yield weapon will cause the same level of damage to occur at a lower overpressure than for a kiloton yield weapon. To adequately predict debris production, debris curves for a range of weapon yields must be constructed. Since only the terminal limb of the curve representing frame collapse is yield sensitive, multiple yields can be covered by constructing a family of terminal limbs imposed on the basic diffraction sensitive portion of the debris curve (initial rising limb and plateau).

To construct the multiyield debris charts, a pair of isodamage curves was constructed. One isodamage curve was plotted from the severe damage

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* Ductility is a measure of the deformation of a structure. In this instance it may be defined as the ratio of the deformation at severe (or collapse) damage to that when the frame is deformed to its yield deflection.

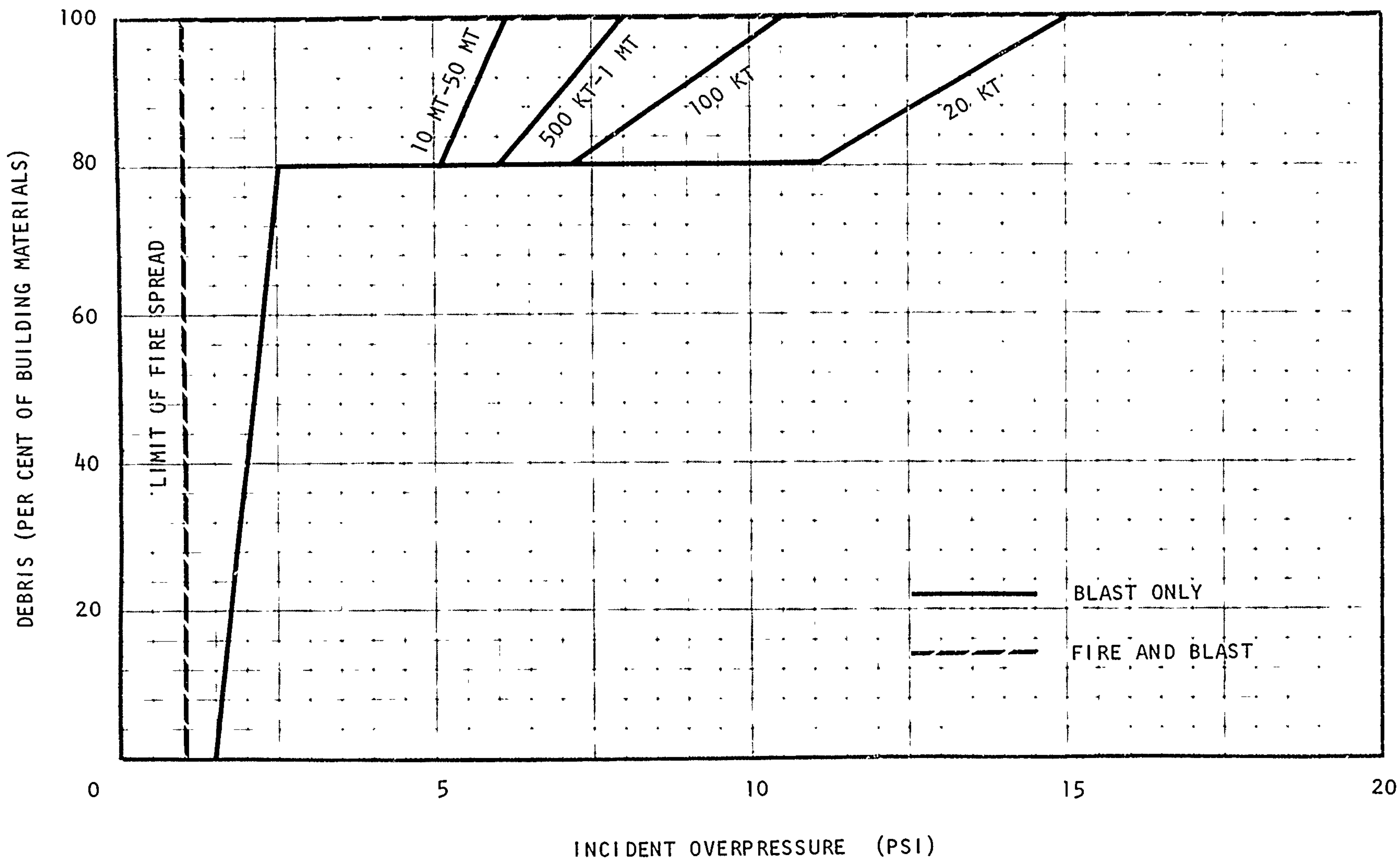

Fig. 3. Percent Debris vs Overpressure — Light Steel Frame Industrial Building (up to 25-ton crane) with Corrugated Asbestos Sheathing

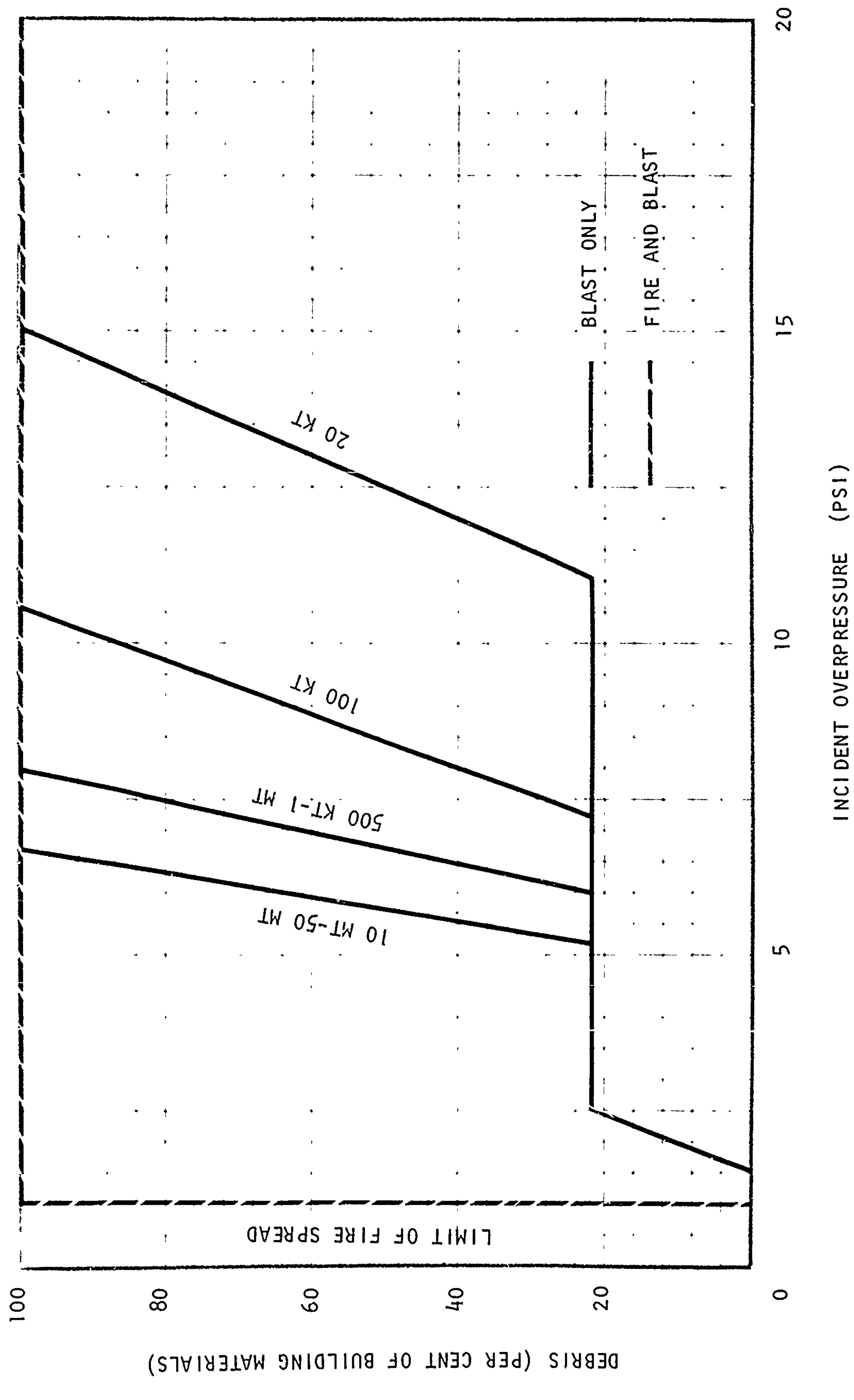

Fig. 4. Percent Debris vs Overpressure – Light Steel Frame Industrial Building (up to 25-ton crane) with Corrugated Metal Sheathing

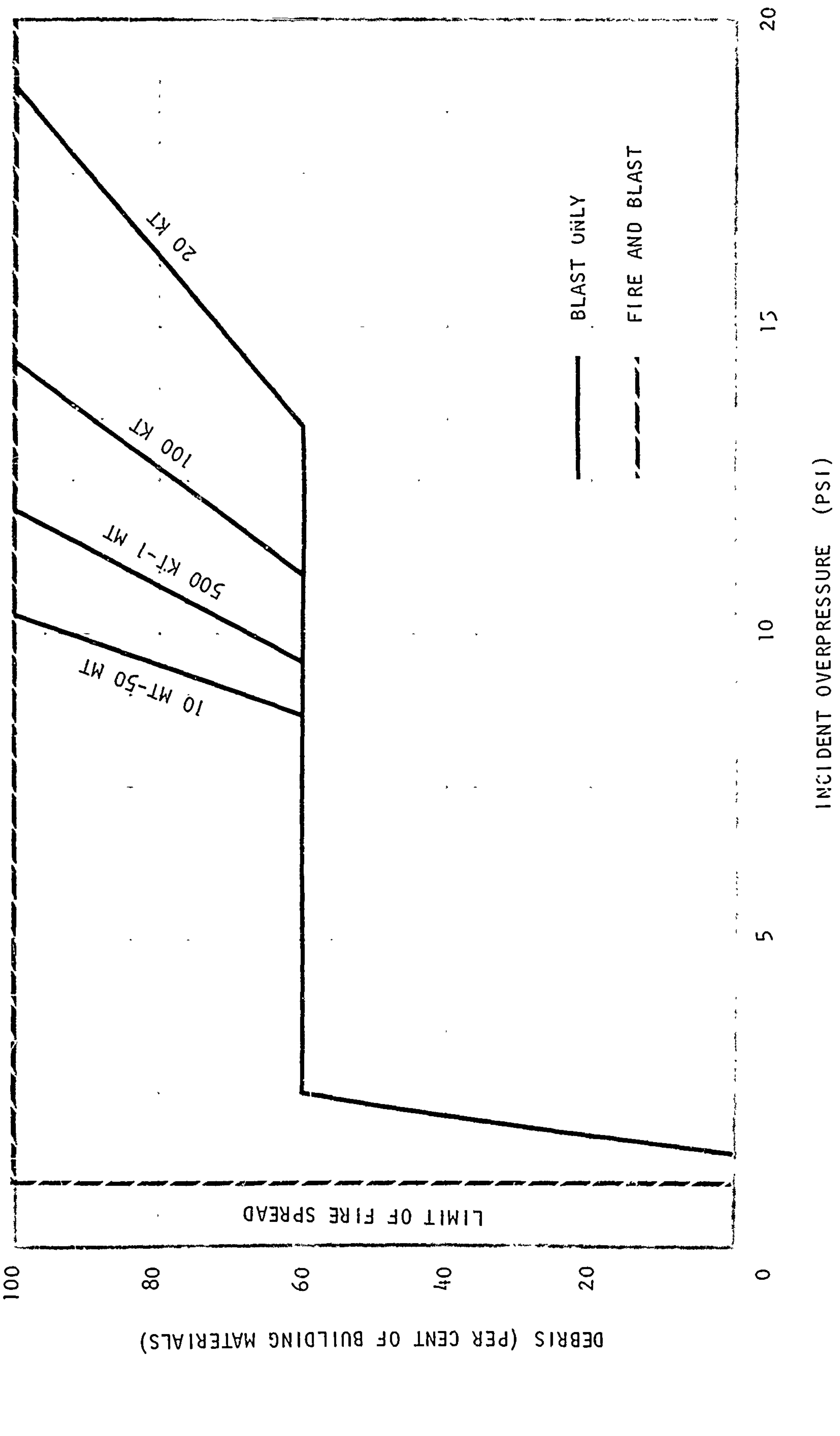

Fig. 5. Percent Debris vs Overpressure – Medium Steel Frame Industrial Building (25- to 50-ton crane) with Corrugated Asbestos Sheathing

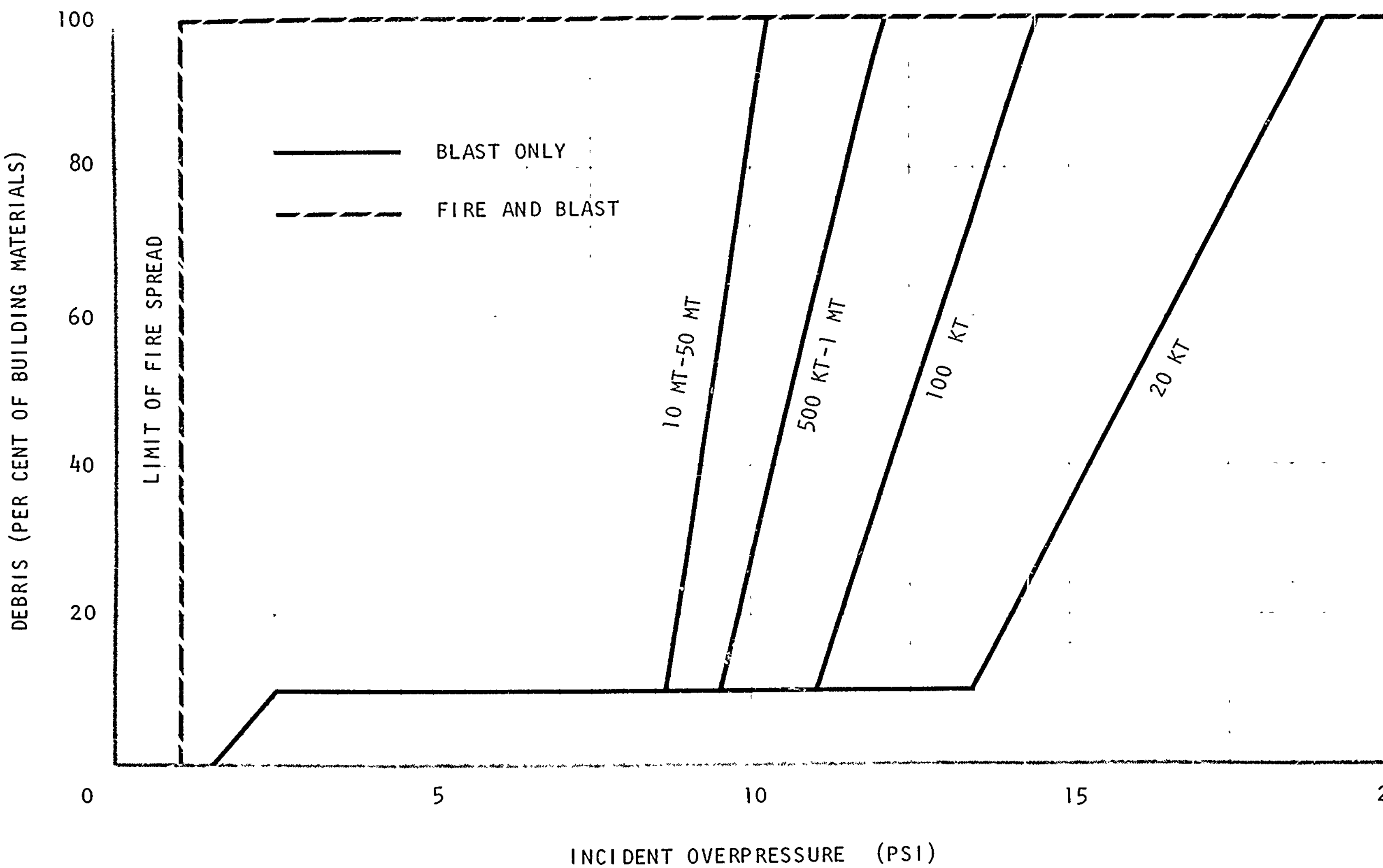

Fig. 6. Percent Debris vs Overpressure — Medium Steel Frame Industrial Building (25- to 50-ton crane) with Corrugated Metal Sheathing

