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CONTENTS OF
STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS
(TM 5-1300, NAVFAC P-397, AFM 88-22)

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Michael Dede and David Kossover, Ammann & Whitney

ABSTRACT

Procedures for structures designed to resist the effects of HE type explosions are presently available in the Tri-Service Design Manual Structures to Resist the Effects of Accidental Explosions (TM 5-1300, NAVFAC P-397, AFM 88-22). However, these procedures are limited to reinforced concrete structures. Since its original publication, a considerable amount of data has been generated which brought about the requirement to revise existing procedures in the manual and incorporate new data. This describes the differences between the old and new manual and discusses the additional data incorporated in the new manual.

CONTENTS OF
STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS
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INTRODUCTION

This paper summarizes the material contained in the design manual Structures to Resist the Effects of Accidental Explosions. This manual, as contained in Reference 1, shall here after be referred to as the "new manual". The present 1969 publication of the "Tri-Service Manual", as contained in Reference 2, shall here after be referred to as the "old manual".

Subsequent to the publication of the old manual, various government agencies conducted several high explosive tests. These tests were perfomed to determine explosive environments, and the response of specific structures and materials. The result of these tests have provided sufficient additional information to revise the H. E. Protection Design Criteria of the old manual.

VOLUME I - INTRODUCTION

Volume I consists of an expanded discussion of the topics in Chapters 1 to 3 of the old manual. The specific global topics are illustrated in Figure 2. The significance of the new manual can be seen in its expanded discussion and treatment of the topics concerned with the safety factor, explosive protection systems, and design tolerances.

Although the factor of safety remains unchanged between the old and new manuals, the new manual contains a discussion of the effects of increasing the flexural strength of a member beyond the design requirements, and the detrimental effect this has on supporting members.

The three components of explosive protection systems are described in detail. Namely, Donor, Protection and Acceptor Systems, are discussed independently and interdependently. The aim of the discussion is to enable the Designer to judge the requirements of each portion of the explosive system, to produce a practical and cost effective system.

The old manual considered three pressure design ranges. The new manual considers only close-in and far-out ranges. However, these two design ranges consider the pressure-time variation rather than the pressure alone on both the acceptor system and the protective structure.

Lastly, the extensive increase in the data pertaining to acceptor sensitivity has been included in the new manual. Specifically, human tolerance to both blast pressure and shock, explosive initiation by fragments, and equipment tolerances to shock loads, are discussed. Knowledge of acceptor sensitivity is an important factor in developing practical and cost effective protective structures.

VOLUME II - BLAST, FRAGMENT AND SHOCK LOADS

This volume is presented in three main sections, as is shown in Figure 3. The first section is concerned with protective structures sustaining the impact of a blast load pressure due to an explosion. The second section is concerned with primary and secondary fragments associated with the break-up of a explosive charge casings, equipment, or buildings containing an explosion. The third section is concerned with the motions induced in protective structures due to an impact with the shock front and/or ground motions due to an explosion.

BLAST LOADS:

A summary of the changes and additions presented in the new manual compared to the old manual is illustrated in Figure 4. Based on recently developed data, the major change in the free air burst curves are the modification of the impulse curves (both incident and reflected waves), and the positive duration of the shock wave, as may be seen in Figure 5.

On the other hand, the magnitude of the blast pressures acting on the ground due to an air burst are completely different, as is shown in Figure 6. Furthermore, the new manual contains impulse loads corresponding to the new peak pressures acting at various locations on the ground, as is shown in Figure 7.

Blast parameters associated with a surface burst explosion of TNT have not changed. However, additional blast parameters for 95 different explosives other than TNT, also detonated on ground (surface burst), have been included. These additional explosives vary in explosive and casing material and shape. An example of this data is shown in Figure 8.

Blast loads from vented explosions refer to those detonations which occur next to a barricade or other obstruction, or within a cubicle type structure, which permits total venting of the explosive effects. The impulse loads associated with close-in detonations presented in the new manual differ from those of the old manual because they are based on new data obtained after the publication of the old manual. Specifically, the new manual contains revised average peak impulse loads, and additionally, the newly developed associated average peak pressures. These average pressures are used in conjunction with the average impulses to define the internal shock loads of a cubicle type structure, as is shown in Figure 9.

Previous data presented for vented explosions assumed that light material panels at one or more sides of a structure would permit total venting. Recent test data has indicated that even light material panels will permit reflections, increasing shock loads within a cubicle. The new manual presents this new data, and defines the magnitude of the internal loads and the pressures venting out of a structure with light material panels.

Blast loads corresponding to confined explosions are similar to those of vented explosions except for the additional long duration loading which occurs within the fully contained structure. These latter additional loads are referred to as quasistatic or gas pressure loads, and are produced by the accumulation of the gaseous products of detonation and the increase in temperature within the fully confining structure. The magnitude of gas pressures presented in the new manual may be seen in Figure 10. In addition, the new manual gives the impulse of this gas pressure load for various charge weight to structure volume ratios. Scaled impulse as a function of scaled vent area is given for various weights of vent covers. A sample of these curves is shown in Figure 11.

The procedures for determining blast loads acting on the exterior of rectangular shelter type structures were available in the old manual. These procedures have been refined and supplemented in the new manual to more closely define the blast environment for a shock front impinging on a shelter not only orthogonally, but at an angle, as illustrated in Figures 12 and 13. In addition to the blast loads acting on the exterior surfaces of a structure, the new manual presents procedures to determine the internal environment due to the leakage of external blast pressures into a structure through openings, as is illustrated in Figure 14.

FRAGMENTS:

Fragment generations from explosions consist of primary fragments formed by the fragmentation of explosive casings or containers, and secondary fragments formed by the break-up of equipment located in the general vicinity of the explosion. Procedures for primary fragments was presented in the old manual. However, the procedure was limited to only cylinderically shaped explosive casings. The new manual has expanded the procedure to contain non-cylinderical containers as well.

The damage caused by secondary fragments is a function of the size and shape, the attained velocities, and the direction of propogation of the missiles. The new manual contains procedures to evaluate all these parameters, as is shown in Figure 15.

SHOCK LOADS:

Blast loads acting on a structure and/or transmitted through the ground to a structure, cause motions in a structure. This motion causes the vibration of internal objects (such as ceilings, walls, equipment, etc.). If the structure or the internal objects are not designed to sustain the shock loads, failure can occur.

Structure motions produced by a shock load due to a detonation can be classified in three categories. The first being the motions due to a direct impact of an air blast. The second being motions produced by an air blast acting on the ground surface. The third being the ground shock effects due to the transmission of the shock wave directly through the ground. The first category generally causes the most severe motions.

The new manual presents procedures to determine the three categories of structure motion. These procedures are summarized in Figure 16. The procedure for determining motions due to a direct air blast impact utilize numeric integration. After determining the air blast loads acting on a structure, a rigid body analysis is performed with consideration for the resisting friction between the structure and the ground. The procedures for the other two categories are based on empirical relationships, established from tests.

After determining the structure motions, shock response spectras may be evaluated to establish the structure shock environment. These shock spectras are to be used to respectively design the structural components.

VOLUME III - PRINCIPLES OF DYNAMIC ANALYSIS

This volume contains the procedures for analyzing structural elements subjected to blast overpressures. The procedures and charts are general and apply to reinforced concrete and structural steel as well as to other materials whose dynamic structural strength can be expressed. The outline of the contents of the volume is listed in Figure 17.

The procedures for determining the resistance-deflection functions have been significantly increased in the new manual. The old manual contained the elastic, elasto-plastic and ultimate resistances and stiffnesses of several one-way and symmetrically supported and reinforced two-way members. The new manual considers additional one-way members with various load and support conditions. The two-way members considered have been increased to include unsymmetrically supported and/or reinforced (if concrete) elements. However, as was the case in the old manual, the elements are for uniform load conditions.

As in the old manual, the new manual utilizes the single-degree-of-freedom method to represent the motions of the actual structure subjected to blast loads. The utilization of the single-degree-of-freedom method requires determining the load, the mass, the resistance, the load factor, the mass factor or as an alternative the load-mass factor. Transformation factors are presented for one way members having variable loadings while load-mass factors are presented for various two-way spanning elements.

The present manual contains two response charts for idealized triangular pressure-time loads. One chart pertains to maximum structure response while the second is used to determine rebound loads. The number of response charts furnished in the new manual has been increased to 216. These new charts cover the maximum elastic response to triangular, rectangular loads, gradually applied loads, triangular pulse loads and sinusoidal loadings. The new charts also cover the maximum resonse of elasto-plastic systems to trangular loads, rectangular loads, gradually applied loads, triangular pulse loads and bilinear-triangular loads. The bilinear-triangular load condition (Figure 18) represents the idealized pressure-time load which would occur in a partially vented structure. Figure 19 illustrates the response curves for bilinear-triangular loads.

In addition to the expanded section on response charts, the new manual contains procedures for performing numerical integration as a means of analyses. These analyses include both the average-acceleration-method as well as the acceleration-impulse-extrapolation-method. Procedures are presented which include damping in a system as well as for analyzing two-degree-of-freedom systems.

VOLUME IV - REINFORCED CONCRETE DESIGN

The technical data in the volume for the design of concrete structures has been greatly expanded from the previous edition (Figure 20). Not only has the existing data been expanded, a considerable amount of new data has been added. This additional data will facilitate the design of more cost effective structures by eliminating conservativeness resulting from a lack of data.

The old manual is concerned primarily with the design of laced reinforced concrete walls to resist the effects of close-in detonations. Some data is included for the design of slabs to resist the blast effects of far range explosions. A well informed individual could adapt and expand this considerable amount of data to enable the not so informed individual to prepare realistic and cost effective designs.

The new manual provides a better estimate of the dynamic capacity of both the concrete and reinforcing steel than the old manual. Based on recent research and testing, the dynamic increase factors for both concrete and reinforcing steel are presented as a function of the actual resonse of the structural elements as well as the values needed for design. In addition, the static yield strength of the reinforcement is increased 10 percent beyond the minimum specified by the ASTM to account for the actual strength steel that is furnished by the steel producers. Finally, the shear capacity of concrete elements as presented in the current manual has proved to be conservative. Therefore, the new manual deletes the capacity reduction factor applied to the shear capacity of concrete.

Conventionally reinforced (unlaced) concrete elements were not extensively treated in the old manual. Only a limited amount of data was presented for the design of one- and two-way elements. This new manual greatly expands this data to include design procedures for slabs and walls of various support conditions, as well as design procedures and deflection criteria for beams and both interior and exterior columns. The design of slabs include not only one- and two-way slabs of various support conditions, but also includes the design of flat slabs. Also, when support conditions permit, tension membrane action of the slabs is incorporated in the design. The inclusion of this membrance action permits the slab to attain relatively large deflections at reduced strength and thereby resulting in substantial cost savings.

The design for close-in blast effects is concerned solely with the design of laced concrete elements in the old manual. Laced concrete walls can be designed for deflections ranging from small to larger to incipient failure conditions and beyond to the design of post-failure fragments. Unlaced concrete walls may also be designed for close-in effects. However, these walls must contain shear reinforcement in the form of single leg stirrups (Figure 21) and the scaled distance between the wall and explosive charge must be greater than 1.0 to prevent breaching of the wall. The charge may be located considerably closer for laced walls.

The relationship between the design parameters for unlaced one- and two-way slabs or panels is illustrated in Figure 22. An element may be designed to attain deflections corresponding to support rotations up to 2 degrees under flexural action (Figure 23). For far range effects, stirrups would be provided if the shear capacity of the concrete is not sufficient to develop the ultimate flexural strength. A Type I cross-section provides the ultimate moment capacity. The flexural action of the element may be increased to 4 degrees support rotation if single leg stirrups are provided to restrain the compression reinforcement. In this deflection range, a Type II cross-section provides the ultimate moment capacity and mass to resist motion. For close-in effects, the element must utilize stirrups. A minimum quantity of stirrups is required even if the shear capacity of the concrete is sufficient to develop the ultimate flexural capacity. The maximum permissible deflection of the element would be limited to 4 degrees support rotation. If spalling occurs, a Type III cross-section provides the ultimate moment capacity.