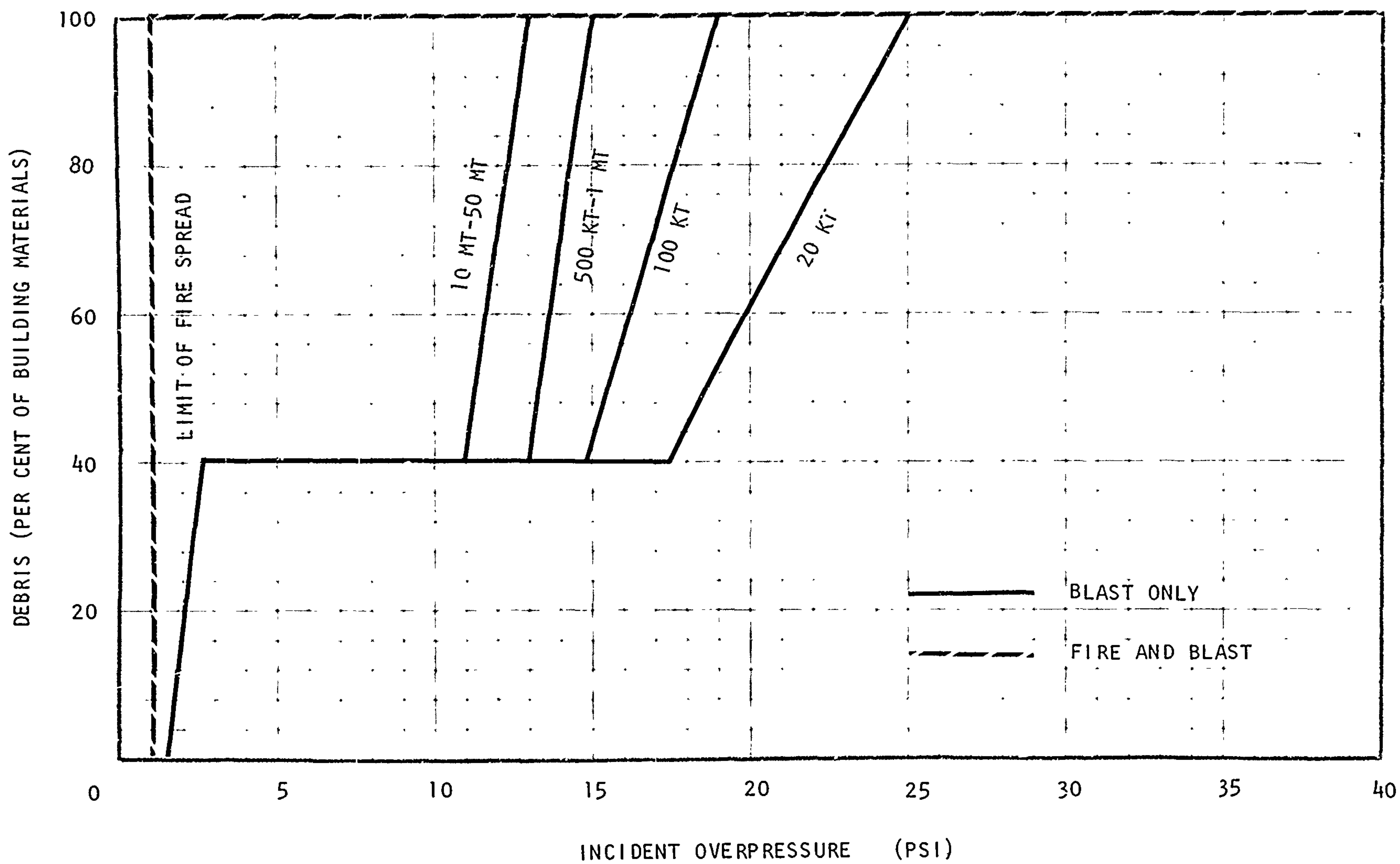

Fig. 7. Percent Debris vs Overpressure — Heavy Steel Frame Industrial Building (60- to 100-ton crane) with Corrugated Asbestos Sheathing

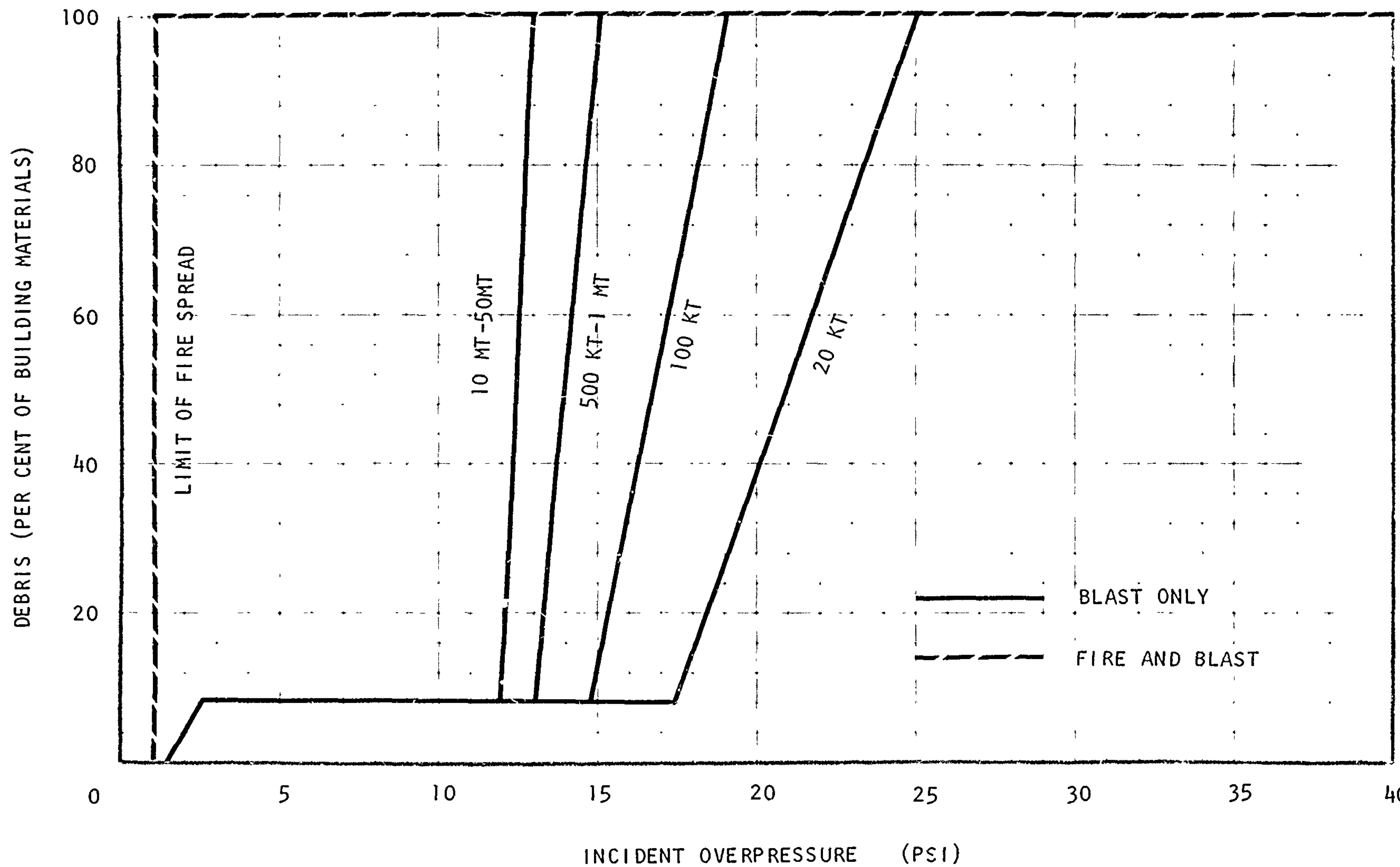

Fig. 8. Percent Debris vs Overpressure — Heavy Steel Frame Industrial Building (60- to 100-ton crane) with Corrugated Metal Sheathing

(incipient collapse) curve of TM 23-200. The other isodamage curve, representing complete collapse, was plotted by altering the ductility to reflect the amount of strain energy required to be absorbed by the structure in going from severe damage to total collapse, and then calculating the overpressures (using methods in Ref. 36) necessary to attain the altered ductility. These isodamage curves were plotted as weapon yield versus overpressure so that for any yield, the overpressure for severe damage, and for total collapse, could be picked off. Having these two overpressures, the terminal limbs were plotted for the yields of interest.

MULTISTORY STEEL OR REINFORCED CONCRETE FRAME STRUCTURES

This category originally covered a wide range of structures due to the nature of the Hiroshima and Nagasaki data. In later analyses, it was possible to refine this category considerably, and to develop a new category for reinforced concrete shear wall buildings from it. The final categories for frame buildings are:

- multistory steel or reinforced concrete frame buildings with earthquake design
    - with light panel exterior walls (Fig. 9)
    - with masonry panel exterior walls (Fig. 10)
- multistory steel or reinforced concrete frame buildings without earthquake design
    - with light panel exterior walls (Fig. 11)
    - with masonry panel exterior walls (Fig. 12)

The different types of wall construction affect the percentage of debris produced for the same level of building response. That is, masonry panel walls represent a much larger percentage of the total structural material than would light panel walls (such as prefabricated metal panels).

Debris production for this class of structure starts with failure of the panel walls and the interior partitions. Light panel exterior walls will

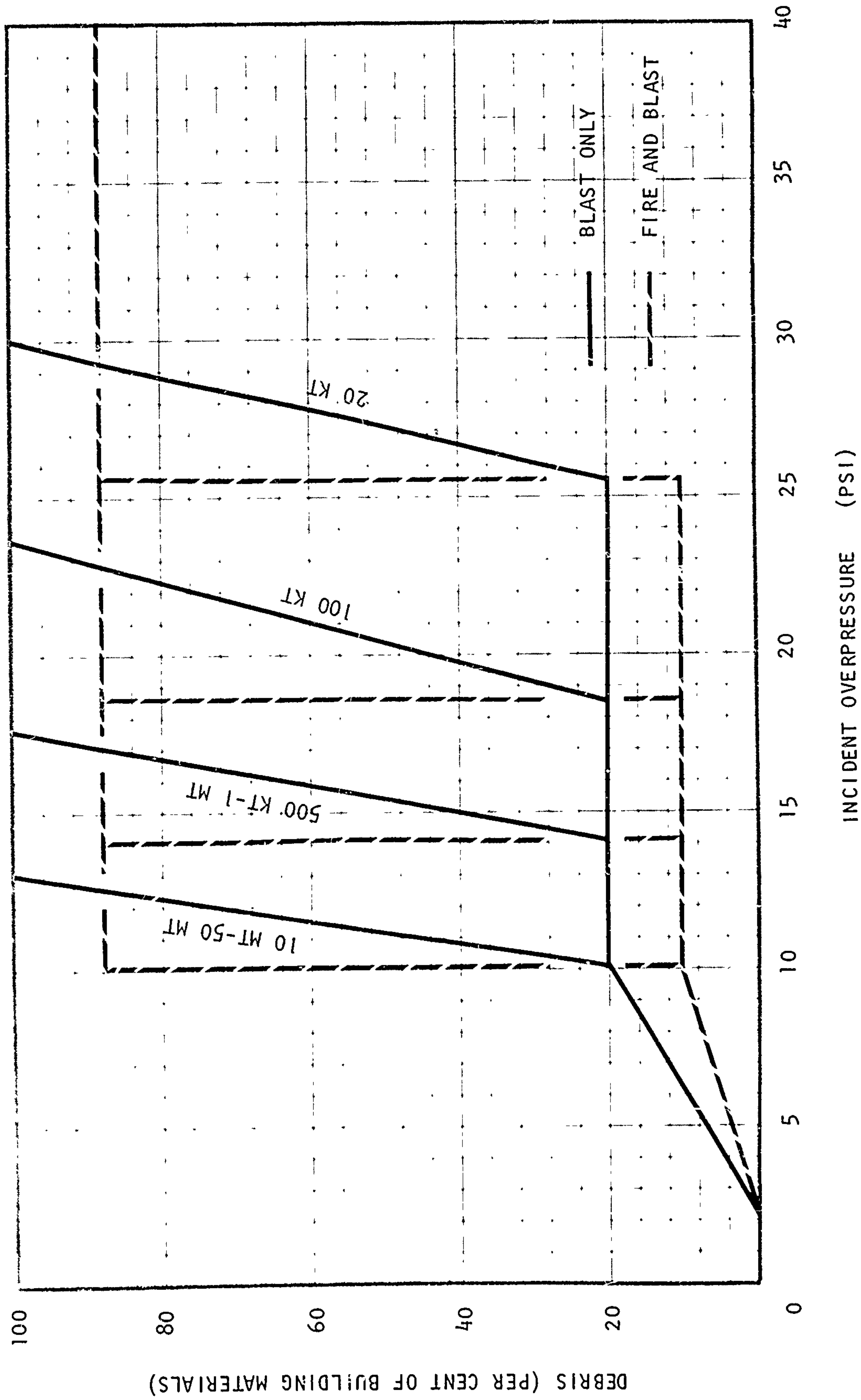

Fig. 9. Percent Debris vs Overpressure — Multistory Steel or Reinforced Concrete Frame Building with Light Exterior Panels - Earthquake Design

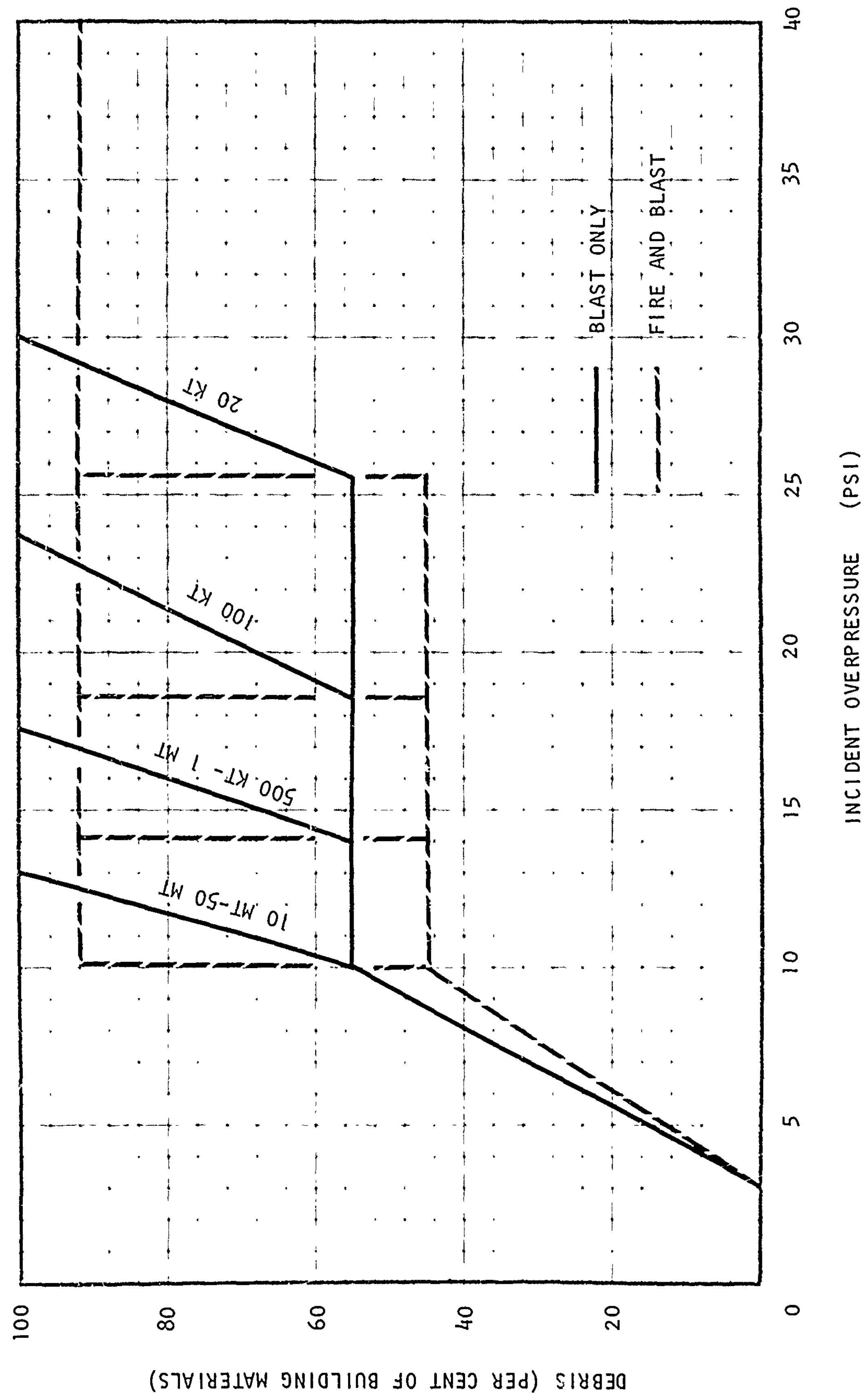

Fig. 10. Percent Debris vs Overpressure -- Multistory Steel or Reinforced Concrete Frame Building with Masonry Exterior Panels -- Earthquake Design