A non-laced element may be designed to attain large deflections, that is, deflections corresponding to 8 degrees support rotation. These increased deflections are possible only under tension membrance action (Figure 24). The element must have sufficient lateral restraint to develop in-plane forces. For close-in effects stirrups are required, while for far range effects, stirrups would be provided only if the shear capacity of the concrete is strength of the element. A Type III cross-section provides the ultimate moment capacity and mass to resist motion.

Flat slab structures are designed to resist the blast and fragments associated with a far range explosion. The relationship between the design parameters for flat slabs is illustrated in Figure 25. Flat slabs may be designed to attain limited or large deflections in the same manner as non-laced elements. Under flexural action alone, the slab may attain deflections corresponding to 2 degrees support rotation. The flexural action may be extended to 4 degrees rotation if single leg stirrups are added to restrain the flexural reinforcement. If sufficient continuous flexural reinforcement is provide, the slab may attain 8 degrees support rotation through tension membrane action. Unless necessary for shear, single leg stirrups are not required for the slab to achieve tension membrane action.

The design of beams as presented in the new manual apply to beams in shear wall type structures rather than rigid frame structures. The design procedure presented is for transverse loads only. Axial loads are not considered. However, the procedure includes the design for torsion. The relation between the design parameters for beams is illustrated in Figure 26. The design of beams is similar to the design of one-way slabs.

Beams are generally employed in structures designed to resist the effects associated with far range explosions. They may be designed to attain limited or large deflections in the same manner as non-laced slabs. Under flexural action alone, a beam may attain 4 degrees support rotation and, if sufficient lateral restraint is provided, the beam may attain 8 degrees support rotation under tension membrane action. Closed stirrups are always required for beams. While usually not the case, beams may be designed to resist close-in explosions. They could generally be employed as pilasters around door openings.

The design of columns is limited to those in shear wall type structures where the lateral loads are transmitted through the floor and roof slabs to the exterior (and interior, if required) shear walls. Due to the extreme stiffness of the shear walls, there is negligible sidesway in the interior columns and, hence, no induced moments due to lateral loads. Therefore, interior columns are axially loaded members not subjected to the effects of lateral load. However, significant moments can result from unsymmetrical loading conditions.

Design procedures are included for both tied and spiral columns. Slenderness effects are included in the procedures. Exterior columns of shear wall type structures are generally designed as beams.

The structural design for brittle mode response contains most of the data from the previous manual. However, prediction curves for the occurrence of spalling of concrete is included. These curves will more realistically predict the need for costly structural steel spall plates. In addition, the structural behavior to primary and secondary fragment impact is expanded.

The new edition of the manual contains a chapter on foundation design. The data presented will enable the Designer to predict the gross motion of structures subject to overturning. The structure motion is based on rigid body motion to predict soil-structure interaction.

The last portion of this volume greatly expands the detailing procedures presently incorporated in the manual. The old manual provides details for laced construction. These details are expanded to include information provided for conventionally reinforced concrete, elements incorporating either single leg stirrups or lacing, flat slabs, beams, columns and foundations.

VOLUME V - STRUCTURAL STEEL DESIGN

This volume covers detailed procedures and design techniques for the blast-resistant design of steel elements and structures subjected to short-duration, high-intensity blast loading. Highlights of this volume are presented in Figure 27.

While the design techniques presented in the old manual are applicable to single-degree-of-freedom, elasto-plastic systems, there was no clear-cut method for determining the properties of a structural steel element, such as moment capacity, resistance, allowable or ultimate stresses, dynamic increase factors equivalent stiffness, etc., that are relevant to such a system. This volume covers the methods as they apply to beam-type and plate-type systems.

The effects of rapidly applied dynamic loads on the mechanical properties of structural steel are considered. Figure 28 illustrates the dynamic increase factors for yield stresses at various strain rates.

The design procedures and applications of this volume are directed toward steel acceptor- and donor-type structures. Donor-type structures, which are located in the immediate vicinity of the detonation may include steel containment cells or steel components of reinforced concrete containment structures such as blast doors or closure plates. In some cases, the use of suppressive shielding to control or confine the hazardous blast, fragment and flame effects of detonations may be an economically feasible alternative. The high blast pressures encountered in these suggest the use of large plates or built-up sections with relatively high resistance. In some instances, fragment impact or pressure leakage must be considered. Acceptor-type structures are removed from the immediate vicinity of the detonation. These include typical frame structures with beams, columns and beam-columns composed of standard structural shapes and built-up sections. In many cases, the relatively low blast pressures suggest the use of standard building compononents such as open-web joists, prefabricated wall panels and roof decking detailed as required to carry the full magnitude of the dynamic loads. Another economical application can be the use of entire pre-engineered buildings, strengthened locally, to adapt their designs to low-blast pressures (up to 2 psi) with short duration.

Beam-type elements differ from plate-type in that the effects of overall and local instability upon the ultimate capacity is an important consideration. The design of these elements, including beams, beam-columns, open-web joists, and cold-formed panels, in which slenderness effects are prominent, are covered in this volume. In general, the ultimate resistance of a beam-type system is reduced in light of local or overall instability. Plate-type elements, in which local or overall instability is not predominant, are covered in much the same way as their reinforced concrete counterparts. Special requirements for blast doors, with respect to their function during and after an explosion, are discussed (Figure 29).

The procedures for the design of structural systems, involving a multi-degree-of-freedom analysis are presented. Preliminary designs for rigid frames and braced frames subjected to blast loads are presented. Methods for proportioning the frame members for maximum economy are considered. Figure 30 illustrates such proportioning by way of collapse mechanisms, for rigid frames. Computer programs, which cover the elasto-plastic dynamic analysis of framed structures, are available for final design.

Some qualitative differences between steel and concrete protective structures warrant special consideration for rebound, stress-interaction, connection integrity and fragments.

(1) The amount of rebound in concrete structures is considerably reduced by internal damping (cracking) and is essentially eliminated in cases where large deformations or incipient failure are permitted to occur. In structural steel, however, a larger response in rebound, up to 100 percent, can be obtained for a combination of short duration load and a relatively flexible element. As a result, steel structures require that special provisions be made to account for extreme responses of comparable magnitude in both directions.

(2) The treatment of stress interaction is more of a consideration in steel shapes since each element of the cross-section must be considered subject to a state of combined stresses. In reinforced concrete, the provision of separate steel reinforcement for flexure, shear and torsion enables the designer to consider these stresses as being carried by more or less independent systems.

(3) Special care must be taken in steel design to provide for connection integrity up to the point of maximum response. For example, in order to avoid premature brittle fracture in welded connections, the welding characteristics of the particular grade of steel must be considered and the introduction of any stress concentrations or notches at the joint must be avoided.

(4) If fragments are involved, care should be given to brittle modes of failure as they affect construction methods. For example, fragment penetration depth may govern the thickness of a steel plate.

VOLUME VI - SPECIAL CONSIDERATIONS IN EXPLOSIVE FACILITY DESIGN

The contents of this volume is new and was not presented in the old manual. This volume is divided into nine subsections, as is shown in Figure 31.

All of the above subsections are independent of each other, and could have been presented in separate volumes. However, their short length, and in some cases their function as introductions to specific manuals in which their topics are completely discussed, made their combination into one volume more desirable.

MASONRY DESIGN:

This subsection describes the procedures for designing a masonry wall subjected to blast overpressures. The design procedures consider free standing masonry walls; masonry walls working in conjunction with structural steel frames, as illustrated in Figure 32; and arch action in masonry walls, permitting the design of walls for large deflections. In addition, this subsection also includes an outline of the design criteria and the dynamic strength of materials to be used for blast resistant designs.

PRECAST CONCRETE DESIGN:

This subsection includes procedures for the design of precast concrete elements subjected to blast overpressures. A method for determining the ultimate strength of a precast element from the static and dynamic material strengths is presented. Methods for performing a dynamic analysis and determining rebound loads are presented. Also presented are recommended details for precast construction, as is shown in Figure 33.

PRE-ENGINEERED BUILDINGS:

Standard pre-engineered buildings are usually designed for conventional loads such as dead, live, snow, and wind loads. Blast resistant pre-engineered buildings must be designed in a similar manner, but with much higher static loads to account for the actual blast loads. This subsection presents methods for the design of the foundation, the metal frame, and the roofing and siding of a pre-engineered building. It includes a method for performing a blast analysis of such a structure. It also includes a recommended specification for pre-engineered buildings subjected to blast overpressures.

SUPPRESSIVE SHIELDING:

This subsection summarizes the design and construction procedures which are outlined in the design manual Suppressive Shields - Structural Design and Analysis Handbook (HNDM 1110-1-2). As is shown in Figure 34, only those shields which have received safety approval have been presented. Also presented are procedures with which new shields may be analyzed and designed. In addition, included are recommended details for penetrations, such as utility and vacuum lines and personnel and equipment doors, along with other required structural details to obtain safety approval.

BLAST RESISTANT WINDOWS:

Historically, explosion effects have produced airborne glass fragments from failed windows at the risk to life and property. Based on a series of explosive tests, guidelines have been developed for the design, evaluation, and certification of windows to safely survive a prescribed blast environment. This subsection contains design criteria for both glazing and frames. In addition, the presented design procedures include a series of design charts, as is shown in Figure 35, as well as construction details.

DESIGN LOADS FOR UNDERGROUND STRUCTURES:

This subsection contains a summary of the data presented in the design manual Fundamentals of Protective Design for Conventional Weapons (TM5-855-1). The data pertaining primarily to the effects of an explosion occurring on or below the ground, and the blast pressures produced on below ground structures, is presented. Also procedures are presented for bomb penetration into earth, as well as for the structural design of below ground walls and roof slabs.

EARTH-COVERED ARCH-TYPE MAGAZINES:

This subsection deals with typical earth covered magazines which are used for the storage of explosives. It is an expansion of a similar section in the old manual, and includes requirements for both metal and reinforced concrete arch magazines (as is shown in Figure 36), including semi-circular and oval shapes. A discussion of the method of design, required safe separation distance between magazines, and construction procedures is also included

BLAST VALVES:

This subsection discusses remote and blast actuated blast valves used for sealing ventilation openings in protective structures. Included is a discussion of the requirements of plenums and fragment protection. Also included is a list of manufacturers and a description of the valves, their pressure capacities, closure times, flow rates, and test data if available. In addition, a recommended specification for poppet valves is included.

SHOCK ISOLATION SYSTEMS:

The data for Shock Isolation Systems presented in this subsection is greatly expanded from that presented in the old manual. The new manual data is basically qualitative rather than quantitative. It includes shock tolerances for personnel and equipment; shock isolation principles; methods of analyzing isolation systems; shock isolation arrangements, including individual and group mounting platform characteristics; isolator arrangements, consisting of base and overhead mounted systems (see Figure 37); and shock isolation devices, such as helical coil, torsion, pneumatic, liquid, and other spring configurations.

STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS
(TM 5-1300, NAVFAC P-397, AFM 88-22)

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COMPUTER PROGRAM REPOSITORIES

FIGURE 1

VOLUME I
INTRODUCTION

GENERAL INTRODUCTION	BACKGROUND, MANUAL SCOPE & FORMAT
SAFETY FACTOR	SAFETY FACTOR APPLICATION
EXPLOSION PROTECTION SYSTEM	DEFINITION OF COMPONENT (DONOR SYSTEM, ACCEPTOR SYSTEM, PROTECTIVE STRUCTURES, ETC.)
DESIGN TOLERANCES	DEFINITION OF DESIGN RANGES, PROTECTION CATEGORIES HUMAN TOLERANCES, EQUIPMENT TOLERANCES, EXPLOSIVE SENSITIVITY

FIGURE 2

VOLUME II

BLAST, FRAGMENT AND SHOCK LOADS

BLAST LOADS	1.	UNCONFINED EXPLOSIONS
	2.	VENTED EXPLOSIONS
	3.	CONFINED EXPLOSIONS
FRAGMENTS	1.	PRIMARY FRAGMENTS - EXPLOSIVE CASING OR CONTAINERS
	2.	SECONDARY FRAGMENTS - CAUSED BY EQUIPMENT BREAKUP
SHOCK LOADS	1.	GROUND MOTION - AIR AND GROUND INDUCED
	2.	AIR BLAST MOTIONS - SLIDING
	3.	SHOCK SPECTRA

FIGURE 3

SUMMARY OF MODIFICATIONS OF BLAST LOADS PRODUCED BY TNT

CHARGE CONFINEMENT	CATEGORY	PRESSURE LOAD	MANUAL		REMARKS
			OLD	NEW	
UNCONFINED EXPLOSION	FREE AIR BURST	UNREFLECTED	X	X	MODIFIED
	AIR BURST	REFLECTED	X	X	MODIFIED
	SURFACE BURST	REFLECTED	X	X	UNMODIFIED
CONFINED EXPLOSION	FULLY VENTED	INTERNAL SHOCK	X	X	MODIFIED
		LEAKAGE	X	X	MODIFIED
	PARTIALLY CONFINED	INTERNAL SHOCK	X	X	MODIFIED
		INTERNAL GAS		X	ADDED
		LEAKAGE		X	ADDED
	FULLY CONFINED	INTERNAL SHOCK	X	X	MODIFIED
		INTERNAL GAS	X	X	MODIFIED

FIGURE 4

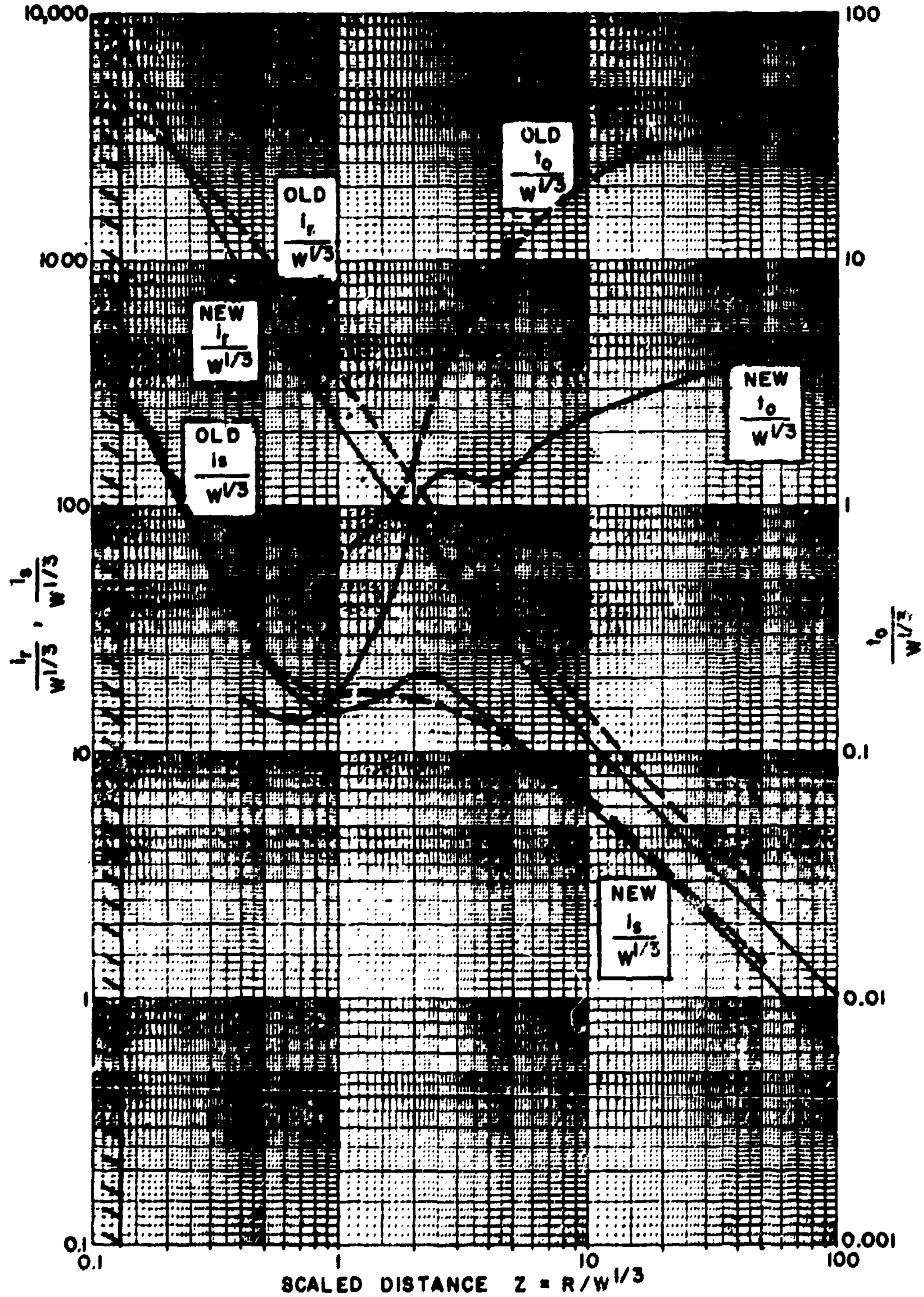


FIGURE 5 MODIFICATION OF FREE AIR BURST CURVES

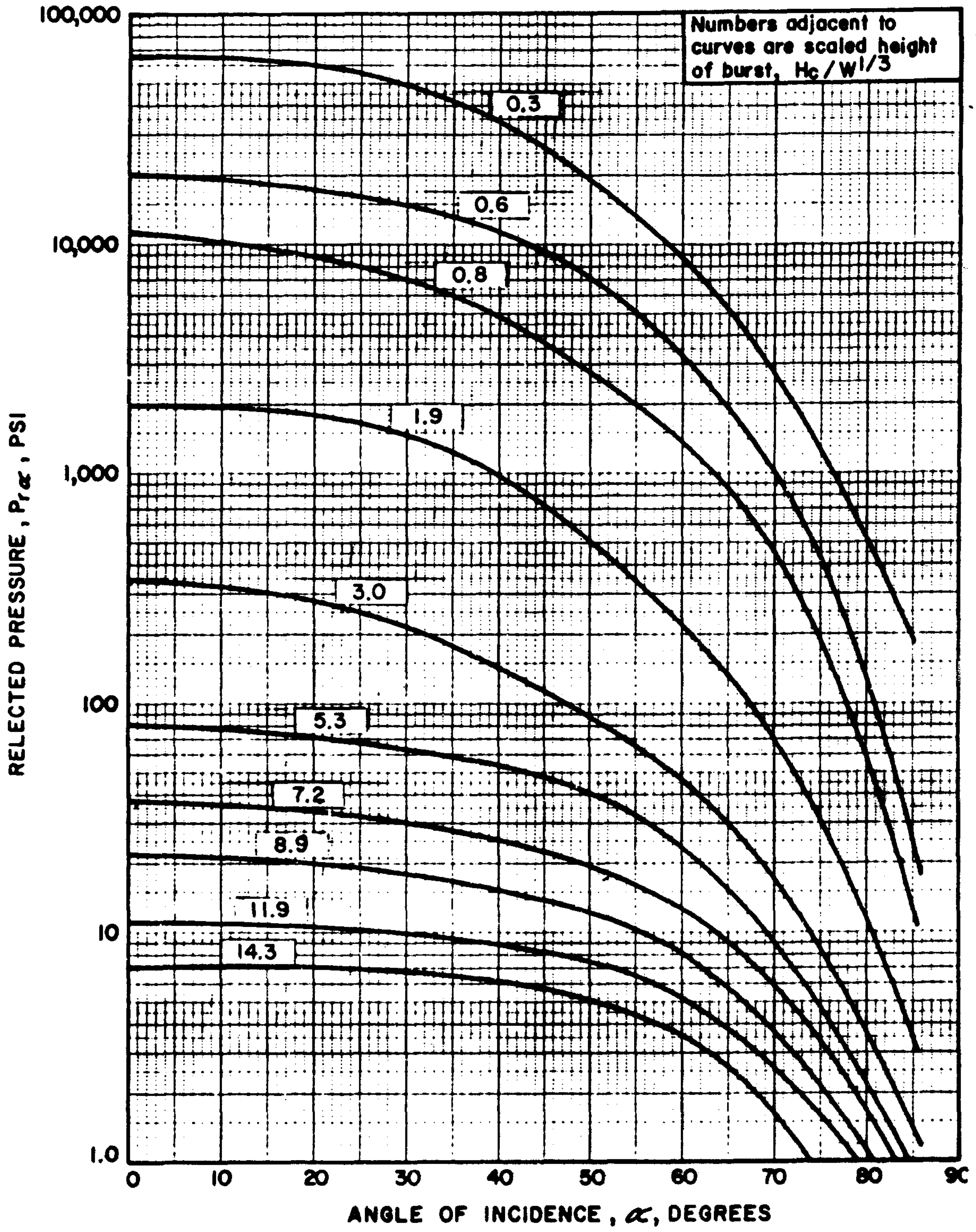


FIGURE 6 BLAST PRESSURES AT GROUND SURFACE DUE TO AN AIR BURST

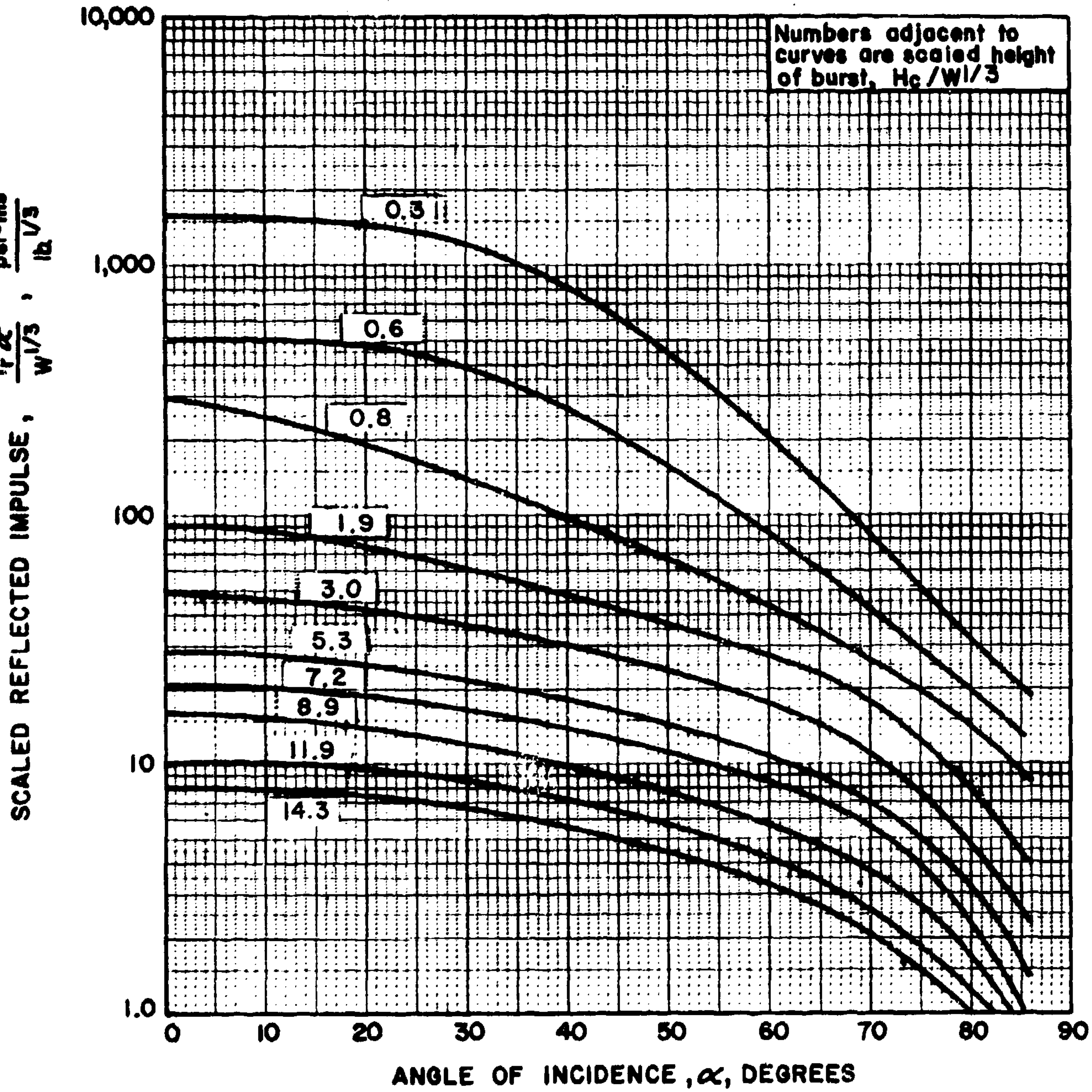
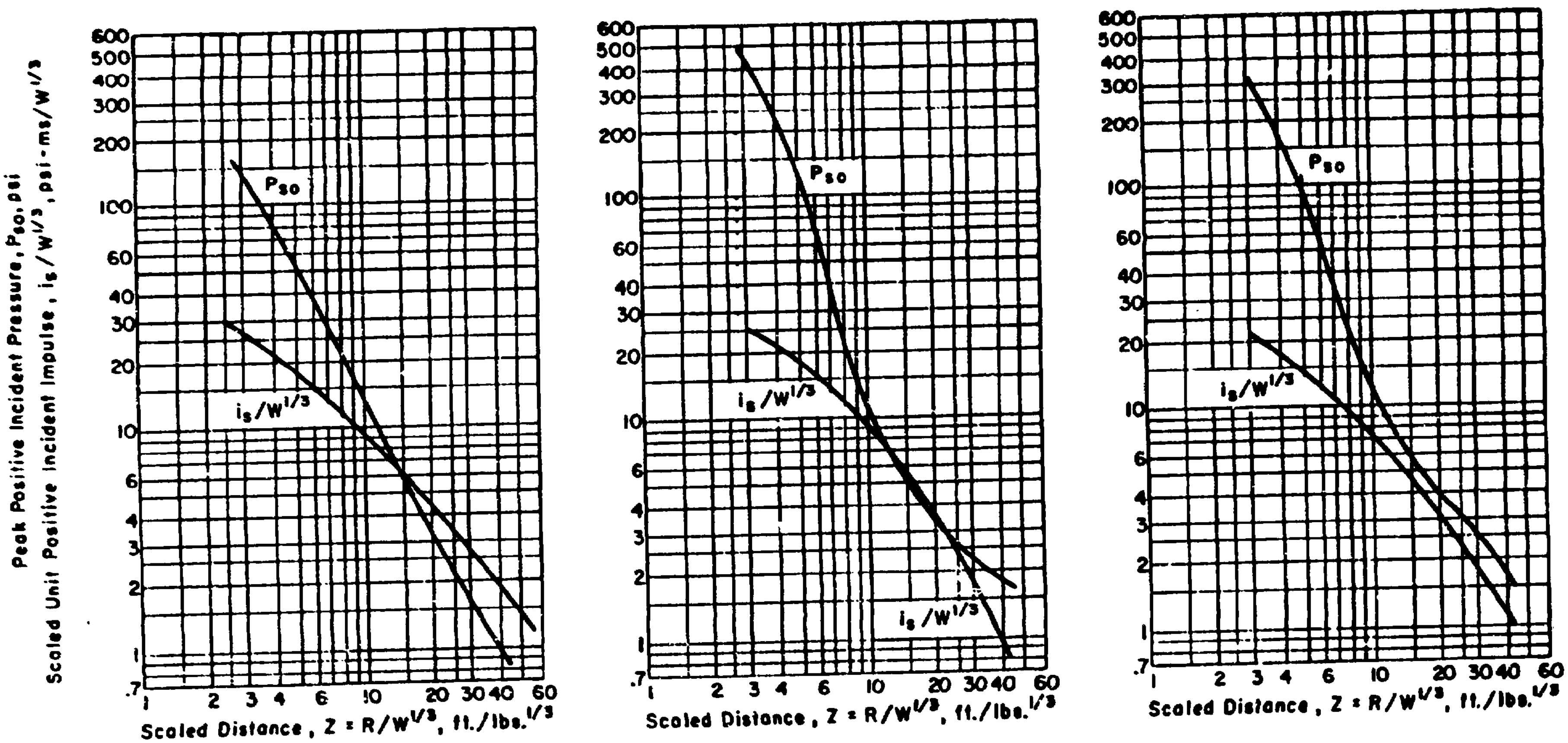