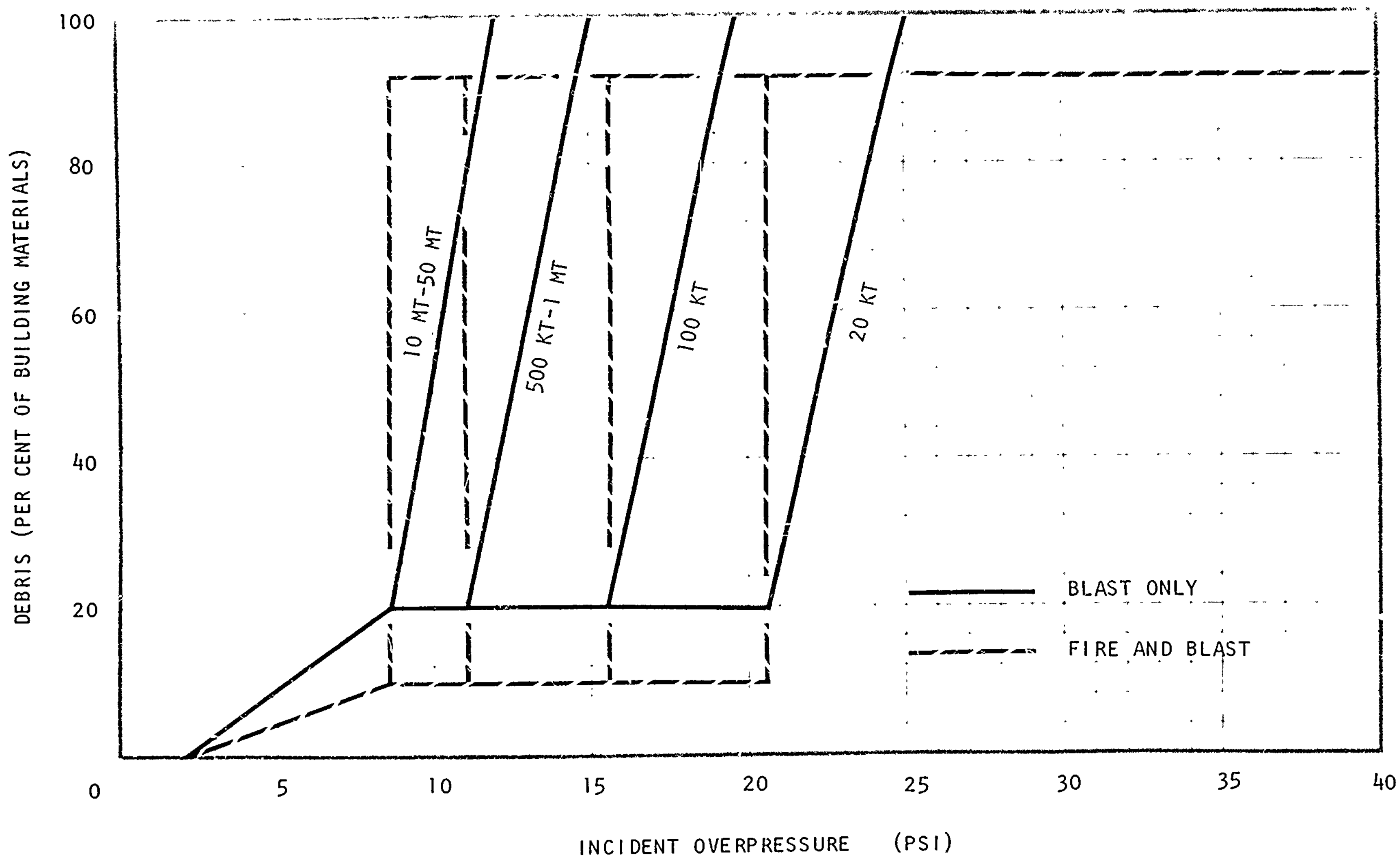

Fig. 11. Percent Debris vs Overpressure — Multistory Steel or Reinforced Concrete Frame Building with Light Exterior Panels - Non-Earthquake Design

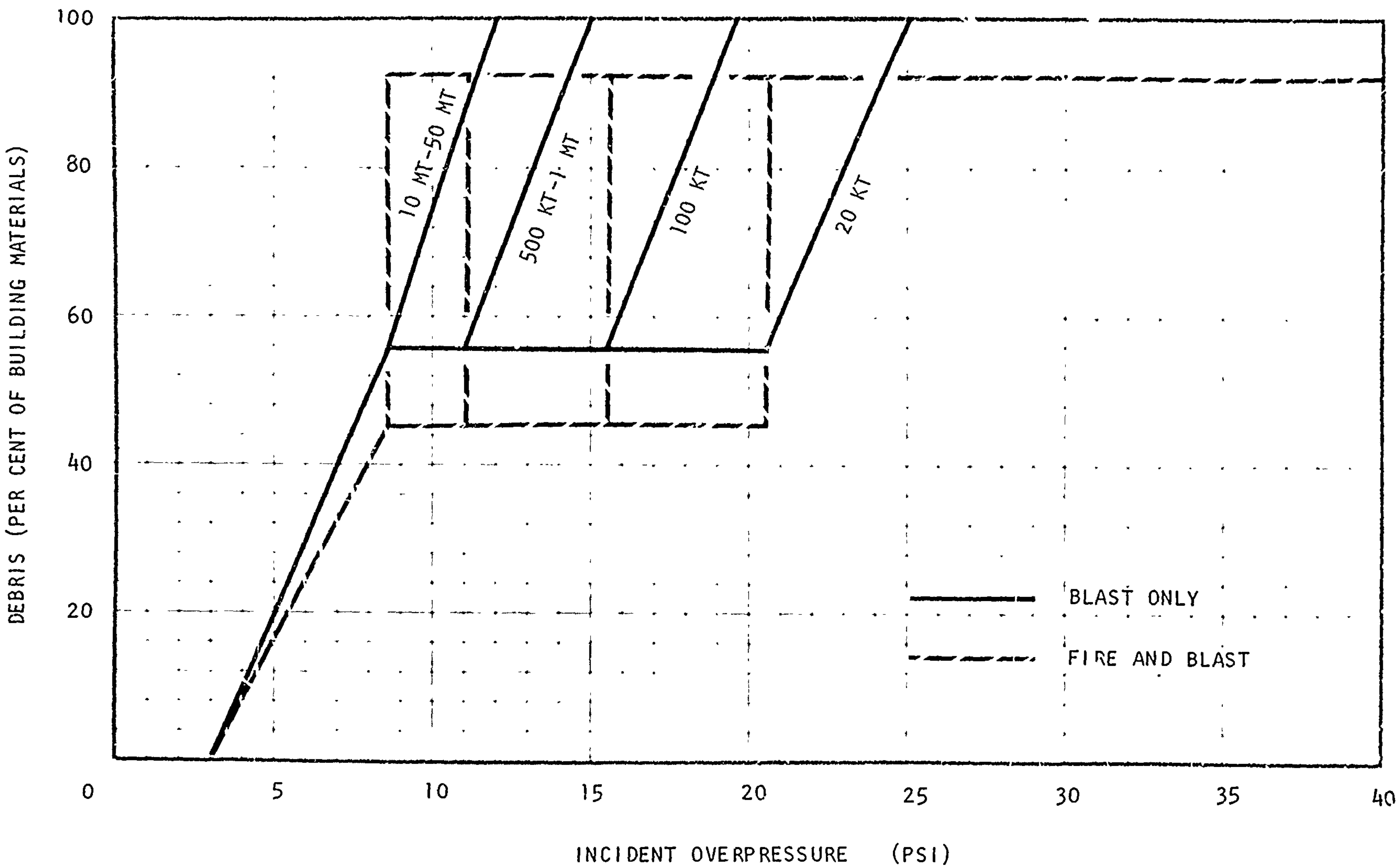

Fig. 12. Percent Debris vs Overpressure — Multistory Steel or Reinforced Concrete Frame Building with Masonry Exterior Panels - Non-Earthquake Design

begin to fail at approximately 2 psi, as will light interior partitions. This, then, is the onset of debris production for a frame building with light panels.

Whereas light curtain walls will start to fail at about the same overpressure as interior partitions, the failure overpressure for masonry exterior walls is somewhat higher. For this reason, the onset of debris production is set at a slightly higher overpressure, 3 psi. At 3 psi some of the interior partitions will have failed and have been ejected, along with miscellaneous items such as suspended ceilings and light contents. The chronology of failure for this type of structure is that the partitions fail first, then the exterior walls, after which the debris level remains at a plateau until the main frame fails. The floors will remain attached to the frame and will collapse with it. The walls and partitions are essentially diffraction-sensitive, and the frame is drag-sensitive.

The Japanese data, along with the weapon test data for building elements, were sufficient to construct the initial portion of the debris charts. However, the onset and completion of structural collapse were much more difficult to determine. Of the literally hundreds of structures surveyed by the USSBS at Hiroshima and Nagasaki, only about 60 could be classified as multistory reinforced concrete or steel frame buildings, and the large majority of these were only 2 or 3 stories tall. In addition, the heights of burst of the weapons used in Japan were great enough so that overpressures large enough to cause complete collapse from these low-yield weapons occurred in the regular reflection region. Mach reflection occurred at approximately 37 psi in Nagasaki, and 11 psi in Hiroshima.

Empirical information on frame distortion and total collapse for a multistory steel or reinforced concrete frame building is virtually non-existent. Consequently, the overpressures necessary for the onset of frame collapse and for the completion of frame collapse were obtained by the same methods used for the steel frame industrial buildings. That is, the onset of collapse was defined by using the severe damage overpressure from TM 23-200, and the overpressure necessary to attain an arbitrary ductility assumed to be complete collapse was calculated. These overpressures, then, defined the final rising limb on the debris chart.

Fire effects on this class of structures would not be severe, if there was no attendant blast damage. Reinforced concrete buildings have natural fire protection, and steel frame buildings can be fire-proofed to attain the same results. Examples of protected steel frame buildings from the San Francisco earthquake and fire showed that the interiors could be completely gutted, and the frames remain virtually undamaged. However, if these buildings sustain heavy blast damage (threshold of collapse), then an uncontrolled fire would likely cause total collapse. The blast damage would cause distortion and racking of the frame, destroying the fireproofing on the steel frame building, and causing spalling of concrete and consequent exposure of reinforcing steel on the reinforced-concrete frame structures. The effects of fire on debris production would be a decrease in the per cent of debris produced due to the consumption of combustible materials up to the point where the frame becomes distorted enough by blast so that the fireproofing is destroyed. At this point, a fire would cause complete collapse of the structure.

The multiyield debris charts for these categories of frame structures were obtained by using a computer code (Ref. 37) together with the severe damage criteria found in TM 23-200 to determine the response to blast of buildings of these types. Two isodamage curves were constructed, representing severe damage and total collapse in the same manner as was done for the steel frame industrial buildings, enabling the final rising limbs of the debris curves to be plotted for various yields.

REINFORCED CONCRETE SHEAR WALL STRUCTURES

In re-examining the data from Hiroshima and Nagasaki to determine the effects of fire on debris production (Ref. 2), it became obvious that another structural category could be defined, that of the reinforced concrete shear wall building.

A shear wall building is distinguished from a frame building by the way in which lateral loads are withstood. The frame building obtains its lateral resistance through the flexural action of columns and beams, while the shear wall building obtains its lateral load carrying capability by diaphragm action of floors and walls. This type of building functions similarly to the load-bearing masonry wall building but is much stronger. Its walls, due to the reinforcing steel, will fracture and go into membrane action and hold together much longer. Since the entire building is made of the same material, the continuity wall to wall and wall to floor or roof is much better.

The debris charts for heavy reinforced concrete shearwall buildings (Figs. 13 and 14) were originally derived from Hiroshima and Nagasaki information. The buildings were not very tall-an average height would be 2 to 3 stories-and were of very heavy construction. This type of construction is not often found in this country.

Another category for shearwall buildings of from 3 to 8 stories in height was found. Two debris charts were constructed for this building category, one for shear wall buildings with light interior panels, and one for shear wall buildings with masonry interior panels (Figs. 15 and 16). The initial rising limb represents the interior panel debris. There is no separate frame in this type of building, so the final rising limb represents the collapse of the walls, floors, and roof.

Blast damage has less of an effect on the ensuing fire damage for this type of building than for any other. Unlike the frame type building, the shear wall building will retain its shear resistance when subjected to fire as long as its concrete walls remain intact. For this reason, the debris curves including fire effects show that fire does not bring about collapse until almost the same amount of distortion that would cause the building to collapse from blast effects only.

These buildings are more diffraction than drag-sensitive. Using the information for severe damage to this category from TM 23-200, the multiyield curves were constructed showing almost no yield dependency.

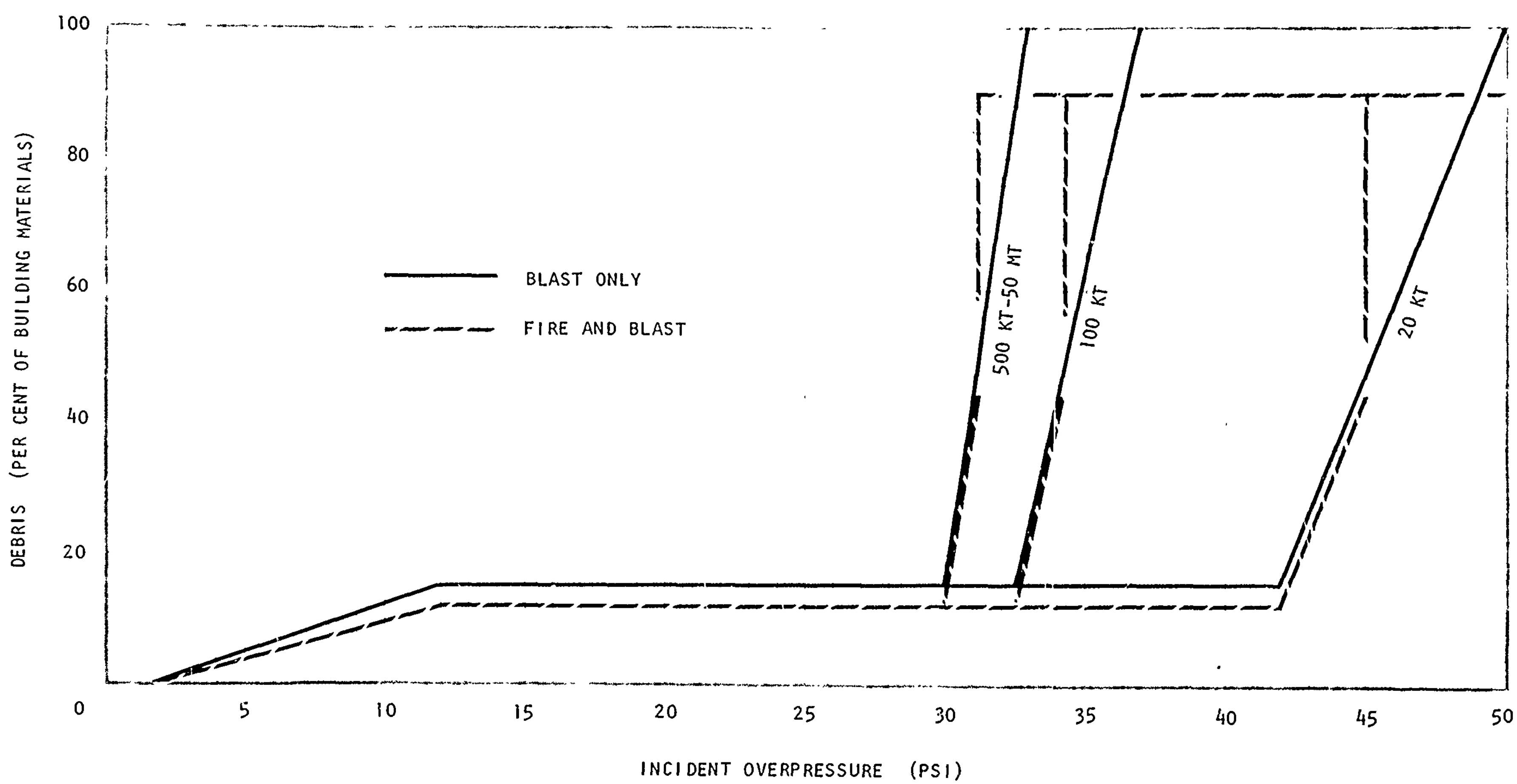

Fig. 13. Percent Debris vs Overpressure — Multistory Heavy Reinforced Concrete Shearwall Building with Light Interior Panels