FIGURE 7 SCALED IMPULSE AT GROUND SURFACE DUE TO AN AIR BURST



a. RDX Slurry Cylindrical

b. RDX 98/2 Orthorhombic

c. RDX 98/2 Cylindrical

FIGURE 8 ILLUSTRATION OF BLAST PARAMETERS FOR OTHER EXPLOSIVE MATERIALS

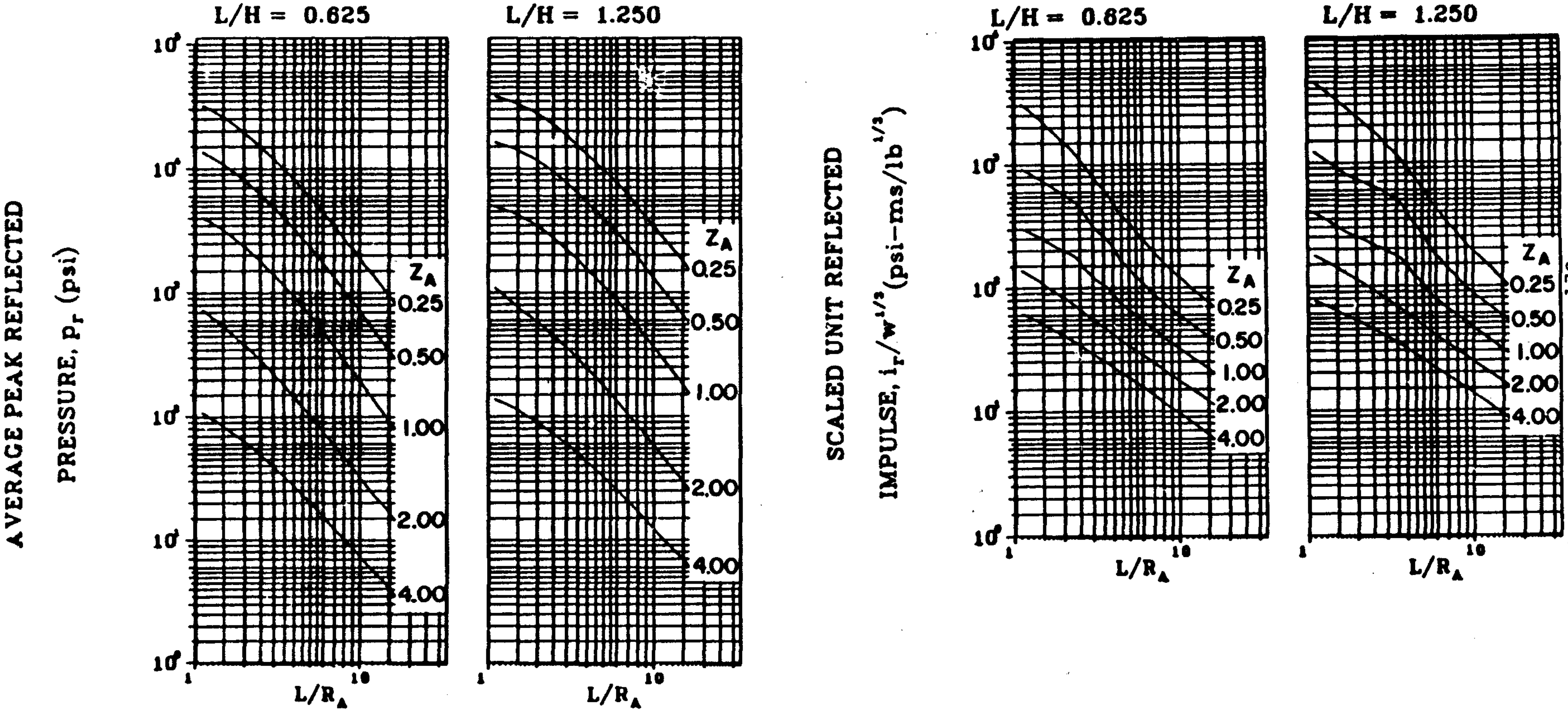


FIGURE 9 ILLUSTRATION OF INTERNAL SHOCK LOADS IN CUBICLE TYPE STRUCTURES

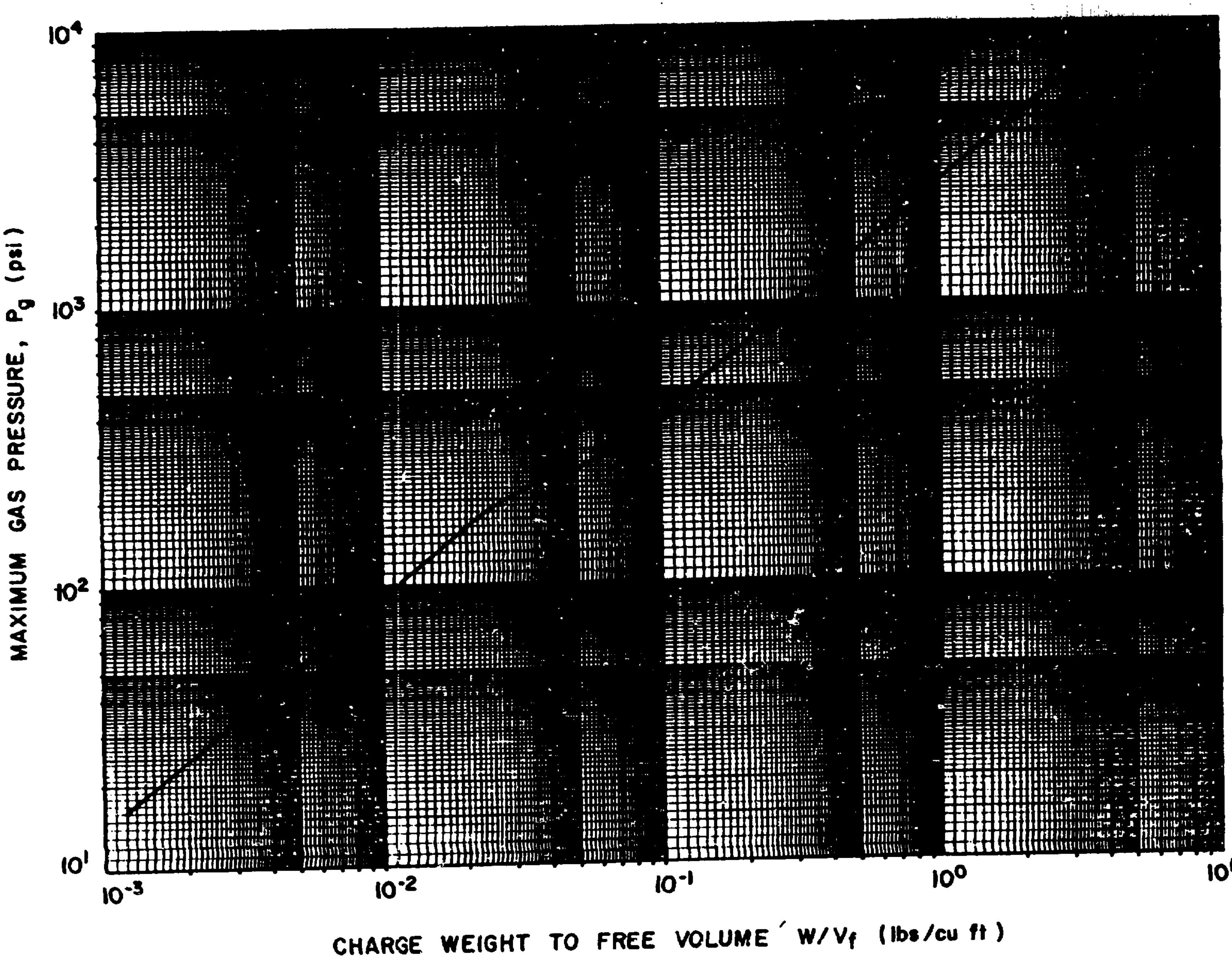


FIGURE 10 PEAK GAS PRESSURE IN A PARTIALLY CONTAINED CHAMBER

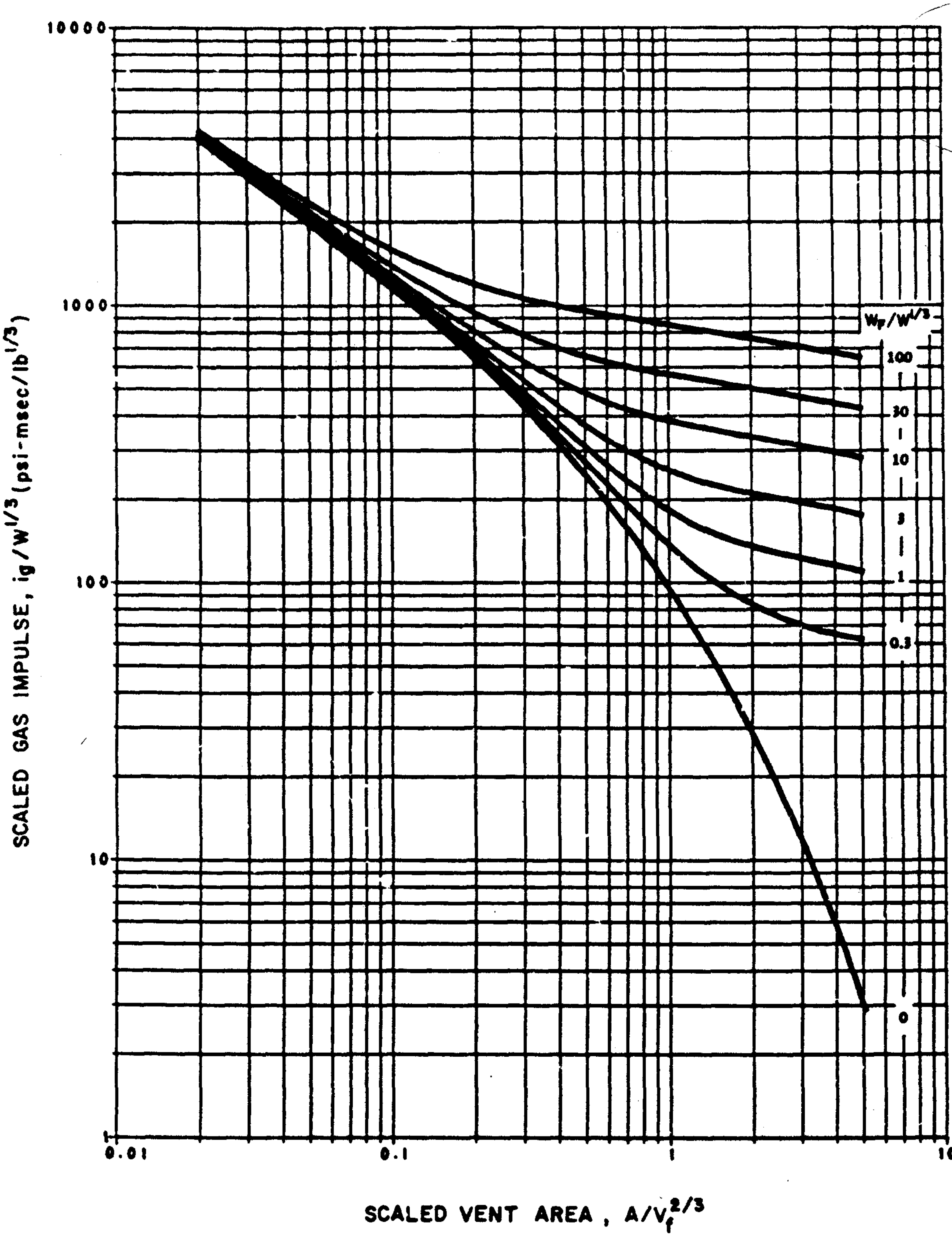


FIGURE 11 SCALED GAS IMPULSE vs. VENT OPENING

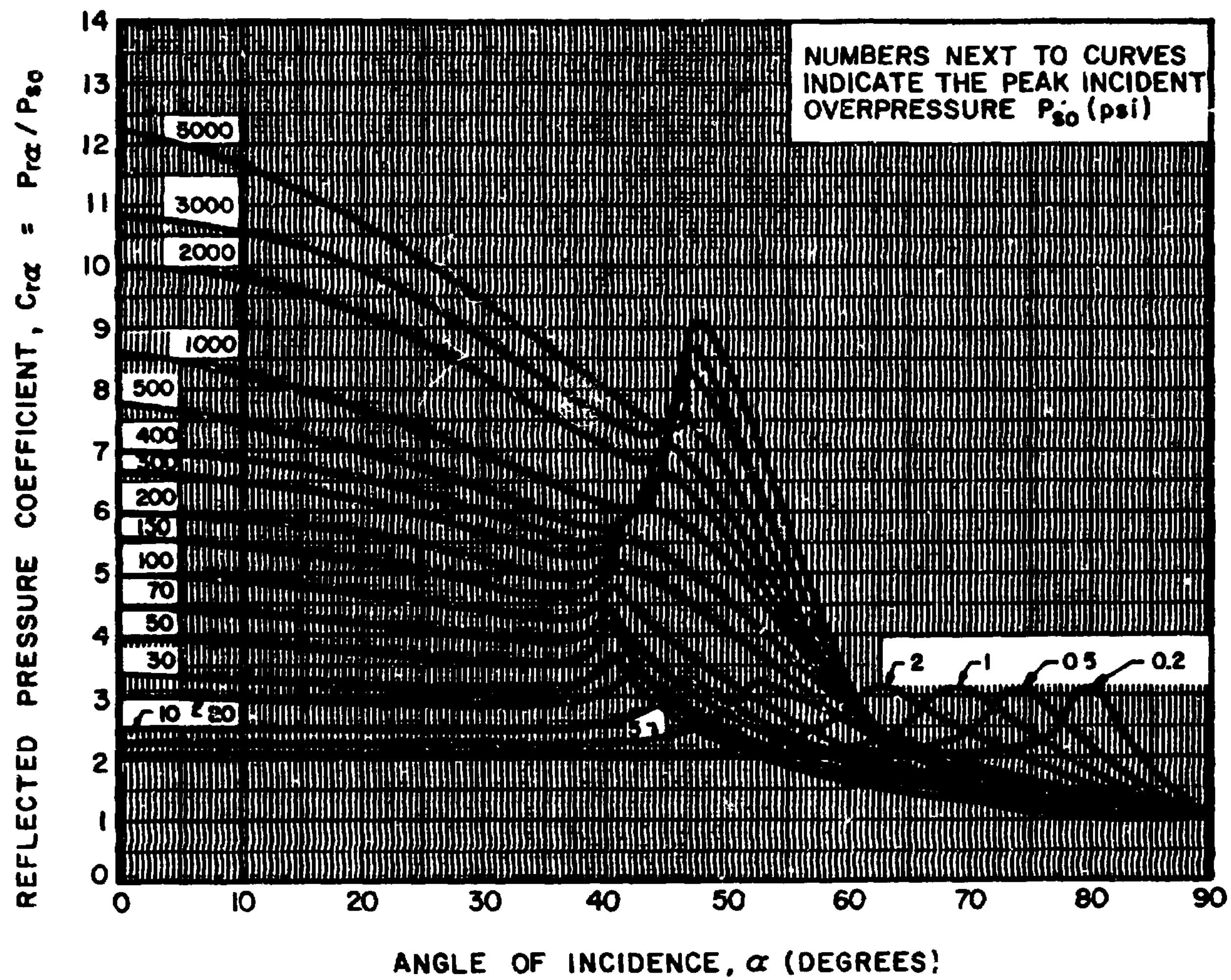


FIGURE 12 REFLECTED PRESSURE COEFFICIENT VERSUS ANGLE OF INCIDENCE

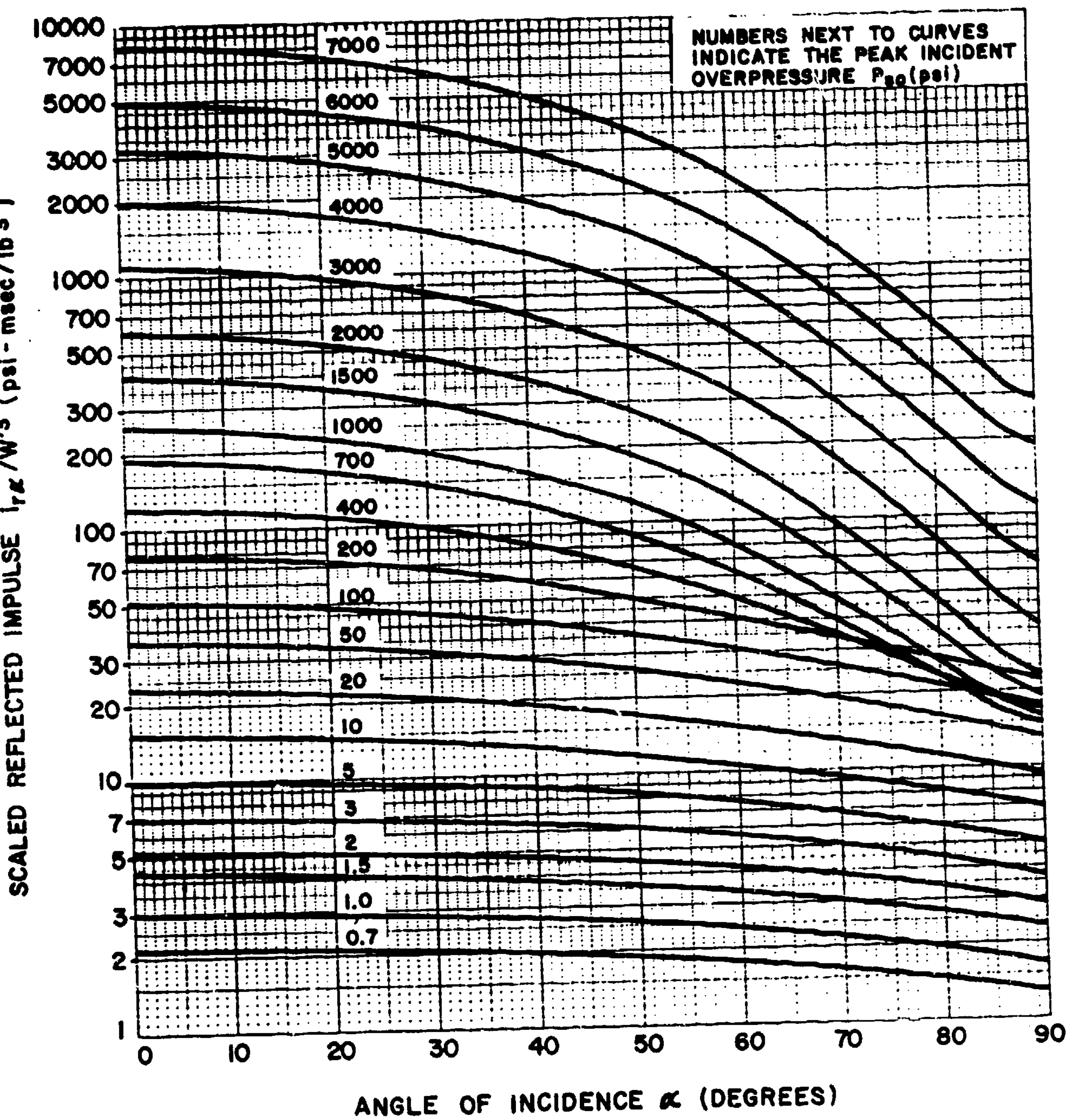
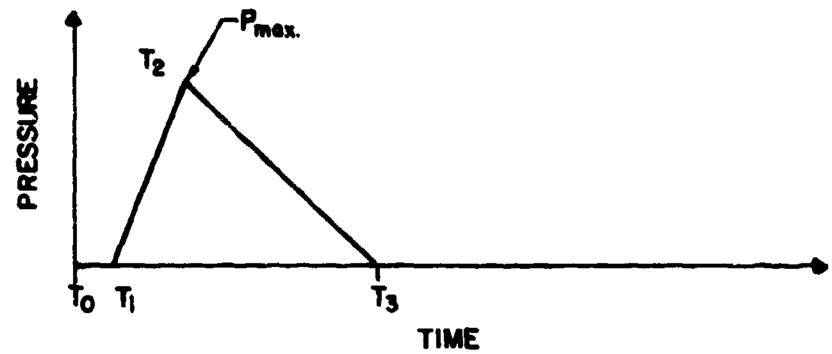
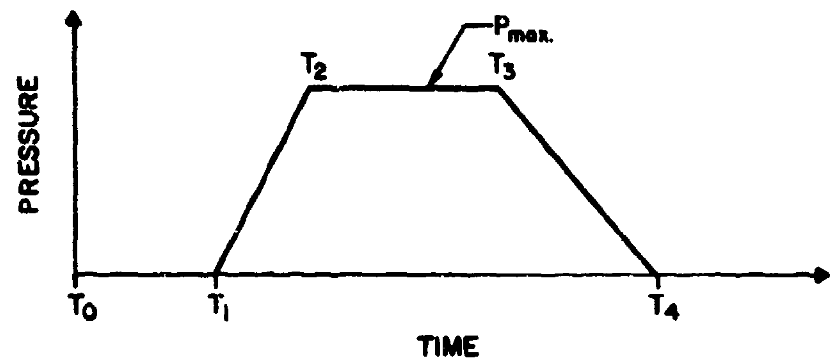


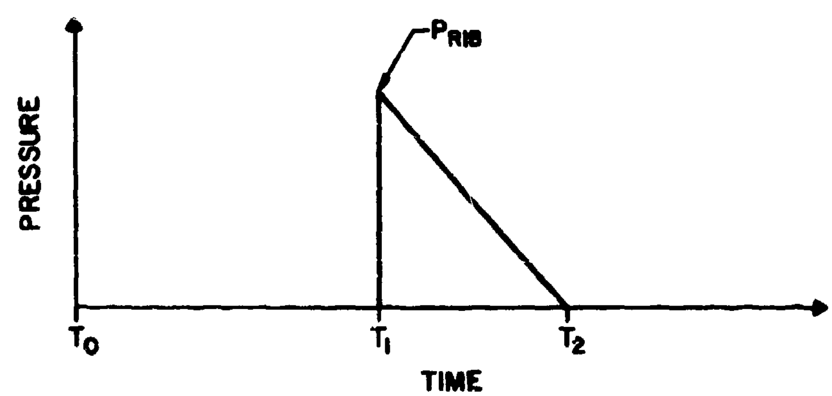
FIGURE 13 REFLECTED SCALED IMPULSE VERSUS ANGLE OF INCIDENCE



a. INTERIOR FRONT WALL SURFACE



b. INTERIOR SIDE WALL OR ROOF SURFACE



c. INTERIOR BACK WALL SURFACE

FIGURE 14 IDEALIZED INTERIOR BLAST LOADS

PRIMARY AND SECONDARY FRAGMENTS

FRAGMENTS	DESIGN PARAMETERS
PRIMARY FRAGMENTS	ESTABLISH FRAGMENT CONFIGURATION
	DETERMINE INITIAL VELOCITY
	DETERMINE VARIATION OF VELOCITY WITH DISTANCE
	DETERMINE IMPACT CHARACTERISTICS