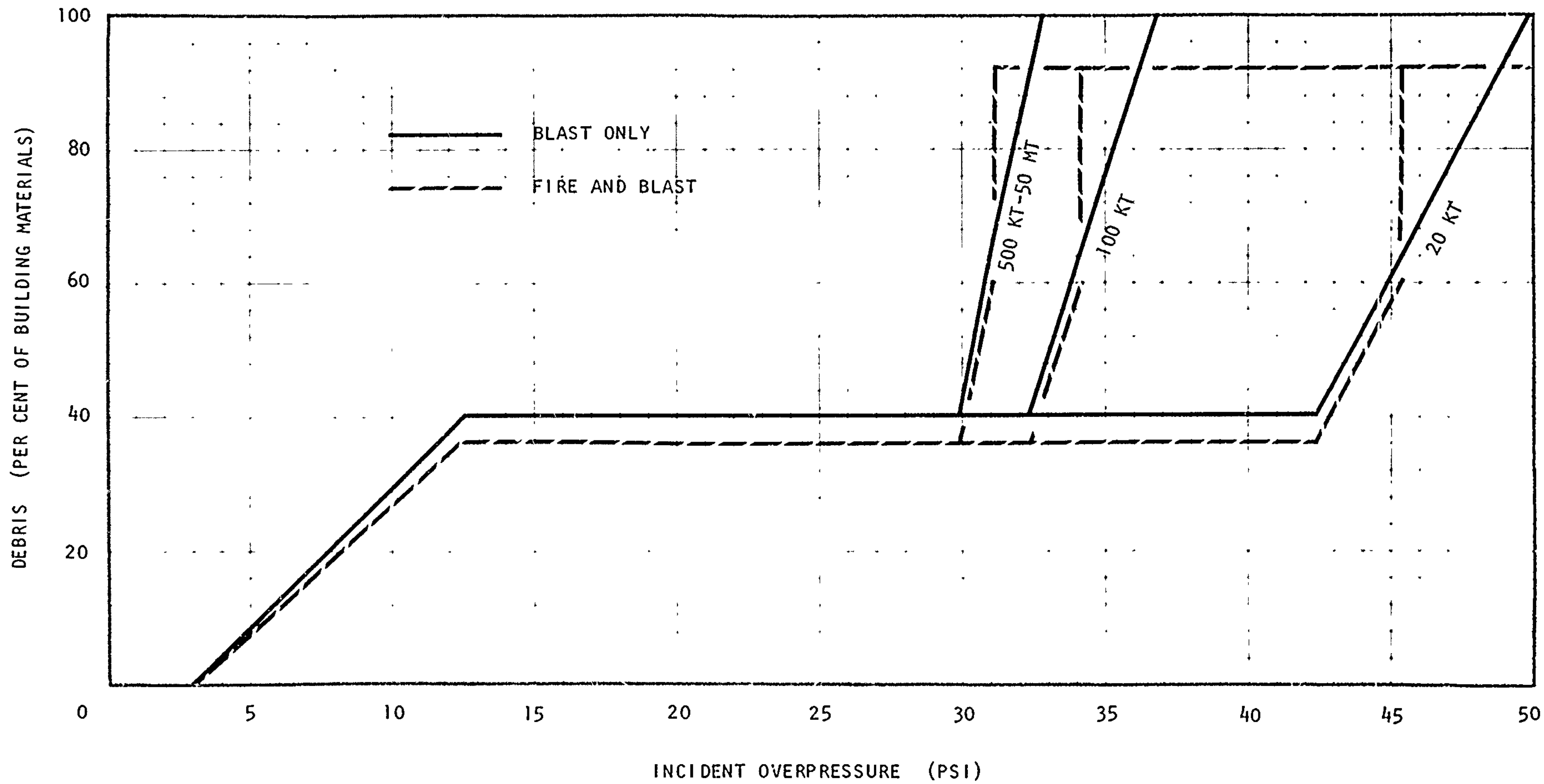

Fig. 14. Percent Debris vs Overpressure — Multistory Heavy Reinforced Concrete Shearwall Building with Masonry Interior Panels

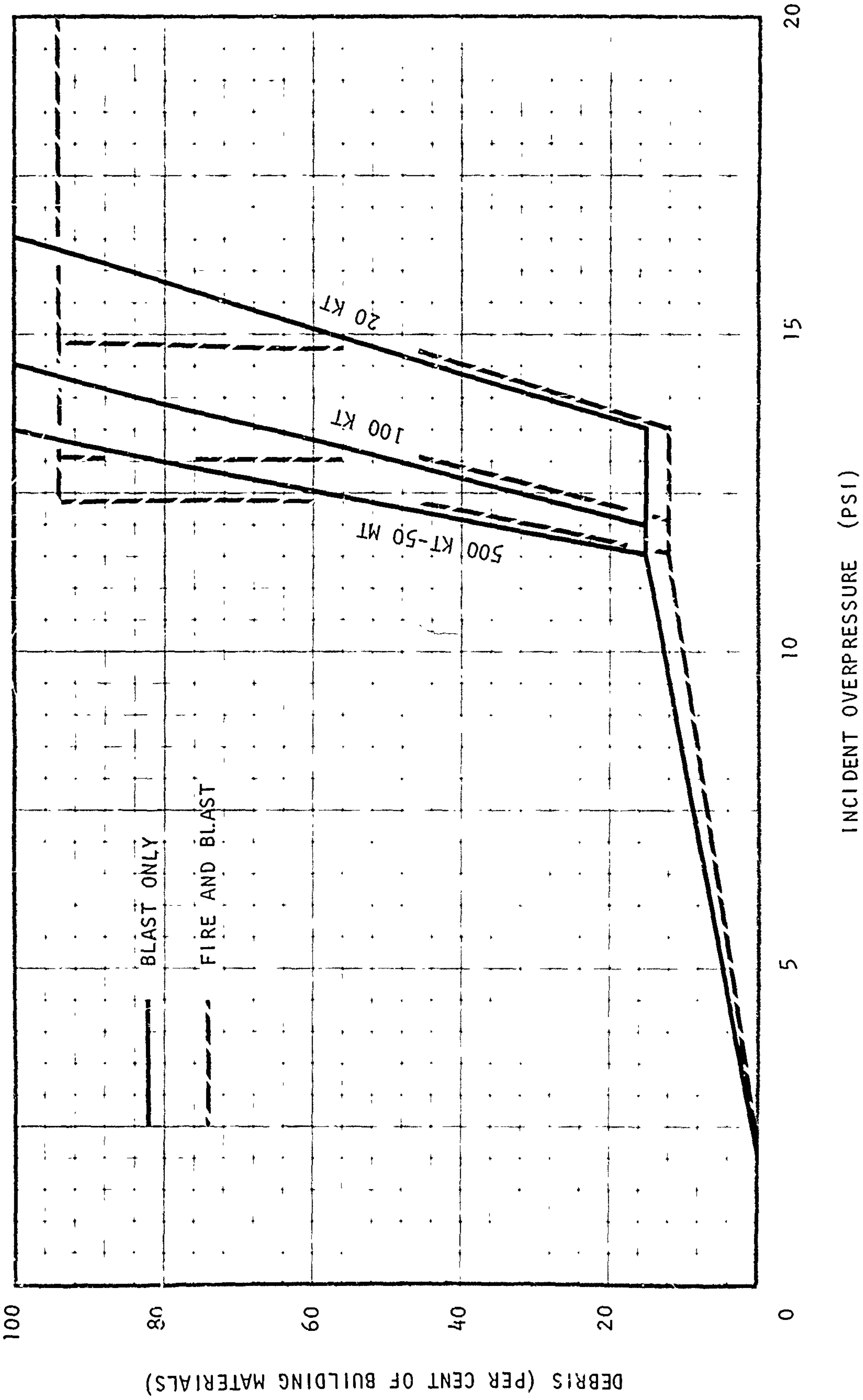

Fig. 15. Percent Debris vs Overpressure – Multistory Reinforced Concrete Shearwall Building with Light Interior Panels

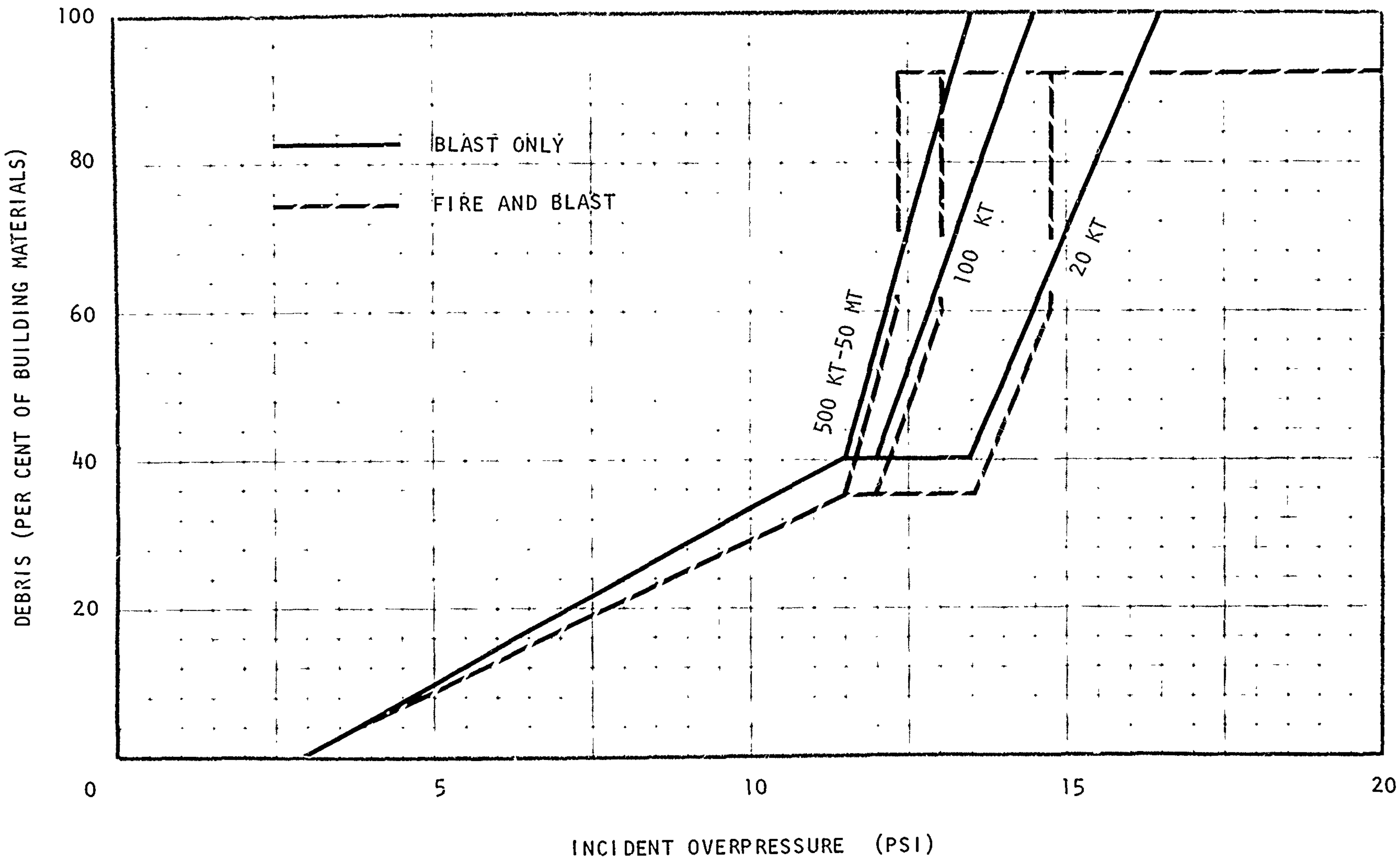

Fig. 16. Percent Debris vs Overpressure — Multistory Reinforced Concrete Shearwall Building with Masonry Interior Panels

Included in the general shear wall category are structures which contain similar lateral resistance elements (light reinforced concrete shear walls) but are not nearly so resistant to blast effects due to their light construction. They differ in roof type and in the type of interior panels and are usually only one or two stories high. The variations in panels were handled in the same fashion as the previously described buildings. A further division had to be created, however, to describe roof type variations. The mill-type roof is usually sheathed with corrugated iron or asbestos sheathing which fails at much lower overpressures (less than 3 psi) than those for the deck portion of the concrete roofs (6 to 10 psi), and contains a much smaller volume of material. The mill-type roof is usually not fireproofed and consequently is much more vulnerable to fire. These effects account for the major differences in the debris charts for these buildings (Figs. 17 through 20).

STRUCTURAL MATERIAL VOLUMES

The debris charts were constructed by calculating the volume of structural material contained in various building components, and determining the percent of these components that became debris. These volume calculations were made using detailed plans of the specific structure being studied.

To make the prediction of debris less tedious and time-consuming, it was necessary to develop simplified means to estimate structural material volumes. Otherwise it would be prohibitively expensive to calculate debris for any large number of structures, as must be done to determine debris depths for an urban area.

Building type and physical dimensions are both easily determinable, and are quite significant as parameters of structural volume. Accordingly, empirical formulas relating these parameters to material volumes were derived utilizing constants that reflect average values (deviations of 10 percent are common and 15 percent rare). These formulas are presented in Table 1. This table also is a complete listing of all the structural types, and includes the percent of each type that is incombustible.

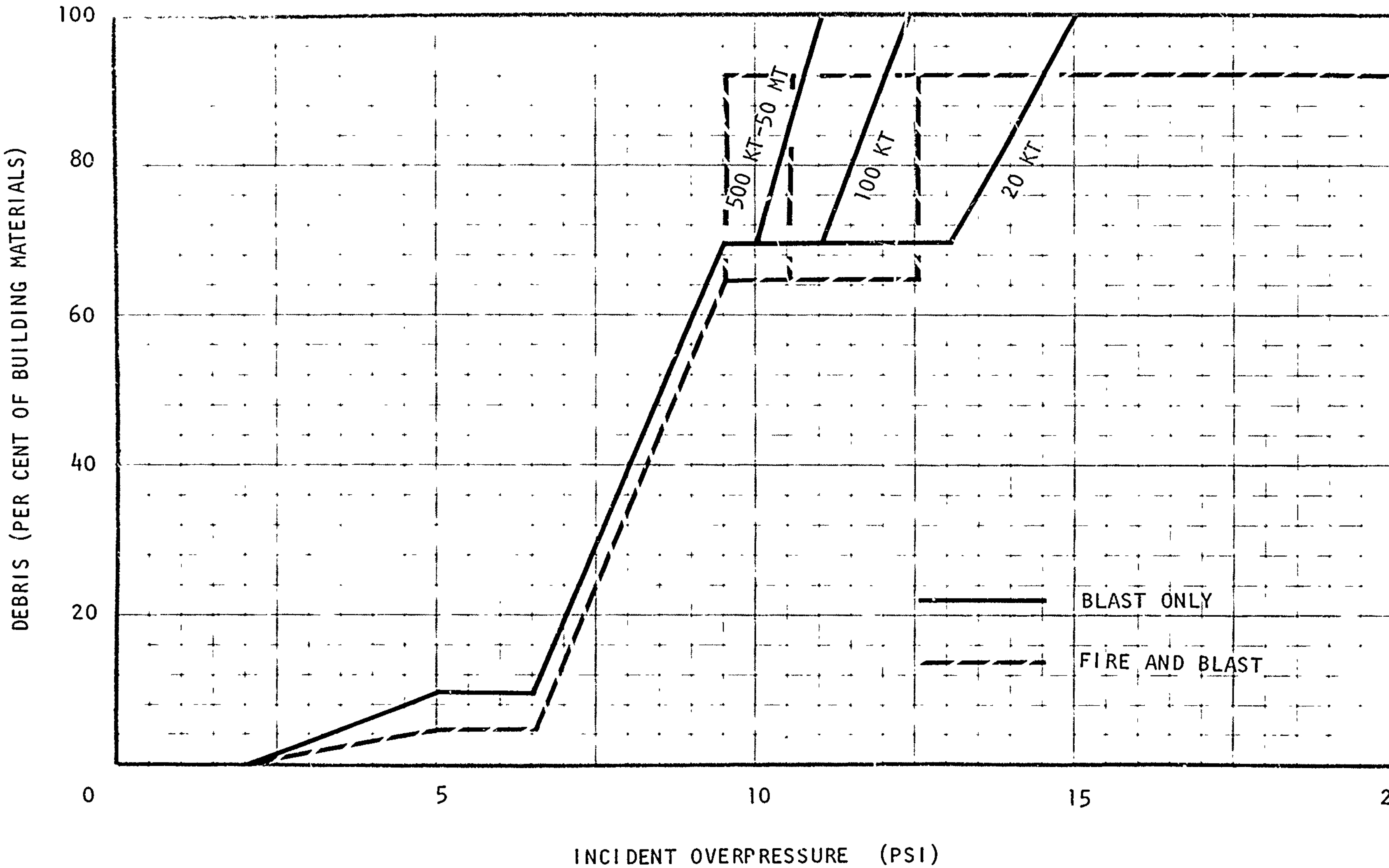

Fig. 17. Percent Debris vs Overpressure — Light Reinforced Concrete Shearwall Building with Concrete Roof and Light Interior Panels

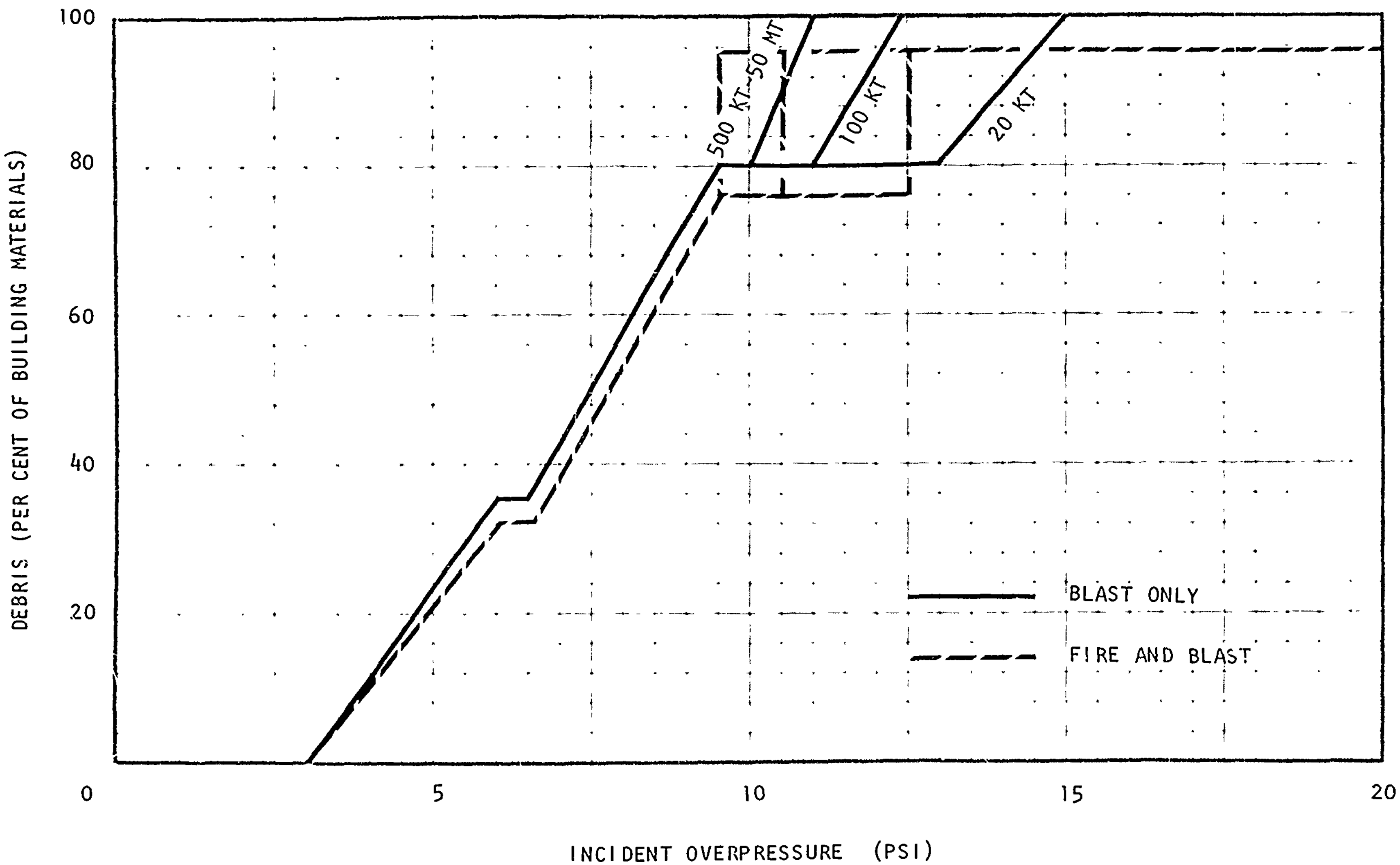

Fig. 18. Percent Debris vs Overpressure — Light Reinforced Concrete Shearwall Building with Concrete Roof and Masonry Interior Panels

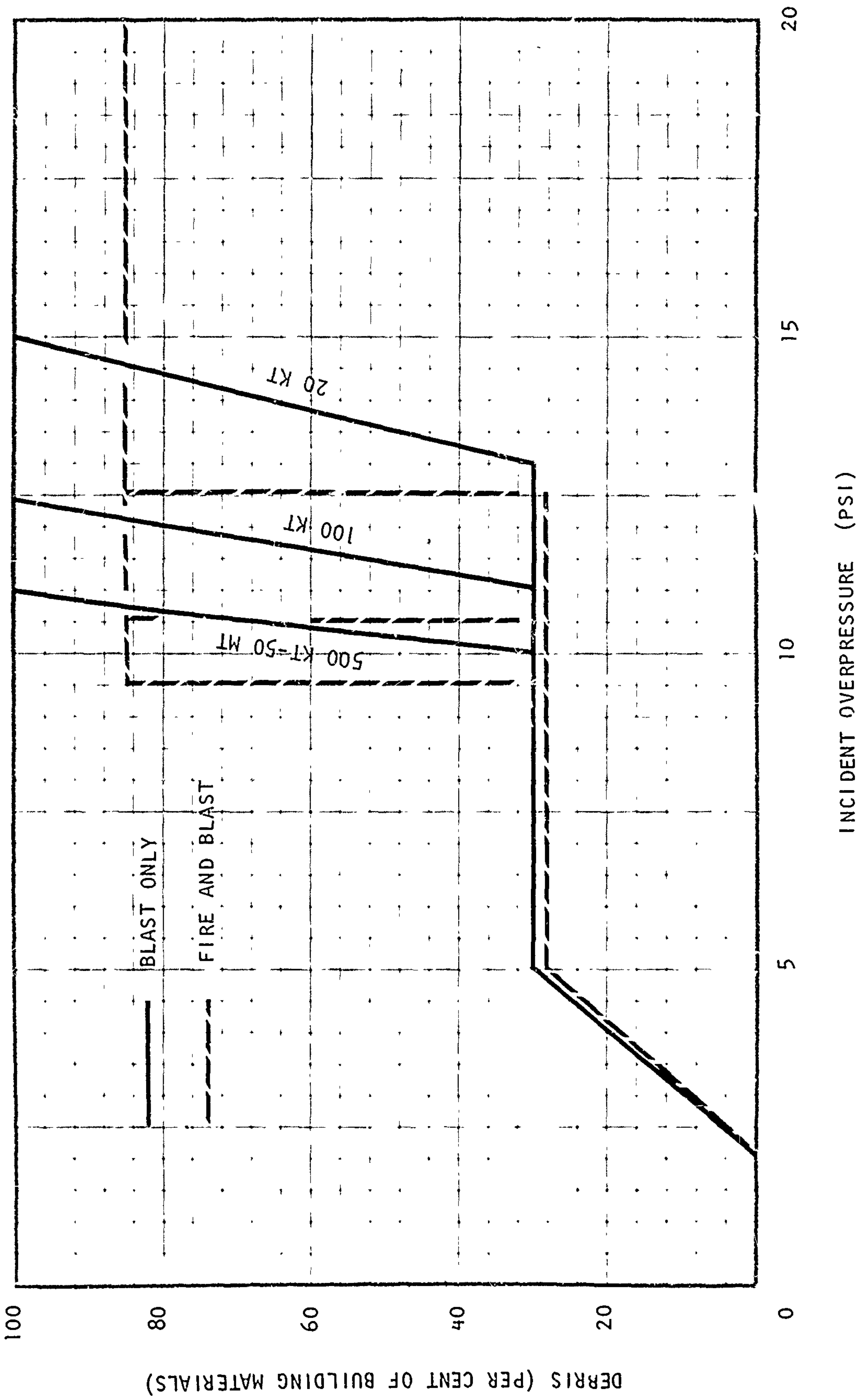

Fig. 19. Percent Debris vs Overpressure – Light Reinforced Concrete Shearwall Building with Mill-Type Roof and Light Interior Panels

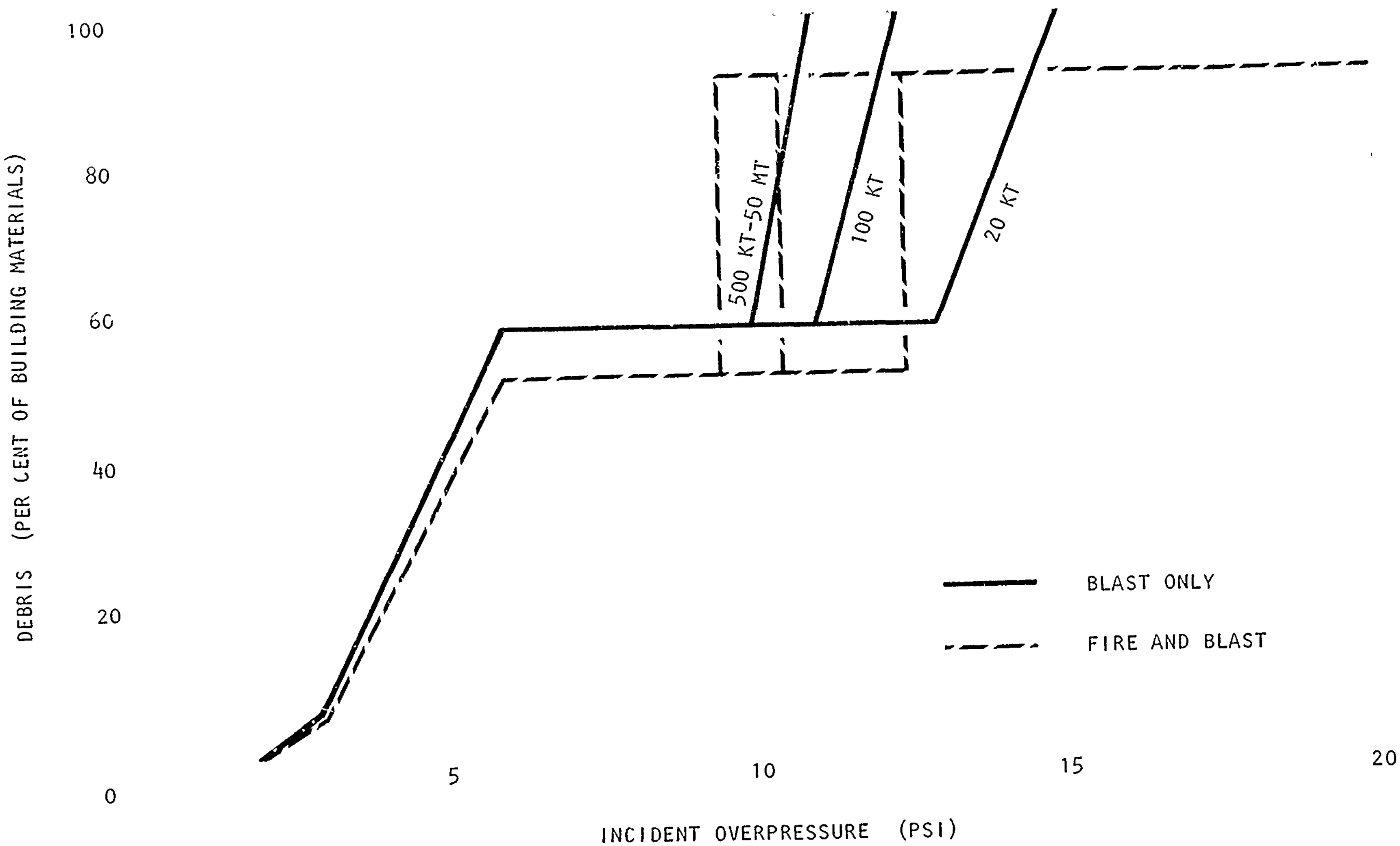

Fig. 20. Percent Debris vs Overpressure – Light Reinforced Concrete Shearwall Building with Mill-Type Roof and Masonry Interior Panels

Table 1

STRUCTURE VOLUME VS BUILDING TYPE

BUILDING TYPE	VOLUME FORMULA*	PERCENT INCOMBUSTIBLE
1. Wood Frame Residential		
a. 1st floor slab on ground	$\left[0.55 + (N-1)(0.525)\right] A_p$	42 - S&P 28 - W&P
b. 1st floor on std. joists	$\left[0.7 + (N-1)(0.525)\right] A_p$	2 - W
2. Steel Frame Industrial		
a. Light W/CI sheathing	$0.02\ A_p$	0
W/CA sheathing	$0.087\ A_p$	0
b. Heavy W/CI sheathing	$0.037\ A_p$	0
W/CA sheathing	$0.095\ A_p$	0
3. Load-Bearing Masonry with or without reinforcing - Combustible interior framing	$0.12\ V_c$	$80 - \frac{1}{300}\left(A_p - 1000\right)$ $1000 < A_p < 7000$
4. Reinforced Concrete Shear-Wall		
a. W/lt. interior panels	$0.07\ V_c$	90
b. W/masonry interior panels	$0.12\ V_c$	93
5. Multistory Steel and Reinforced Concrete Frame with Earthquake Design		
a. W/lt. interior panels	$0.07\ V_c$	88
b. W/masonry interior panels	$0.11\ V_c$	92
6. Multistory Steel and Reinforced Concrete Frame (non-earthquake design)		
a. W/lt. interior panels	$0.063\ V_c$	88
b. W/masonry interior panels	$0.10\ V_c$	92

* These formulae reflect solid volume of material (i.e., no void-void ratio = 0). The void ratio (usually taken as unity) is best applied after summation of contributory volumes. This minimizes the number of calculations required for making debris volume or debris depth estimates.

Table 1, cont.

BUILDING TYPE	VOLUME FORMULA*	PERCENT INCOMBUSTIBLE
7. Light Reinforced Concrete Shear-Wall (single story)		
a. Concrete roof w/lt. interior panels	0.07 V_c	92
b. Concrete roof w/masonry interior panels	0.075 V_c	94
c. Mill roof w/lt. int. panels	0.037 V_c	85
d. Mill roof w/masonry interior panels	0.05 V_c	92

LEGEND:

V_c contained volume

A_p plan area

N number of stories

S&P stucco exterior plaster interior

W&P wood exterior plaster interior

W all wood

CI corrugated iron

CA corrugated asbestos

BUILDING CONTENTS VOLUMES

The contents of buildings can contribute significantly to the amount of debris produced. Therefore the volume of the contents must be added to the volume of the structural material to get an accurate estimate of debris depth.

Both the amount and character of debris from building contents will depend upon the occupancy of the building. Detailed information was found, for different occupancies, on both the total weight of contents per square foot and the amount of these contents that is combustible.

Data found in reports from the National Bureau of Standards and other sources (Refs. 37-40) proved to be quite useful in determining quantities of contents for various occupancies. The data presented in these reports were obtained by actually weighing and categorizing the contents of several buildings and then converting the weights to pounds per square foot for various building area uses. The data were quite detailed, giving weights and areas for each area usage encountered (such as various weights in sections of a department store) and for each floor in multistory buildings. The data were grouped into occupancy classifications and weighted averages were used to determine the average load per square foot for each occupancy. The volume of building contents is calculated by multiplying the plan area of the building times the number of stories of the building times a volume coefficient. The volume coefficient varies with the building occupancy and was obtained from the average load per square foot for packed density (no voids between articles). The volume coefficients, both before and after fire, are contained in Table 2.

Building contents become debris when by action of blast and/or fire, their usefulness is destroyed or their remains constitute a clean-up problem instead of a part of a resource. With this definition in mind, the following criteria were adopted:

Table 2

BUILDING CONTENTS LOADS AND VOLUME FACTORS

OCCUPANCY	PSF COMBUSTIBLE	PSF TOTAL	VOLUME FACTOR K $\left(V = KA_pN\right)^*$	
			TOTAL	AFTER FIRE
1. Apts. and Residential	3.5	5	0.625	0.02
2. Auditoriums and Churches	1	1.5	0.25	0.007
3. Garage				
a. Storage	1	15	0.75	0.30
b. Repair	1	11	0.55	0.20
4. Gymnasium	0.3	0.5	0.09	0.003
5. Hospitals	1.2	3	0.375	0.03
6. Hotels	4	5	0.625	0.013
7. Libraries	24	26	0.75	0.027
8. Manufacturing				
a. Comb. Mdse. fabrics, furniture	13.5	18	1.8	0.07
b. Incombustible	1	11	0.55	0.20
9. Offices	7	12	1.2	0.10
10. Printing Plant				
a. Newspaper	10	23	0.9	0.20
b. Books	50	60	1.7	0.13
11. Schools	9.5	11	1.6	0.02
12. Storage				
a. Gen. Mdse.	14	35	6	0.3
b. Special		**		
13. Stores				
a. Retail Dept.	7.5	12	2	0.10
b. Wholesale	10	16	2.7	0.12
14. Restaurant	2	3.5	0.6	0.02

* V = Volume in cubic feet

A_p = Plan area in square feet

N = Number of stories

** 25 percent of design load

ACTION	CONTENTS CONSIDERED AS DEBRIS
Contents destroyed by fire alone	No
Contents ejected by blast	Yes
Contents destroyed by blast	Yes
Building destroyed by blast or fire	Yes
Contents destroyed by fire together with blast	Yes
Contents displaced by blast but not destroyed or ejected	No

To apply these criteria, the state of the contents — whether displaced, ejected, burned, or destroyed by blast — must be known. Determination of whether the articles have been merely displaced by blast or destroyed and/or ejected is quite difficult. Therefore techniques for prediction of damage to and ejection of building contents were based on logical extensions of related techniques.