	DETERMINE IMPACT EFFECTS
SECONDARY FRAGMENTS	ESTABLISH FRAGMENT CONFIGURATION
	DETERMINE BLAST LOAD ACTING ON FRAGMENT
	EVALUATE FRAGMENT VELOCITY
	DETERMINE DIRECTION OF FLIGHT
	DETERMINE IMPACT CHARACTERISTICS
	DETERMINE IMPACT EFFECTS

FIGURE 15

SHOCK LOADS

STRUCTURE MOTIONS	DESIGN PROCEDURE
1. AIR BLAST MOTIONS	INTERGRATION PROCEDURE
2. AIR INDUCED GROUND MOTIONS	EMPERICAL PROCEDURE
3. GROUND INDUCED MOTIONS	EMPERICAL PROCEDURE
4. SHOCK RESPONSE SPECTRA	DETERMINE OF INTERNAL MOTIONS AND STRESSES IN EQUIPMENT

FIGURE 16

VOLUME III

PRINCIPLES OF DYNAMIC ANALYSIS

- RESISTANCE-DEFLECTION FUNCTIONS
  1. ULTIMATE RESISTANCE FOR ONE WAY SLABS AND BEAMS
  2. ULTIMATE RESISTANCE AND CRACK LINE PATTERNS FOR TWO-WAY SLABS AND FLAT SLABS
  3. ELASTIC, ELASTO-PLASTIC AND PLASTIC DEFLECTION CRITERIA
- DYNAMICALLY EQUIVALENT SYSTEMS
  1. LOAD, MASS AND RESISTANCE FACTORS
  2. LOAD-MASS FACTORS
  3. NATURAL PERIOD OF VIBRATION
- DYNAMIC ANALYSIS
  1. DESIGN CHART METHOD: 216 CHARTS FOR VARIOUS LOAD TYPES
  2. NUMERICAL INTERGATION PROCEDURES:
     - A. AVERAGE ACCELERATION METHOD
     - B. ACCELERATION IMPULSE EXTRAPOLATION METHOD
     - C. TWO-DEGREE-OF-FREEDOM SYSTEM AND DAMPING
  3. IMPULSE METHOD