In most occupancies, the durability of the typical contents is not too different from that of the interior panels with respect to displacement by blast. (An exception to this is permanently installed heavy industrial machinery or equipment.) If the blast intensity were sufficient to destroy the panels, in all likelihood the contents of the building would also suffer. In this same vein, if portions of the blast-formed debris from the interior panels were to be ejected from the building, it is logical to assume that part of the building contents would likewise be ejected. If all the debris from the interior panels were to be ejected from the building, the major part of the building contents would undoubtedly also be ejected. Thus, the debris charts can also be used for contents debris, by recognizing that the initial rising limb of most of the debris charts is essentially the result of panel failure. The beginning of the first plateau generally represents the point at which panel failure would be complete and — in accord with the relationship between panel failure and building contents ejection just described — it would also represent the point at which all the building contents become debris. For lower overpressures, the percent of contents converted to debris can be estimated by linear interpolation. Notice that if the contents are destroyed by fire acting with blast, they are considered to be debris. In this case, the debris volume is determined by using the after-fire coefficient, and applying the percent read from the chart to this volume.

Descriptions of the composition of debris from various types of building uses are contained in Table 3. The Light, Medium, and Heavy headings refer to building light, moderate, and severe damage.

INPUT DATA FOR DEBRIS PREDICTIONS

The debris prediction charts form the basic tool for predicting debris. However there is much information which must be known before the debris charts can be used. In general, the input data required are weapon size and location, and detailed information on the structures of interest.

General topographic information about the city, its prominent features, and surrounding area can be obtained from quadrangle maps available from the U.S. Geological Survey. These maps are also useful in locating the weapon burst point, since they are referenced in both spherical coordinates (longitude and latitude) and in Universal Transverse Mercator coordinates.

Detailed knowledge of individual buildings would best be obtained from the construction plans. However these are not readily available, and sometimes are too detailed, making it hard for someone who is not knowledgeable to ascertain the pertinent details. Lacking construction drawings, the best structural information may be obtained from Sanborn Maps.* These maps are intended for fire insurance information, and therefore show the type of construction (including wall thicknesses), occupancy of the structure, number of

* Available from the Sanborn Map Company, Pelham, New York.

Table 3

DEBRIS DESCRIPTIONS

I. Commercial - With Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Counter-top furnishings Desk-top furnishings	Glass Doors Suspended ceilings Roofing materials Roof ventilators Corrugated asbestos and iron siding Plaster Suspended lighting fixtures Signs attached to structure
B. Medium	Office furniture Office machines Vending machines	Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Full filing cabinets Safes	Roof decks Floor decks Steel and reinforced concrete framing members Plumbing fixtures Mechanical equipment

Table 3, cont.

I. Commercial - Without Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Desk-top furnishings Counter-top furnishings Magazines Hanging clothing Books	Glass Doors Suspended ceilings Roofing materials Roof ventilators Heating ductwork Signs attached to structure Corrugated asbestos and iron siding Plaster Suspended lighting fixtures
B. Medium	Office furniture Office machines Display cases Vending machines	Light wood sheathing Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Full filing cabinets Safes	Light roof decks Light floor decks Heavy partitions Wood studs, joists, and rafters Plumbing fixtures Mechanical equipment

Table 3, cont.

II. Industrial - With Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Trash cans Light warehoused materials	Glass Metal doors Roofing materials Roof ventilators Suspended heaters Suspended lighting fixtures Corrugated asbestos and iron siding Signs attached to structure
B. Medium	Light industrial machinery Hand tools Vending machines Medium warehoused material	Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Heavy industrial machinery Industrial trucks Heavy warehoused material	Overhead cranes Light roof decks Light floor decks Mechanical equipment

Table 3, cont.

II. Industrial - Without Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Rags Papers Trash cans Light warehoused material	Glass Doors Roofing materials Roof ventilators Suspended heaters Suspended lighting fixtures Corrugated asbestos and iron siding
B. Medium	Light industrial machinery Hand tools Vending machines Medium warehoused material	Light wood sheathing Light partitions Light metal curtain walls Lighting fixtures Light roof decks on metal trusses
C. Heavy	Heavy industrial machinery Industrial trucks Heavy warehoused material	Overhead cranes Light roof decks Light floor decks Wood studs, joists, and rafters Plumbing fixtures Mechanical equipment

Table 3, cont.

III. Residential - With Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Small appliances	Glass Roofing materials Roof ventilators
B. Medium	Light furniture	No change from light category
C. Heavy	Heavy furniture Major appliances Automobiles (in garage)	Furnaces Water heaters Plumbing fixtures

Table 3, cont.

III. Residential - Without Fire

	TYPICAL COMPOSITION	
	BUILDING CONTENTS	STRUCTURAL DEBRIS
A. Light	Lamp Shades Drapes Linens Magazines Dishes Small appliances Books	Glass Doors Roofing materials Roof ventilators
B. Medium	Light furniture	Light wood sheathing
C. Heavy	Heavy furniture Major appliances Automobiles (in garage)	Wood studs, joists, and rafters Furnaces Water heaters Plumbing fixtures

stories (including basement), height, floor plan from which the length and width may be scaled, and any unusual features. Usually a Sanborn Map sheet will contain four blocks in a downtown area, and eight or more in a residential area. A personal survey of the building and photographs are invaluable. The more accurate and detailed the input information is, the more accurate the debris predictions will be.

DEBRIS DISTRIBUTION

Once the volume of structural debris has been calculated, it becomes necessary to distribute it in some manner over the area of interest. At the onset of the debris research effort, it was hoped to be able to come up with a method to predict the amount of debris that ended up away from the building. However the photographic coverage in the USSBS reports was not comprehensive enough to make this distinction. Therefore the per cent debris shown on the debris charts is the total debris produced without regard to its being on-site or off-site.

At present, the procedures for distributing the debris represent the least refined portion of the debris prediction model. Prediction of debris distribution takes many variables into account. The size of the debris particles, and the interaction of the debris particles with the remaining structure and the blast wave are all important considerations in predicting the final location of debris. Just as important is being able to predict the shape of the blast wave as it strikes the building. The building density of the city complex, the orientation of the structure, and the presence of debris particles from other damaged structures all have an effect on the characteristics of the blast wave. As yet, the state of the art does not allow these variables to be predicted for either the blast wave or the structure, and until they can be predicted, a highly refined scheme for distributing debris is not justified.

Therefore a very simple method has been adopted to distribute building and contents debris. All of the debris volumes are added, and assumed to be distributed evenly over an area. The determination of the area is the only attempt made to refine the prediction. Usually, the debris from all the structures in one block is summed up and distributed over the area of that block, including adjacent streets (Fig. 22). However, modifications to this assumed area are possible, and even called for, under certain conditions. For example a 20-story building would certainly spread its debris over a much larger area than its own block. And if there are large open areas, such as parking lots or parks, these also must be considered in the distribution scheme.

Although the assumption of even debris distribution is not at all realistic for an individual building, the more buildings that are considered, the more reliable the calculated debris depth will be, assuming there are no extreme differences between two adjacent blocks. This is a valid assumption for a given urban area, such as a residential area, although it can be grossly in error for the central business district. The debris from any one building might be spread over two or three blocks, but the error in assuming it to be confined to a single block will be lessened due to debris from other similar buildings in other blocks ending up in the block under consideration.

The problems of variations in the orientation of the building to the blast wave and of city complex effects on the blast wave are accounted for in the way the debris charts were derived. All of these effects were inherent in the Hiroshima and Nagasaki data, in fact it would be difficult to separately account for them.

DEBRIS DEPTH CALCULATIONS

Up to this point, methods have been presented to allow the calculation of the volume of debris, and to determine the area over which this debris is to be evenly spread. However, the debris will not form a solid mass of material, but will contain void spaces. Simple experiments have shown that blocks dropped in a random manner will have a void ratio* of about 1.0 (Ref. 41). Until such time as a more accurate method to determine the void ratio is available,

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* The ratio of the volume of voids to the volume of solids. A void ratio of 1.0 means that a unit of debris will be one-half air, and one-half debris.

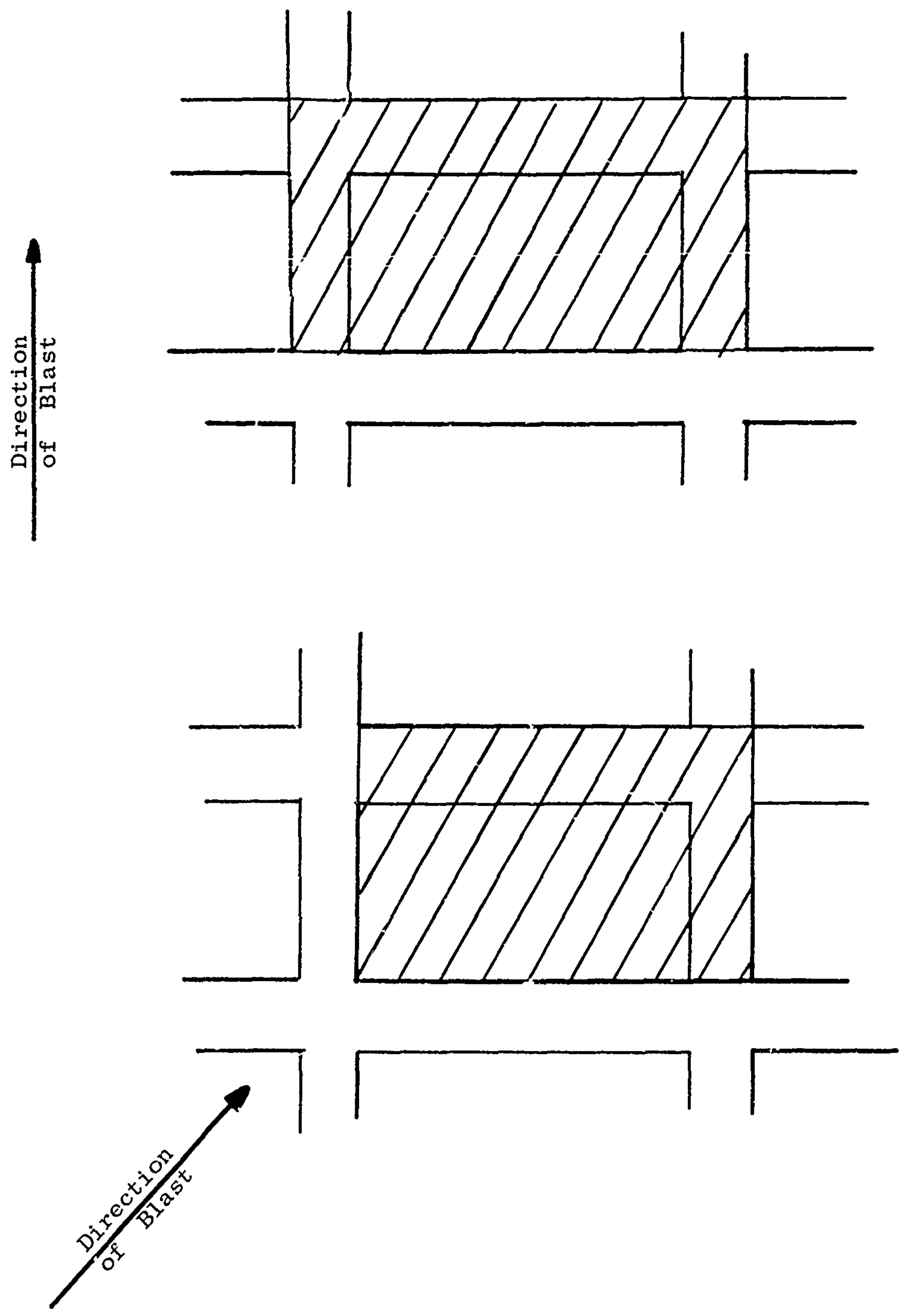

Fig. 22. Debris Distribution Schemes

this value is the one that will be used. However, it should be recognized that the total collapse of steel or reinforced concrete frame buildings will create a jumbled mass of steel or reinforced concrete with a void ratio much greater than 1.0. The calculation of the debris depth is:

$$\text{Debris Depth} = \frac{(1 + \text{Void Ratio})\ (\text{Debris Volume})}{\text{Area of Debris Distribution}}$$

DEBRIS PREDICTION MODEL

In the preceding sections, the details of the method used to predict debris depths has been presented. The step-by-step procedure to determine debris depths is:

1. Plot overpressure vs distance curve from yield and height of burst of weapon.
2. Determine occupancy, type, and size of building (usually from Sanborn Maps).
3. Determine overpressure at building's location.
4. Enter proper curve (for type of building and size of weapon) with overpressure to obtain percentage of structure converted to debris by
   a. blast only.
   b. blast and fire (if in burned area).
5. Determine percent of contents of the building converted to debris from debris curve for the building type.
6. Calculate total structural material volume.
7. Calculate total volume of contents.
8. Apply percentage figures to structural and contents volumes to determine volume of debris from building.
9. Sum up all contributions for area of interest.
10. Apply void ratio and divide volume by specified area to determine debris depth.

Debris depths for an entire city are expressed in a different manner than depths for a smaller area. Ideally depths would be calculated on a block by block basis for the entire city, but obviously this is much too time consuming. Besides, the basic form of input, the Sanborn Map, is not available for every block in a city. Consequently a sampling technique has to be used for residential areas.

By use of aerial photographs, land-use maps, street maps, and most importantly, an on-site reconnaissance, it is possible to select relatively homogeneous residential areas. A block is chosen in this area, and the buildings in this block are said to be typical of the buildings in the remainder of the blocks in the area. Strip commercial areas may also be typified for a number of blocks by a single block. However the downtown built-up commercial area must be covered on virtually a block-by-block basis. This removes the problems caused by an unusually tall structure or open space.

Once the debris depths are calculated, debris depth contours can be constructed. These are lines drawr so that all points represent the same debris depth. These contours are plotted by referring to the on-site reconnaissance, and to the aerial photographs. The contours represent an overall view of the debris depths throughout the city, and will not adequately serve the needs of persons needing specific information, such as debris depths along a route. It is to fulfill this need for specific information that this handbook has been prepared.

Section 3
PREDICTION OF GENERAL BUILDING DAMAGE

GENERAL

In the course of developing the debris prediction methods described in the preceding section, a considerable amount of information concerning building damage has been collected. This information ranges from insight on the behavior of entire buildings gained from Hiroshima and Nagasaki, to failure overpressures for panel walls and partitions, obtained from the Nevada and Pacific weapons tests. Using this information, URS has been able to predict building damage in general terms for typical buildings.

This means that we predict a certain percent of the windows, doors, and interior partitions to be debris, and also the damage to the roof, exterior walls, and frame. The minimum amount of input information needed is that contained on Sanborn Map sheets. Photographs are quite useful, since they show the window sizes and locations which cannot be learned from Sanborn Maps. A combination of construction drawings and photographs is ideal, since some estimates of damage to interior partitions may then be given, having knowledge of their construction and of the window openings.

The procedures that are presented herein to predict damage are by no means exact, and care should be used in applying them so that no more reliability than is justified be attributed to them. Exact prediction of building damage depends upon many variables, some of which are beyond the state of the art. The breakup of building elements depends upon the air blast loading and resulting response of the elements. The air blast will be modified due to effects of surrounding buildings and transported debris. If the element under consideration is an interior wall, the size of the openings in the exterior wall and whether or not it fails has a great effect on the interior blast wave. All of these factors (and others) make exact predictions of building damage impossible. However, by utilizing experimental information, blast wave. All of these factors (and others) make exact predictions of building damage impossible. However, by utilizing experimental information, and adapting it to the building of interest, a general inference may be made of the damaged condition.

At the beginning of this section, it was stated that damage predictions were limited to typical buildings. By typical, it is meant a building that fits into one of the categories for which a debris chart exists. Buildings which fit into one of the debris chart categories, but which have abnormalities such as an irregular floor plan or a mixture of construction types, must be treated carefully.

AIDS TO DAMAGE PREDICTION

Before damage predictions are attempted, it is necessary to have a general idea of how buildings and their elements respond to blast. The Effects of Nuclear Weapons (Ref. 24) is an excellent source of damage information, both theoretical and empirical. It provides a great deal of background and insight into the behavior of buildings. Along with The Effects of Nuclear Weapons, the section of this document which describes the debris charts also gives insight into the manner in which buildings break up to form debris. Theoretical considerations are beyond the scope of this document, and they require a good deal of proficiency in using structural dynamics. Also theory is quite lacking in many areas of structural response, such as total collapse.