FIGURE 17

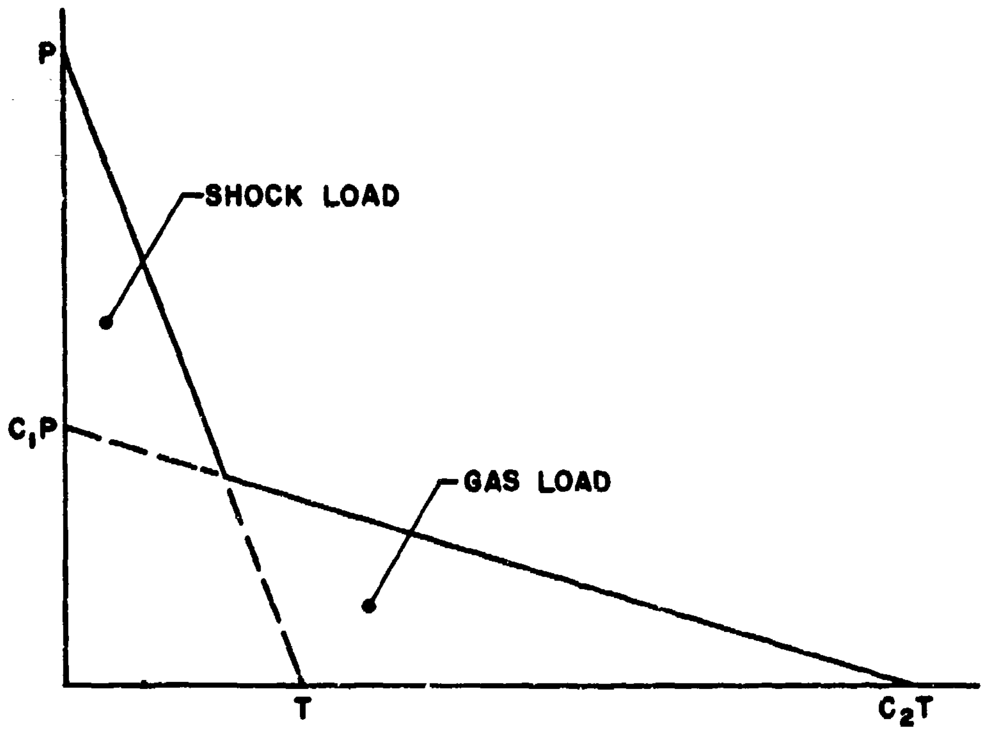


FIGURE 18 IDEALIZED BILINEAR-TRIANGULAR PRESSURE-TIME LOAD

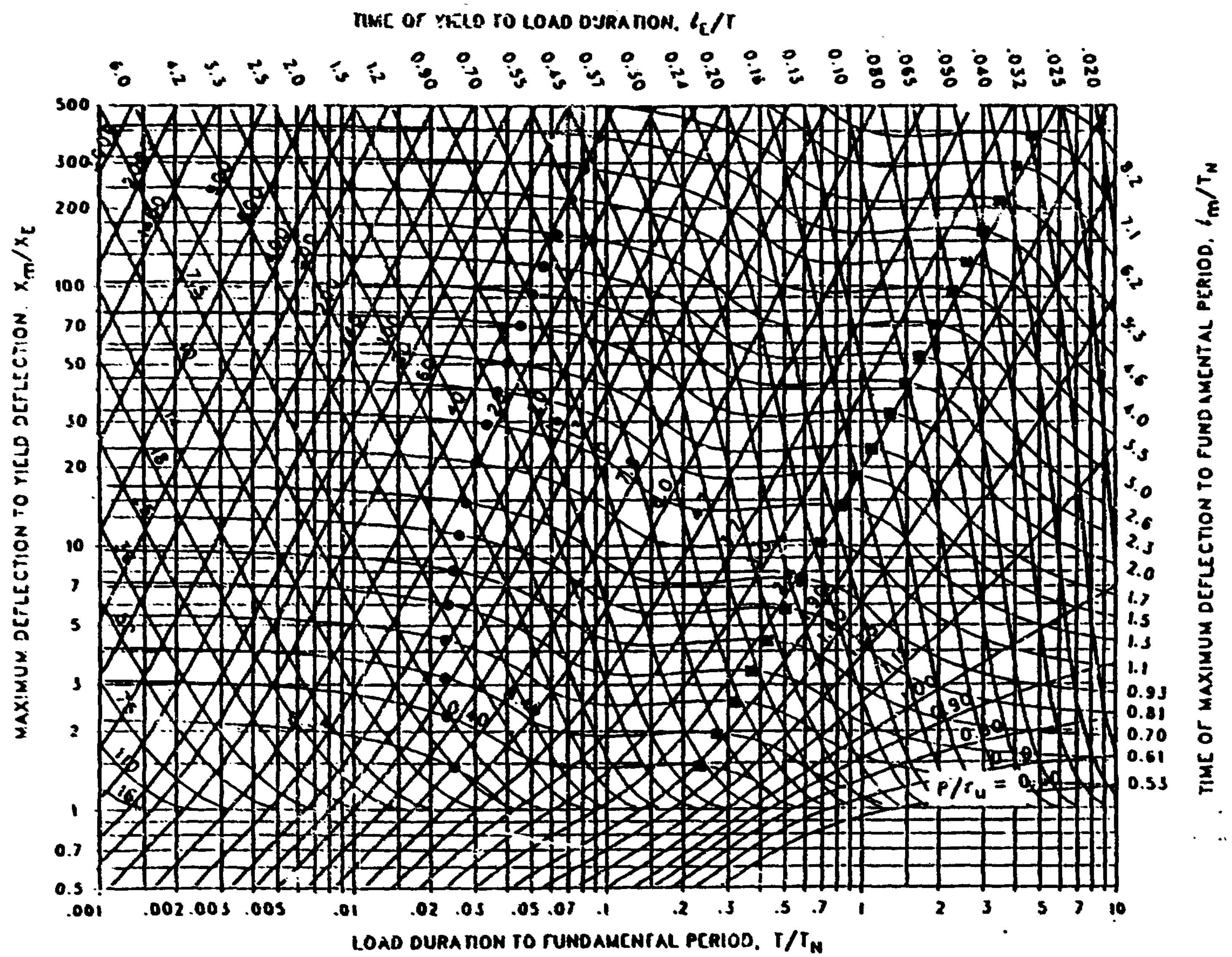


FIGURE 19 MAXIMUM RESPONSE OF ELASTO-PLASTIC SYSTEM FOR BILINEAR-TRIANGULAR PULSE (C_1=0.178, C_2=10)

VOLUME IV

REINFORCED CONCRETE DESIGN

- **DYNAMIC CAPACITY OF MATERIALS**
  1. INCREASE DYNAMIC INCREASE FACTORS
  2. INCREASE MINIMUM YIELD STRENGTH
  3. INCREASE SHEAR CAPACITY
- **DESIGN FOR CLOSE-IN EFFECTS**
  1. LACED REINFORCED CONCRETE
  2. SINGLE LEG STIRRUPS
- **DESIGN FOR INTERMEDIATE RANGE**
  1. ONE AND TWO WAY PANELS
  2. BEAM AND COLUMNS
  3. FLAT SLAB CONSTRUCTION
  4. TENSION MEMBRANE ACTION
- **FOUNDATION DESIGN**
  1. OVERTURNING ANALYSIS
  2. SOIL/STRUCTURE INTERACTION
  3. FOUNDATION COMPONENT DESIGN
- **BRITTLE MODE DESIGN**
  1. SPALLING
  2. FRAGMENT PENETRATION
- **CONSTRUCTION DETAILING**
  1. LACED REINFORCED CONCRETE
  2. SINGLE LEG STIRRUPS
  3. BEAM AND COLUMN
  4. FLAT SLABS
  5. FOUNDATIONS