Table 4 represents a compilation of Japanese and weapon test data. They are quite useful in predicting damage to elements of structures when properly modified. A study of the weapons test reports referred to in Table 4, while not necessary, will help to provide further insight.

METHOD OF DAMAGE PREDICTION

It cannot be emphasized too strongly that the following method cannot give an exact prediction of building damage. In fact, the more exact one attempts to be, the more the chance of going astray in the predictions. The user is

Table 4

DAMAGE TO BUILDING ELEMENTS

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
12" wall	G16B1N	35		U	20	No detectable damage
10" wall	B95HP245	17		D	20	Bulged badly
8" panel	WT741p270	13	35.6	D	0	Calculated maximum overpres-sure
8" wall	G51NP241	12		F	UNK	Punched out
8" wall	G51NP239	12		D	0	Starting to fail
8" wall	G10B8NP44	8		D	30	Badly bowed
8" panel	WT741p162	7.5	18.4	D	0	4' horizontal crack
8" panel	WT741p67	4.5	10.2	U	0	No observable damage
6-1/2" wall	G4B28N	10		U	30	5% superficial damage
6" wall	G17B35AP122, 123	35		F	UNK	Walls punched out
6" wall	Unknown (H or N)	18		F	UNK	Wall gone
6" (1/4% steel) wall	WT724p38	12	32.3	F	0	Blown out
6" wall	B76HP198	4.2		D	<5	Bulding inward - very poor concrete

REINFORCED CONCRETE

Table 4, (cont.)

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
12" reinforced	WT741P270	10	25.9	D	0	Calculated maximum overpressure
12" reinforced	WT741p164	7.5	18.4	D	0	Minor cracking
12" solid	WT741p125	7.5	18.4	F	0	20% blown out - wall broken down middle and rotated inward
12" solid	WT741p270	7	16.9	D	0	Calculated maximum overpressure
12" solid	WT741p35	4.5	10.2	U	0	No damage
8" reinforced	WT741p270	5.5	12.9	D	0	Calculated maximum overpressure
8" reinforced	WT741p164	~4.5	(2.1)	D	0	Rear wall, spalled at top on outside face - 3' crack from top down on inside face
8" reinforced	WT741p169	~3.5	(1.7)	D	6	Rear wall displaced outward 1/2"
8" solid	WT724p36	12	32.3	F	0	Only fringes of brick remain
8" solid	WT741p140	7.5	18.4	F	0	85% blown out
8" solid	WT724p36	7.1	17.2	D	0	Slight cracking and deflection
8" solid	WT741p270	4.5	10.2	D	0	Calculated maximum overpressure
8" solid	WT741p47	4.5	10.2	U	0	Some spilling
8" solid	WT724p36	4.2	9.5	U	0	Almost damage free, a few hairline cracks
8" - 12" solid	ENWp163	7-8	16.9-19.8	F	UNK	Shearing and flexure failures

BRICK PANELS

Table 4, (cont.)

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
4" brick + 8" block	WT724p38	12	32.3	F	0	90% blown out
4" brick + 8" block 12' span	WT741p133	7.5	18.4	F	0	90% blown out
4" brick + 8" block 16' span	WT741p151	7.5	18.4	D	0	75% blown out
4" brick + 8" block 16' span	WT741p202	7.5	18.4	F	0	80% blown out
4" brick + 8" block 20' span	WT741p135	7.5	18.4	F	0	90% blown out
4" brick + 8" block 12' span	WT741p40	4.5	10.2	U	0	Slightly spalled
4" brick + 8" block 16' span	WT741p58	4.5	10.2	U	0	Slight spalling - some vertical flexure cracks
4" brick + 8" block 20' span	WT741p42	4.5	10.2	U	0	Slight spalling - slight crack on inside face
4" brick + 8" block	WT741p270	4.5	10.2	D	0	Maximum calculated overpressure
4" brick + 8" block 0.75" top space w/∠ for bearing -16' span	WT741p156	7.5	18.4	F	0	85% blown out
4" brick + 8" block 0.75" top space w/∠ for bearing -16' span	WT741p62	4.5	10.2	F	0	75% blown out, poor construction, dubious bond between brick & block, and few brick ties
4" brick + 8" block 0.75" top space w/∠ for bearing	WT741p270	2.6	5.6	D	0	Maximum calculated overpressure
4" brick + 2" cavity + 8" block	WT741p149	7.5	18.4	F	0	95% blown out

BRICK AND BLOCK PANELS

Table 4, (cont.)

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
4" brick + 2" cavity + 8" block	WT741p149	7.5	18.4	F	0	95% blown out
4" brick + 2" cavity + 8" block	WT741p270	2.6	5.6	D	0	Maximum calculated overpressure
4" brick + 3" block	WT741p180	7.5	18.4	U	18	Bowed in
4" brick + 8" block	WT741p174, 184, 187, 190, 193, 196, 199, 206, 210, 213, 126, 222	7.5	18.4	U	22	Bowed in and minor cracking
4" brick + 8" block	WT741p219	7.5	18.4	U	37	Bowed in, crack
4" brick + 8" block	WT741p177	7.5	18.4	U	67	Vertical cracks over entire length
4" brick + 8" block	WT741p83	4.5	10.2	U	18	Vertical hairline cracks, slight bow
4" brick + 8" block	WT741p77, 86, 89, 92, 95, 98, 101, 106, 110, 113, 116, 122	4.5	10.2	U	22	Slight spalling and cracks, some bow
4" brick + 8" block	WT741p119	4.5	10.2	U	37	Vertical crack
4" brick + 8" block	WT741p80	4.5	10.2	U	67	Vertical hairline crack
4" brick + 4" block	WT741p137	7.5	18.4	F	0	95% blown out
4" brick + 4" block	WT741p147	7.5	18.4	F	0	98% blown out
4" brick + 4" block	WT741p44	4.5	10.2	F	0	85% blown out

BRICK AND BLOCK PANELS, (cont.)

Table 4, (cont.)

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
4" brick + 4" block	WT741p52	4.5	10.2	F	0	90% blown out
4" brick + 4" block	WT741p60	4.5	10.2	F	0	95% blown out, poorly filled joints between brick and block
4" brick + 4" block	WT741p270	2.2	4.7	D	0	Maximum calculated overpressure
4" brick + 4" tile	WT741p159	7.5	18.4	F	0	95% blown out
4" brick + 4" tile	WT741p64	4.5	10.2	F	0	98% blown out
4" brick + 4" tile	WT741p270	1.8	3.8	D	0	Maximum calculated overpressure
12" block	WT741p144	7.5	18.4	F	0	85% blown out
12" block	WT724p38	7.1	17.2	F	0	85% blown out
12" block	WT741p49	4.5	10.2	F	0	80% blown out
12" block	WT741p270	4.3	9.7	D	0	Maximum calculated overpressure
8" block	WT741p130	7.5	18.4	F	0	90% blown out
8" block	WT724p37	7.1	17.2	F	0	90% blown out
8" block	WT741p37	4.5	10.2	F	0	90% blown out
8" block	WT741p270	2.6	[illegible].6	D	0	Maximum calculated overpressure
8" - 12" block	ENWp163	2-3	4.2-6.6	F	UNK	Wall shattered

BRICK AND BLOCK PANELS, (cont.)

Table 4, (cont.)

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
precast R/C channels ~2' wide	WT741p172	4.5	(2.1)	F	0	Rear wall - all failed by folding in middle
precast R/C channels ~2' wide	WT741p175	3.5	(1.7)	U	0	Vertical cracking
precast R/C channels ~2' wide	WT741p270	1.8	3.8	D	0	Maximum calculated overpressure
corrugated steel siding	WT724p37	4.2	9.5	F	0	100% blown out except panels on edges held by ∠
22 gauge corrugated metal	WT741p168	4.5	(2.1)	F	0	3 sheets hanging by top bolts only. 5 sheets torn completely loose and blown out
22 gauge corrugated metal	WT741p270	1.8	3.8	D	0	Maximum calculated overpressure
22 gauge corrugated metal	WT741p71	3.5	(1.7)	D	0	Bowed in but remaining in place
corrugated asbestos	WT724p37	4.2	9.5	F	0	Completely shattered
corrugated asbestos	WT741p170	4.5	(2.1)	F	0	Completely shattered
corrugated asbestos	WT741p73	3.5	(1.7)	F	0	Completely shattered
corrugated asbestos	ENWp163	1-2	2.1-4.3	F	UNK	Shattering
corrugated steel or aluminum	ENWp163	1-2	2.1-	F	UNK	Connection failure followed buckling
wood siding	WT724p37	4.2	9.5	F	0	Completely shattered
wood siding	ENWp163	1-2	2.1-	F	0	Fails at main conncection allowing entire panel to be blown in

PANELS

Table 4, (cont.)

DESCRIPTION	DATA SOURCE	p_o	p_r	DAMAGE	% OPENING	REMARKS
corrugated asbestos roofing on wood trusses	WT24p38	4.2	9.5	F	N/A	Asbestos completely removed, wood trusses ok
corrugated steel roofing on wood trusses	WT724p38	4.2	9.5	F	N/A	Only one section remained on front slope. Wood trusses completely broken
glass windows, large and small	ENWp163	0.5-1	1.0-2.1	F	0	Shattering, occasional frame failure

PANELS, (cont.)

LEGEND

U	Undamaged	WT741p270	Weapon Test Report 741, page 270
D	Damaged	p_o	Incident overpressure
F	Failed	p_r	Reflected overpressure for Weapon Test Reports. Numbers in ( ) indicate equivalent incident overpressures where there was no reflection at p_o
UNK	Unknown		
G16B1N	Group 16, Building 1, Nagasaki		
B95HP245	Building 95, Hiroshima, Photo 245		

cautioned to keep this in mind when attempting to predict building damage.

The first item to consider in predicting building damage is the incident overpressure which may be determined from the weapon parameters. The overpressure values listed in Table 4 as being from weapons tests are for incident values where reflection occurs. If no reflection occurs (such as at the rear wall of a building) then the damage should be referenced to the value appearing in the column for reflected overpressure. For example, if a building with brick panel walls is subjected to 4.5 psi, then the damage to the rear wall panels should be estimated by referring to similar panels subjected to a reflected pressure of 4.5 psi. The front walls are damaged by 4.5 psi which is reflected to 10.2 psi.

Once the overpressure that the structure experiences is determined, the debris chart applying to that category, along with Table 5, should be consulted to determine the level of damage. This will indicate which specific elements of the structure should be examined in detail by use of Table 4 . However it should always be kept in mind that the building elements listed in Table 4 were tested under more or less ideal conditions (except for the Japanese data). Virtually any real-life situation is non-ideal, so that the overpressures in the table may be considered the lower limits for the damage that is described.

If the building is essentially diffraction-sensitive, that is, if it is wood-frame or non-reinforced load-bearing masonry, then the damage must be described in more general terms, since these types fail more as a unit, and not in relatively well-defined stages.

All categories of buildings undergo light damage at about 1 psi. Light damage, unless otherwise noted in the following descriptions, consists of most of the windows being blown out*, doors being damaged and possibly some blown off, and interior partitions being slightly distorted. The extent of this

* Windows may be blown out at as low as 0.25 psi, although 0.5 psi is a more usual value.

Table 5

INTERPRETATION OF DEBRIS CHARTS (MT WEAPON)

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Heavy reinforced concrete shearwall with light interior panels	2	Interior panels start to fall	Interior panels failed by fire
	12	Interior panels failure complete	C
	30	Main structure, walls and horizontal diaphragms start to fail	C
	31		Blast damaged walls and diaphragms fail; building failure complete
	33	Building failure complete	

NOTE: C - combustible portions of debris consumed.

Table 5, cont.

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Heavy reinforced concrete shearwall with masonry interior panels	3	Interior panels start to fail	C
	12	Interior panel failure complete	C
	30	Main structure, walls, and horizontal diaphragms start to fail	C
	31		Blast damaged walls and diaphragms fail; building failure complete
	33	Building failure complete	
Multistory reinforced concrete shearwall building with light interior panels	2	Interior panels start to fail	Interior panels failed by fire
	11.5	Interior panels failure complete	C
	11.5	Main structure, walls, and horizontal diaphragms start to fail	C
	12.3		Blast damaged walls and diaphragms fail, building failure complete
	13.5	Building failure complete	

Table 5, cont.

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Multistory reinforced concrete shearwall building with masonry interior panels	3	Interior panels start to fail	C
	11.5	Interior panels failure complete	C
	11.5	Main structure, walls, and horizontal diaphragms start to fail	C
	12.3		Blast damaged walls and diaphragms fail; building failure complete
	13.5	Building failure complete	
Multistory steel or reinforced concrete frame Earthquake design and masonry exterior panels	2	Panels start to fail	Panels failed by fire
	10	Panel failure complete	C
	10		Blast distorted frame fails, building failure complete
	10	Frame and horizontal diaphragms start to fail	
	13	Building failure complete	

Table 5, cont.

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Multistory steel or reinforced concrete frame Earthquake design and masonry exterior panels	3	Panels start to fail	C
	10	Panel failure complete	C
	10		Blast distorted frame fails; building failure complete
	10	Frame and horizontal diaphragms start to fail	
	13	Building failure complete	
Multistory steel or reinforced concrete frame building	2	Panels start to fail	Panels failed by fire
Non-earthquake design with light exterior panels	8.5	Panel failure complete	C
	8.5		Blast distorted frame fails; building failure complete
	8.5	Frame and horizontal diaphragms start to fail	
	12	Building failure complete	

Table 5, cont.

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Multistory steel or reinforced concrete frame	3	Interior panels start to fail	C
Non-earthquake design with masonry exterior panels	8.5	Interior panels failure complete	C
	8.5		Blast distorted frame fails; building failure complete
	8.5	Frame and horizontal diaphragms start to fail	
	12	Building failure complete	
Light reinforced concrete shearwall with concrete roof and light interior panels	2	Interior panels start to fail	Interior panels failed by fire
	5	Interior panels failure complete	C
	6.5	Roof slab starts to fail	C
	9.5	Roof slab failure complete	C
	9.5		Roof framing and walls fail; building failure complete
	10	Roof framing and walls start to fail	
	11	Building failure complete	

Table 5, cont.

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Light reinforced concrete shearwall with concrete roof and masonry interior panels	3	Interior panels start to fail	C
	6	Interior panels failure complete	C
	6.5	Roof slab starts to fail	C
	9.5	Roof slab failure complete	C
	9.5		Roof framing and walls fail; building failure complete
	10	Roof framing and walls start to fail	
	11	Building failure complete	

Table 5, cont.

BUILDING TYPE	OVERPRESSURE (psi)	BLAST DAMAGE	FIRE AND BLAST DAMAGE
Light reinforced concrete shearwall with mill type roof and light interior panels	2	Roof sheathing and interior panels start to fail	Roof and interior panels failed by fire
	5	Roof sheathing and interior panels failure complete	C
	9.5		Roof framing and walls fail; building failure complete
	10	Roof framing and walls start to fail	
	11	Building failure complete	
Light reinforced concrete shearwall with mill type roof and masonry panels	2	Roof sheathing and interior panels start to fail	Roof and framing failed by fire
	3	Roof sheathing failure complete	C
	6	Interior panels failure complete	C
	9.5		Blast damaged walls fail; building failure complete
	10	Roof framing and walls start to fail	
	11	Building failure complete	

damage depends upon the size and orientation of the structure. If the interior is quite shielded due to many interior partitions or small window areas, then most of the light damage will occur in rooms on the blastward side of the building.

The following damage descriptions apply for megaton range weapons. The descriptions are tabulated for all building categories in Table 6.

- Damage to Wood Frame Buildings

  Moderate damage occurs at about 2.0 psi and may be described as having the wall framing cracked, roof badly damaged (many rafters failed, some sections collapsed or blown off), and the interior partitions distorted and partially displaced. The floors will be distorted, with general cracking and some breakage of joists. Severe damage occurs at about 3.5 psi and at this point the frame is shattered and distorted to such an extent that the structure is on the verge of collapse.

- Damage to Load-Bearing Masonry Buildings

  Moderate damage (about 4.0 psi) consists of badly cracked exterior walls, and cracked and distorted interior partitions. Severe damage occurs at approximately 6.0 psi, and is defined by the collapse of many of the bearing walls resulting in the collapse of some of the structure.

- Damage to Steel Frame Industrial Buildings

  Light damage to this category of structures includes the distortion of the light wall material if it is metal. Moderate damage takes place at about 4.0 psi for the light frame building to about 6.0 psi for the heavy frame building. Moderate damage consists of slight distortion of the frame, girts, and purlins, causing cranes (if any) to be inoperable. Severe damage (approximately 5.0 psi for light frame to 11.0 psi for heavy frame buildings) causes severe distortion of frame.

- Damage to Multistory Reinforced Concrete Frame Office Type Building

  Moderate damage occurs at about 6.0 psi and consists of all of the wall panels blown out, some frame distortion, and some spalling of concrete at beam-column connections. Approximately 8.5 psi causes severe damage, which is severe frame distortion and incipient collapse, to buildings that are not designed to resist earthquakes. Approximately 10.0 psi causes similar severe damage to buildings designed to withstand earthquakes.

- Damage to Multistory Steel Frame Office Type Building

  The damage overpressures and descriptions are identical to those for the reinforced concrete frame building.

Table 6

DAMAGE DESCRIPTIONS

Structure No	Description of Structure	Description of Damage: Severe	Moderate	Light
1	Wood frame residential	Frame shattered and distorted so that for the most part collapsed	Wall framing cracked, roof badly damaged (many rafters failed, some sections collapsed), interior partitions distorted and partially removed. Wood floors distorted, general cracking and some breakage of joists	Windows out, doors destroyed or off, interior partitions cracked
2	Wall-bearing building, brick apartment house type, up to 3 stories.	Many bearing walls collapse, resulting in collapse of most of structure	Exterior walls badly cracked, interior partitions cracked, distorted and partially removed	Windows out, doors destroyed or off, interior partitions cracked
3	Wall-bearing masonry building, monumental type, up to 4 stories	Many bearing walls collapse resulting in collapse of structure supported by these walls, some bearing walls may be shielded enough by intervening walls so that part of the structure may receive only moderate damage	Exterior walls facing blast badly cracked, interior partitions cracked and distorted and partially removed Toward far end of building damage may be reduced	Windows out, doors destroyed or off, interior partitions cracked
4	Reinforced masonry building with concrete or reinforced masonry spandrels.	Walls shattered, severe wall and floor distortion, incipient collapse	Exterior walls badly cracked, interior partitions cracked, distorted and partially removed Structural elements (floors, roof, framing, etc) distorted, extensive cracking and spalling or masonry	Windows out, doors destroyed or off, interior partitions cracked
5	Light steel frame industrial building, single story, with up to 5-ton crane capacity Lightweight, low-strength sheathing	Severe distortion or collapse of frame	Some distortion of frame, girts and purlins Cranes (if any) not operable until repairs made	Windows out, doors destroyed or off, light sheathing removed
6	Medium steel frame industrial building, single story, with 25-30-ton crane capacity. Lightweight, low-strength sheathing.	Severe distortion or collapse of frame	Some distortion of frame, girts and purlins, cranes not operable until repairs made	Windows out, doors destroyed or off, light sheathing removed
7	Heavy steel frame industrial building, single story, with 60- 100-ton crane capacity Lightweight, low-strength sheathing.	Severe distortion or collapse of frame	Some distortion of frame, girts and purlins, cranes not operable until repairs made	Windows out, doors destroyed or off, light sheathing removed
8	Multistory steel frame office type building, 3- 10 stories (non-earthquake-resistant construction), low-strength panels	Severe frame distortion, incipient collapse	Some frame distortion, panels and partitions removed	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked
9	Multistory steel frame office type building, 3- 10 stories (earthquake-resistant construction), low-strength panels.	Severe frame distortion, incipient collapse	Some frame distortion, panels and partitions removed	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked
10	Multistory reinforced concrete frame office type building, 3 - 10 stories (non-earthquake-resistant construction), low-strength panels	Severe frame distortion, incipient collapse	Some frame distortion, panels and partitions removed Some floor and roof damage General spalling of concrete at beam-column connections	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked
11	Multistory reinforced concrete frame office type building, 3 - 10 stories (earthquake-resistant construction), low-strength panels	Severe frame distortion, incipient collapse	Some frame distortion, panels and partitions removed Some floor and roof damage General spalling of concrete at beam-column connections	Windows out, doors destroyed or removed, light siding removed, interior partitions cracked
12	Multistory heavy reinforced concrete shear wall building	Walls shattered, severe floor and wall diaphragm distortion, incipient collapse	Walls breached or on the point of being so, structure permanently racked Extensive spalling of concrete Interior partitions badly distorted or destroyed	Windows out, doors destroyed or removed, interior partitions cracked
13	Multistory light reinforced concrete shear wall building	Walls shattered, severe floor and wall diaphragm distortion, incipient collapse	Exterior walls breached or on the point of being so, interior partitions badly distorted or destroyed Structure permanently racked, extensive spalling of concrete	Windows out, doors destroyed or removed, interior partitions cracked
14	Light reinforced concrete shear wall building, single story, with mill type roof	Severe distortion of walls and roof frame Incipient collapse	Some distortion of walls and roof frames, interior panels removed	Windows out and doors destroyed or off, light roof sheathing removed, interior partitions cracked
15	Light reinforced concrete shear wall building with light concrete roof	Severe distortion of walls and roof beams Incipient collapse	Some distortion of walls, roof slabs partially punched out	Windows out and doors destroyed or off, interior partitions cracked

- Damage to Multistory Reinforced Concrete Shear Wall Buildings

  Moderate damage occurs at approximately 7.0 psi and is characterized by cracking and bowing of exterior walls and distortion and destruction of interior partitions. The structure will be permanently racked, and the concrete will be extensively spalled. Severe damage takes place at about 11.5 psi and at this level of damage the exterior walls are shattered, the floor diaphragm is severely distorted, and the entire structure is on the verge of collapse.

- Damage to Single Story Light Reinforced Concrete Shear Wall Buildings

  Moderate damage is about 5.0 psi for this type of building, and entails slight distortion of walls and roofs. Severe damage occurs at about 10.0 psi and the walls and roof are severely distorted and the building is on the verge of collapse.

EXAMPLES OF DAMAGE DESCRIPTIONS

Some examples of damage predictions follow,* to indicate what level of detail might be expected. These descriptions were made using the information found on Sanborn Map Sheets and photographs.

MISCELLANEOUS CONSIDERATIONS

The following are some considerations that should be kept in mind when damage predictions are made:

- If a structure has a light roof (such as gypsum poured over metal forms supported by steel trusses) then the roof will undergo distortion and stripping of the deck at 2-3 psi. This will be especially true of the roof overhangs the exterior building wall.

- A difference exists in damage between a wall with windows and one without. Windows decrease the exterior wall damage from a given overpressure, but increase the interior damage.

- If there are no windows, or the window area is small, then the overpressure front will travel over the roof more rapidly than it will advance through the structure. This will cause an unbalanced pressure on the roof. A differential pressure of 4-5 psi would likely cause failure in a light concrete roof slab (~ 3-in. thick) under these conditions.

- An unbalanced pressure of 7-8 psi on a first story floor (e.g., over a basement with few openings into it) may cause collapse.

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* These descriptions appear on p. 74 ff.

- Suspended ceilings fail at about 1.5-2 psi. This failure can cause serious degradation of fireproofing for steel floor girders.

- Light interior partitions (e.g., metal stud and wallboard) will fail at around 2-3 psi.

- Light weight prefabricated metal curtain walls fail at quite low overpressures, perhaps as low as 2 psi.

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	4.4 psi
Fire:	No
Building Type:	Single-story dwelling
Frame:	Wood frame
Exterior Walls:	Wood
Interior Walls:	Lath and plaster
Roof:	Composition shingles
Floors:	Wood on joists

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	All out
Suspended Ceiling:	-
Roof:	Blown off
Floors:	Collapsed
Exterior Walls:	All blown in
Interior Walls:	80% blown out
Frame:	-
Debris:	Roof and some wall panels off-site
Remarks:	Virtually destroyed except for some interior partitions

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	3.75 psi
Fire:	No
Building Type:	Two-story school
Frame:	Steel
Exterior Walls:	8-in. concrete block with 4-in. brick facing
Interior Walls:	Metal lath and plaster. Masonry
Roof:	Steel deck with tar and gravel
Floors:	Reinforced concrete

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	All out
Suspended Ceiling:	Out with some portions dangling
Roof:	Decking failed with 50% hanging from trusses. Trusses intact
Floors:	Undamaged
Exterior Walls:	Cracked with 20% of brick facing spalled off
Interior Walls:	All cracked. Lath and plaster 30% blown out. Masonry 10% blown out
Frame:	Undamaged
Debris:	20% ejected

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	5.0 psi
Fire:	No
Building Type:	12 - 27 story department store with about 90,000 sq ft floor area
Frame:	Steel
Exterior Walls:	12-in. brick curtain walls and 12-in. brick faced curtain walls
Interior Walls:	Mostly light
Roof:	Concrete
Floors:	Concrete

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	60% out
Suspended Ceiling:	80% out
Roof:	Undamaged
Floors:	Undamaged
Exterior Walls:	Slight cracking on blastward side
Interior Walls:	50% out
Frame:	Slight permanent distortion
Debris:	Mostly on-site
Remarks:	-

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	2.7 psi
Fire:	No
Building Type:	a. 1 story reinforced concrete shear wall with reinforced concrete roof
	b. 1 story wood frame industrial with light panels
Exterior Walls:	Reinforced concrete and light panels
Interior Walls:	Reinforced concrete and light panels
Roof:	a. Reinforced concrete (label room and warehouse)
	b. Assume corrugated iron or corrugated asbestos sheathing
Floors:	Concrete on grade

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	90% out
Suspended Ceiling:	Not applicable
Roof:	Reinforced concrete - no damage. Corrugated iron or corrugated asbestos - 95% removed
Floors:	No damage
Exterior Walls:	Reinforced concrete cracking with some bowing Light panels - 95% blown out
Interior Walls:	Reinforced concrete cracking with some bowing Light panels - 95% blown out
Frame:	Light damage
Debris:	On site
Remarks:	Lightly damaged

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	6.5 psi
Fire:	No
Building Type:	Two-story store
Frame:	Reinforced concrete
Exterior Walls:	8-in. concrete block curtain walls
Interior Walls:	Light
Roof:	Reinforced concrete
Floors:	Reinforced concrete

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	All out
Suspended Ceiling:	All out
Roof:	Bowed down on blastward side
Floors:	No damage
Exterior Walls:	Walls on blastward side all out. Remaining walls 50% out
Interior Walls:	All out
Frame:	Moderately distorted
Debris:	Scattered off-site
Remarks:	Severe damage

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	3.8 psi
Fire:	No
Building Type:	Two and three story city hall
Frame:	Reinforced concrete
Exterior Walls:	9-in. reinforced concrete, 12-in. brick, and 8-in. tile
Interior Walls:	Both heavy masonry and light lath and plaster
Roof:	Reinforced concrete
Floors:	Reinforced concrete

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	85% out
Suspended Ceiling:	All out
Roof:	Undamaged
Floors:	Undamaged
Exterior Walls:	Essentially undamaged
Interior Walls:	Masonry walls cracked. Light walls 60% out
Frame:	Undamaged
Debris:	Mostly on-site
Remarks:	Large window openings relieve pressure so that exterior walls are undamaged

BUILDING ENVIRONMENT AND PHYSICAL DESCRIPTION

Incident Overpressure:	2.1 psi
Fire:	No
Building Type:	1 story, concrete shear wall with mill roof and steel frame industrial with wood roof and corrugated asbestos siding. Wood and concrete floors. Wood posts throughout
Exterior Walls:	Reinforced concrete and corrugated asbestos
Interior Walls:	Reinforced concrete and corrugated asbestos
Roof:	Mill type
Floors:	Wood and concrete

BUILDING DAMAGE AND DEBRIS DESCRIPTION

Glass:	All out
Doors:	50% out
Suspended Ceiling:	Not applicable
Roof:	55% sheathing removed
Floors:	No damage
Exterior Walls:	Slight cracking in concrete. 60% corrugated asbestos removed
Interior Walls:	Same as exterior where occurring
Frame:	No damage
Debris:	Mostly within building
Remarks:	Light damage

Section 4
SUMMARY

DEBRIS MODEL

The debris prediction model explained in this handbook was developed to enable the prediction of the amount of structural debris resulting from a nuclear weapon attack on an urban area. Debris is defined as the material contained in those portions of a building that have undergone complete failure. The philosophy behind its development was to utilize actual data as much as possible. To this end, the Hiroshima and Nagasaki experiences and the Nevada and Pacific weapons tests were the basis for developing charts to predict the per cent of structural material becoming debris as a function of overpressure. At present, these debris charts cover five basic structure types: wood frame residential, load bearing masonry, steel frame industrial, reinforced concrete shearwall, and multistory steel or reinforced concrete frame office type. With various refinements of these basic categories, there are twenty different debris charts, covering both kiloton and megaton yield weapons. The debris charts are for blast effects alone, or for blast combined with fire.

Methods have been developed to estimate the volume of structural material in a building, and the volume of contents contained in a given occupancy.

To apply the debris model, it is necessary to know the weapon parameters to determine overpressure, building size and type to determine material volume, and occupancy to determine contents volume. All of the necessary structure information may be found on Sanborn Maps. The steps to be followed to determine debris are:

1. Plot overpressure vs distance curve from yield and height of burst of weapon.
2. Determine occupancy, type, and size of building (usually from Sanborn Maps).

3. Determine overpressure at building's location.

4. Enter proper curve (for type of building and size of weapon) with overpressure to obtain percentage of structure converted to debris by:

   a. blast only.

   b. blast and fire (if in burned area).

5. Determine percent of contents of the building converted to debris from curve for the building type.

6. Calculate total structural material volume.

7. Calculate total volume of contents.

8. Apply percentage figures to structural and contents volumes to determine total volume of debris from building.

9. Sum up all contributions from area of interest.

10. Apply void ratio and divide volume by specified area to determine debris depth.

By use of the methods presented in this report, debris depths may be calculated for an area in a city, a route through a city, or the entire city.

DAMAGE PREDICTIONS

The data gathered during the construction of the debris charts contained information on damage to many different types of buildings and building elements. With this information, it has been possible to predict damage, in general terms, to specific structures. The accuracy of these predictions depends upon the amount of information known about the structure and its surroundings.

However, even with detailed structure information the damage descriptions are mostly qualitative. For example, rather than predicting that 10 ft of the blastward exterior second floor wall has been blown in, the description would be that 25 per cent of the blastward exterior wall is blown in.

Before damage estimates are attempted, one should have a general idea of how buildings respond to blast. The best way to accomplish this is to read the chapter in The Effects of Nuclear Weapons (Ref. 24) on air blast loading and on structural damage. Having this background, one is better able to understand the inter-relationships of loading, response, and damage.

Once the building category and incident overpressure are determined, the debris charts are used to get an overall idea of damage. For example, if the overpressure indicates that a frame structure has not lost all of its walls, (i.e., initial rising limb of curve indicated) then the table of damage to building elements is referred to in order to determine the damage to specific elements. The damage to the interior elements is determined by considering how their loading is affected by the presence, or absence, of the exterior walls. It must be remembered that the elements of the structure must be considered with regard to their interaction with other elements.

VALIDITY OF DAMAGE PREDICTIONS

The philosophy behind the development of the debris charts should be kept in mind both when calculating debris and when predicting damage. The debris charts represent the development of an empirical, not theoretical, methodology to determine quantities of structural debris.

A debris chart refers to a "typical" building within a certain category of structures. By typical is meant no unusual features such as a cross-shaped floor plan, or a length much greater than the width. These charts are most accurate when applied to a large number of structures of the same type throughout an area. Any one specific structure is likely to have features that make the chart's predictions inaccurate, however, these non-typical features will be averaged out with a number of structures. This will be especially true in considering the effects of building orientation to the path of the blast wave. In Nagasaki, a steel frame industrial structure situated so that its long axis was normal to the direction of travel of the blast wave was partially collapsed, while an adjacent similar building, located such that its long axis was parallel to the direction of blast wave propagation, was still standing. Theoretical consideration of an idealized steel frame office type structure show the opposite to be true, due to the larger number of frames receiving a drag loading in that direction. So it may be seen that there may be a great deal of difference due to orientation, and the difference may not be in the same sense from building type to building type. In fact, due to construction details, it may even differ within the same type. Clearly all these considerations could not be covered in the debris charts. Therefore when using these charts to predict debris or damage from an individual structure, they must not be used blindly, but rather as a guide to the response of the building to the applied blast loading.

Experiments such as those being performed in the URS Shock Tunnel are adding to the understanding of structural component failure and will result in a more accurate methodology for predicting building damage. From the limited number of experiments and theoretical analyses conducted to date, it would seem that damage would occur at overpressures lower than those indicated in Table 4. Although it is premature to make any changes, it should be noted that changes are possible in the future. The important thing to remember is that these damage prediction methods are based on incomplete historical data and are likely to change as the understanding of damage mechanisms is increased.

Section 5

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13 ABSTRACT

This report is a compilation and summary of the efforts of the URS Corporation to develop a method to predict the amounts of structural debris that would result from the blast and fire effects of a nuclear weapon attack upon an urban area. The report is divided into two sections, the first dealing with the development of the debris prediction model and its use. The second section sets forth a method to predict building damage using the information accumulated during the development of the debris model.

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