FIGURE 20

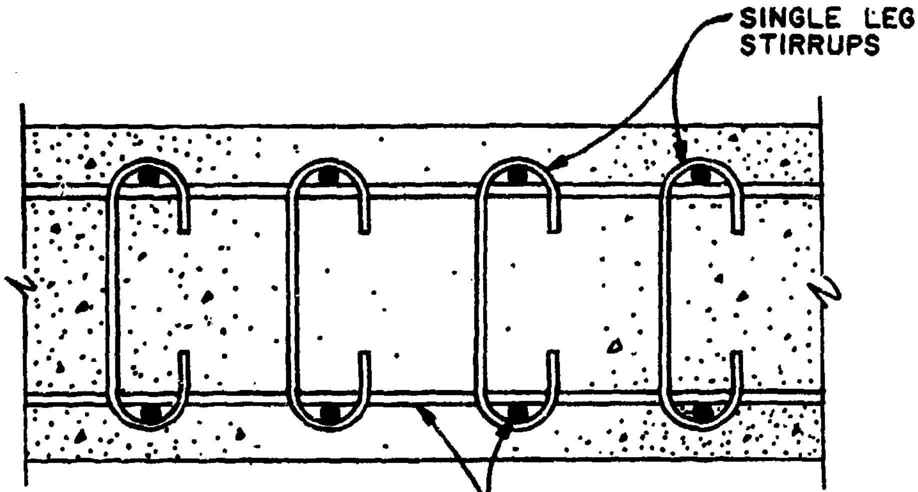


FIGURE 21 SINGLE LEG STIRRUPS

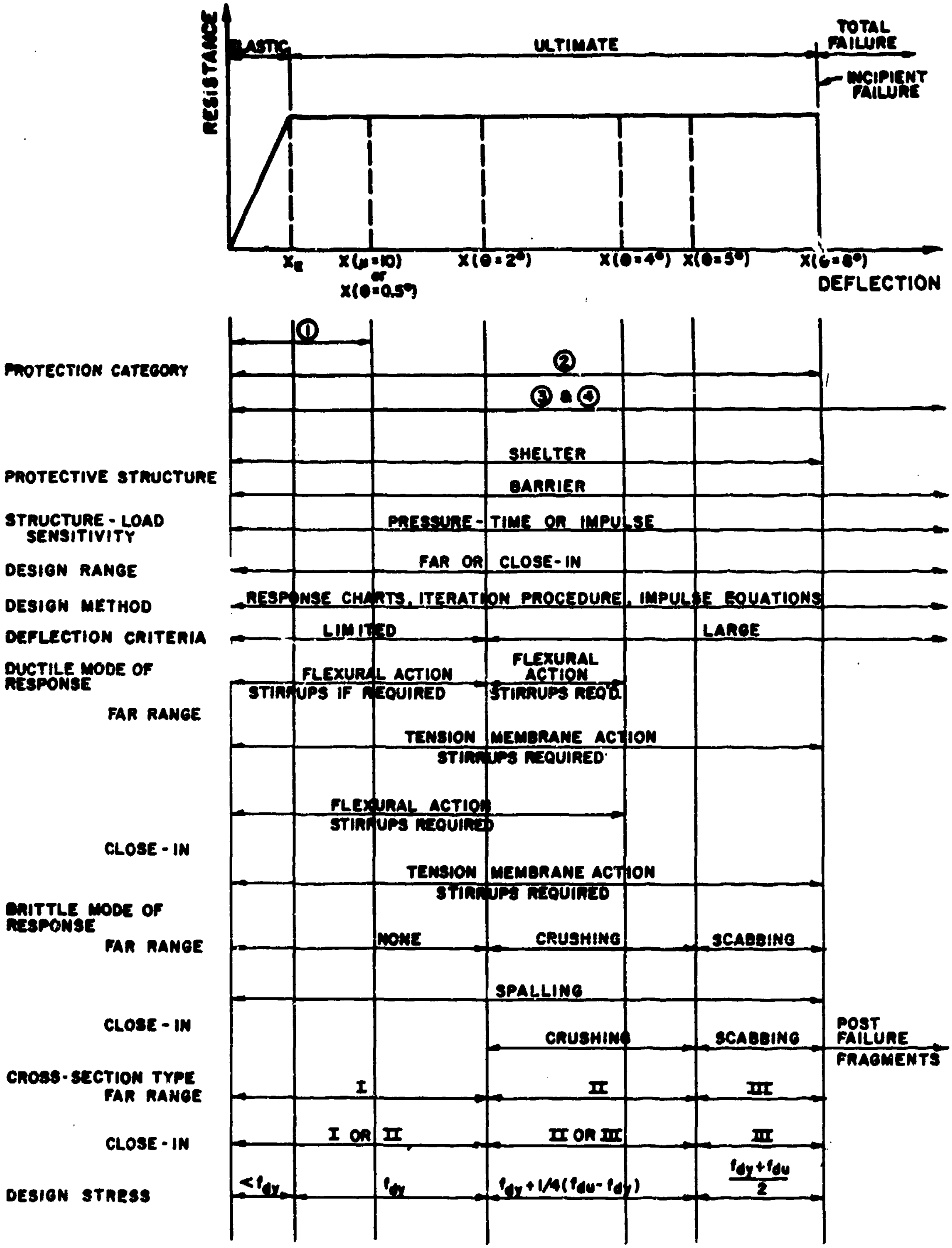


FIGURE 22 RELATIONSHIP BETWEEN DESIGN PARAMETERS FOR UNLACED ELEMENTS

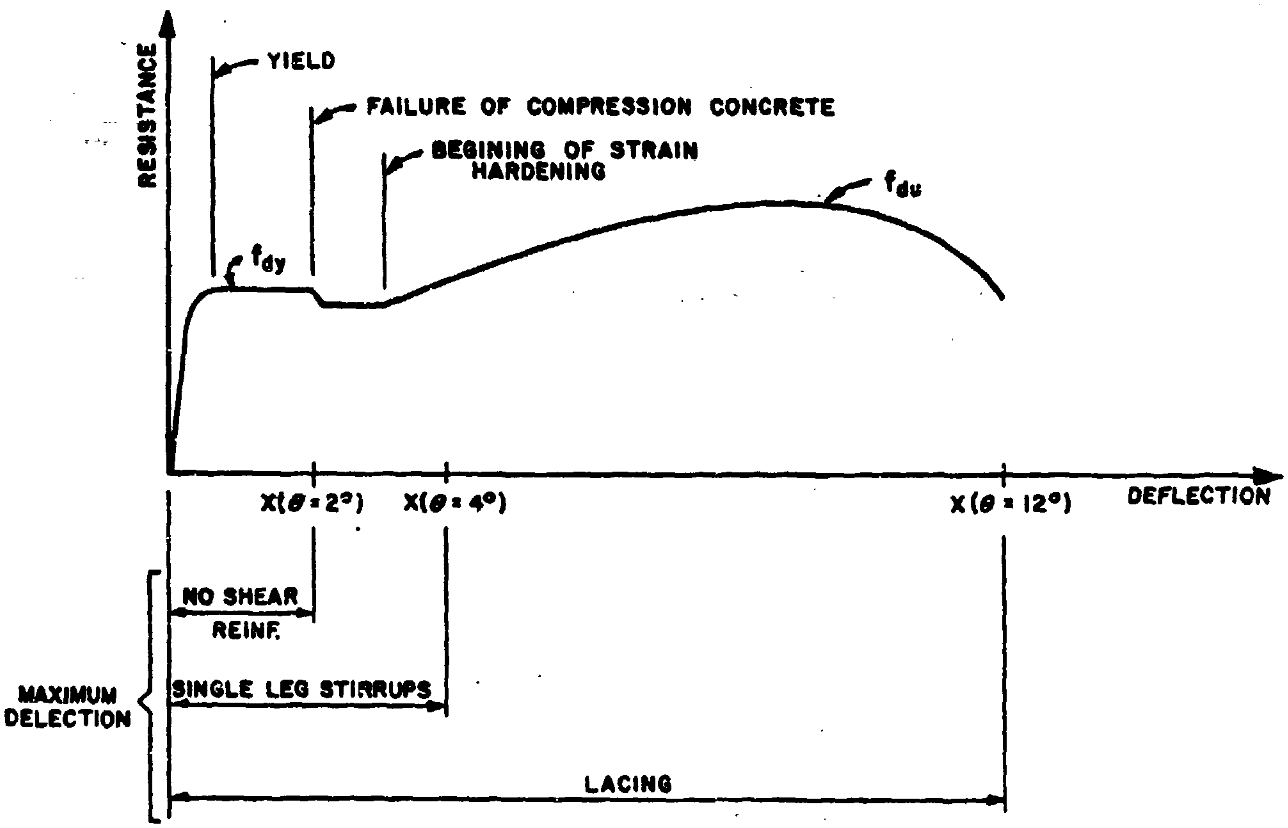


FIGURE 23 TYPICAL RESISTANCE-DEFLECTION CURVE FOR FLEXURAL RESPONSE OF CONCRETE ELEMENTS

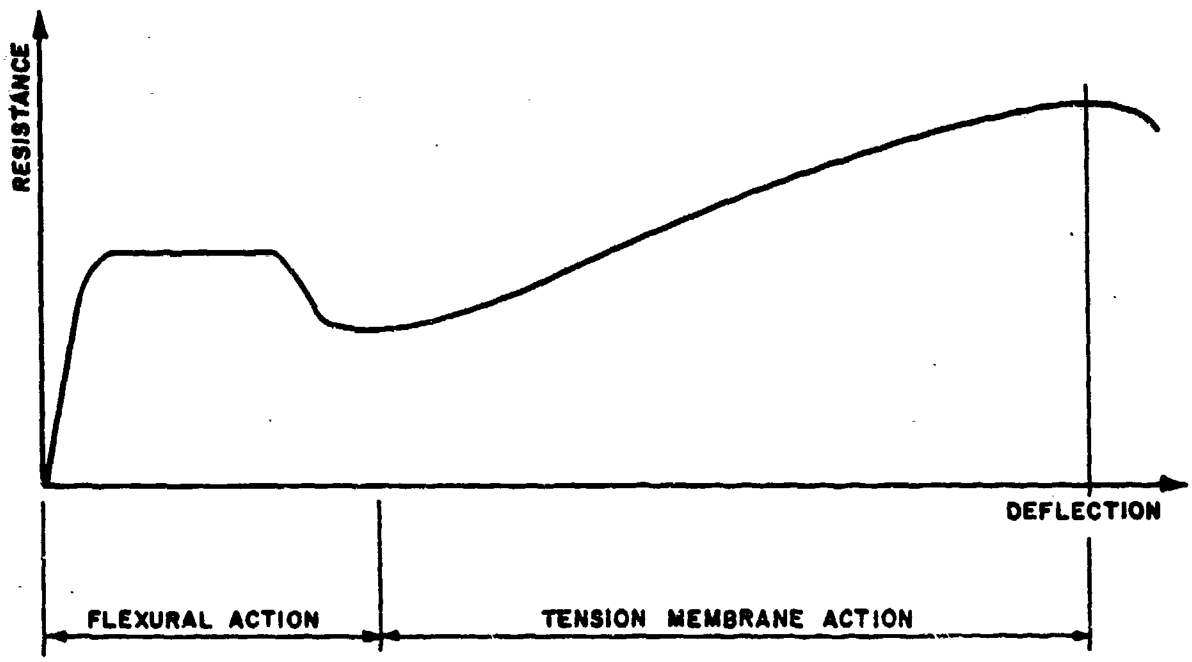


FIGURE 24 TYPICAL RESISTANCE-DEFLECTION CURVE FOR TENSION MEMBRANE RESPONSE OF CONCRETE ELEMENTS

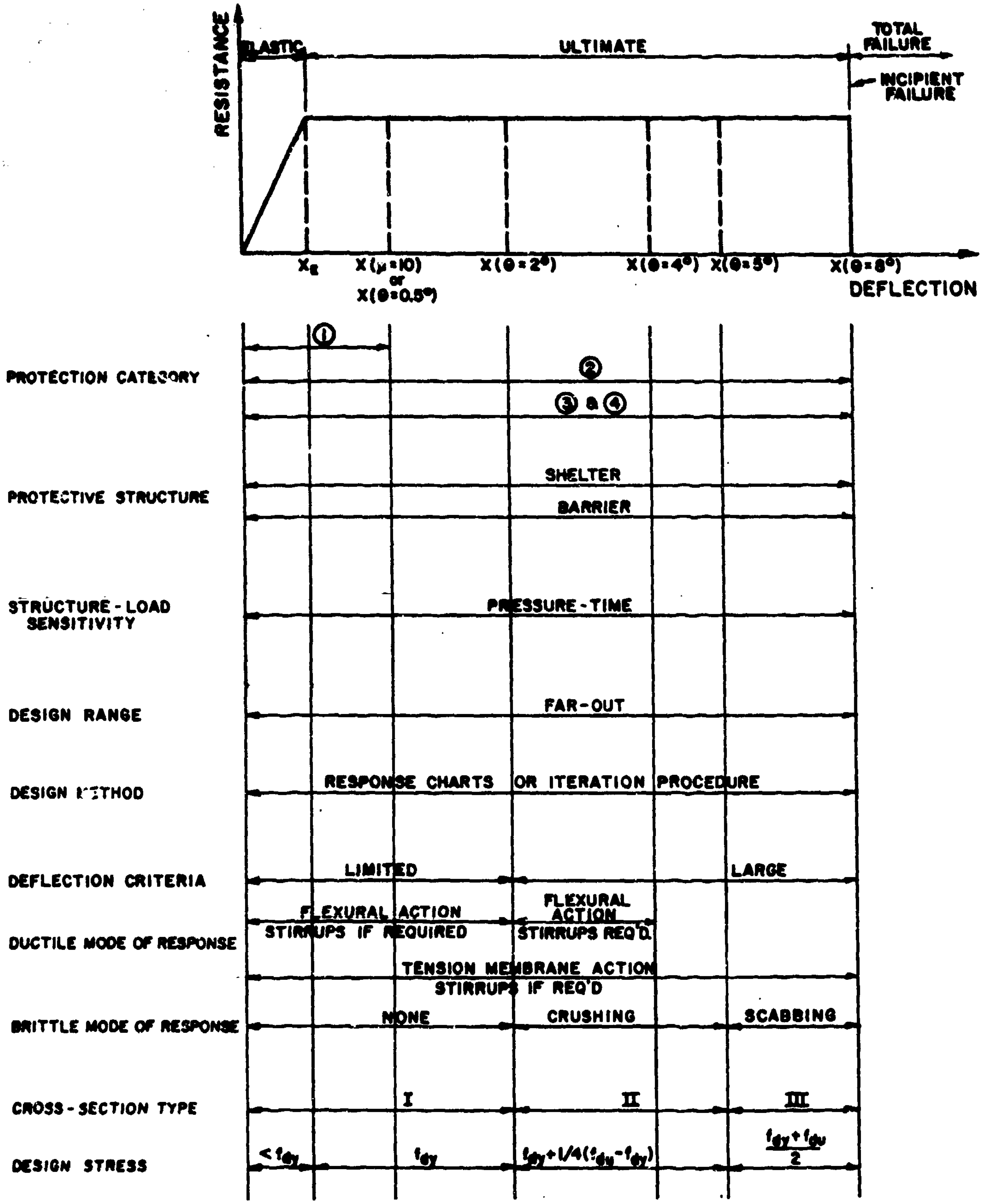


FIGURE 25 RELATIONSHIP BETWEEN DESIGN PARAMETERS FOR FLAT SLABS

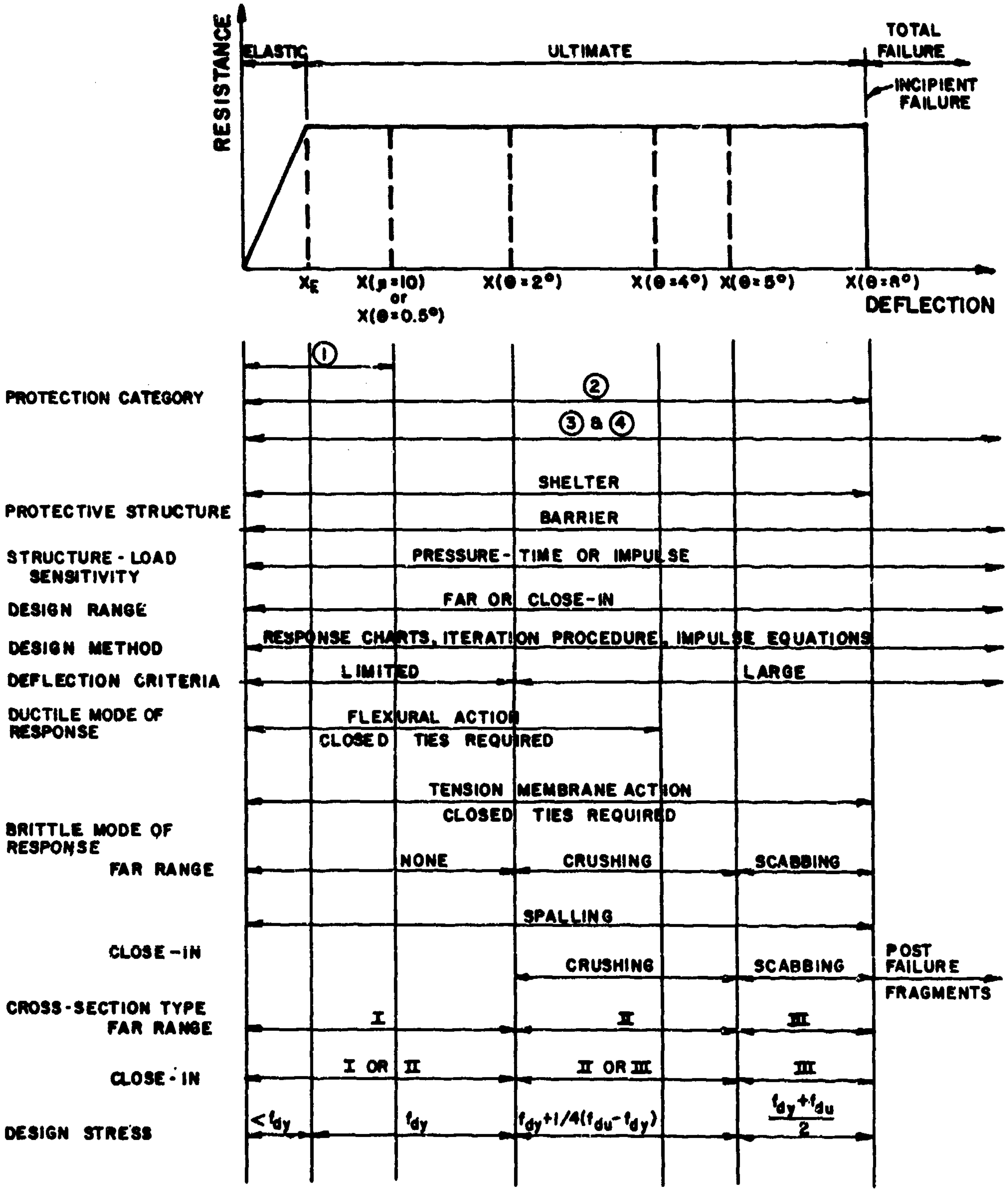


FIGURE 26 RELATIONSHIP BETWEEN DESIGN PARAMETERS FOR BEAMS

VOLUME V
STRUCTURAL STEEL DESIGN

- **MECHANICAL PROPERTIES**
  1. STATIC STRESSES
  2. DYNAMIC STRESSES
- **DESIGN OF ELEMENTS**
  1. BEAMS AND PLATES
  2. COLUMNS AND BEAM COLUMNS
  3. BLAST DOORS
  4. COLD FORMED STEEL PANELS
- **PREL. FRAME ANALYSIS**
  1. SINGLE BAYS AND MULTI BAYS
  2. RIGID FRAMES AND BRACED FRAMES
  3. PRELIMINARY SIZING OF FRAME MEMBERS
- **CONSTRUCTION**
  1. FRAMING REQUIREMENTS
  2. CONNECTION DETAILS
- **FRACTURE DESIGN**
  1. CLOSE-IN EFFECTS
  2. STEEL CONTAINMENT STRUCTURES

FIGURE 27

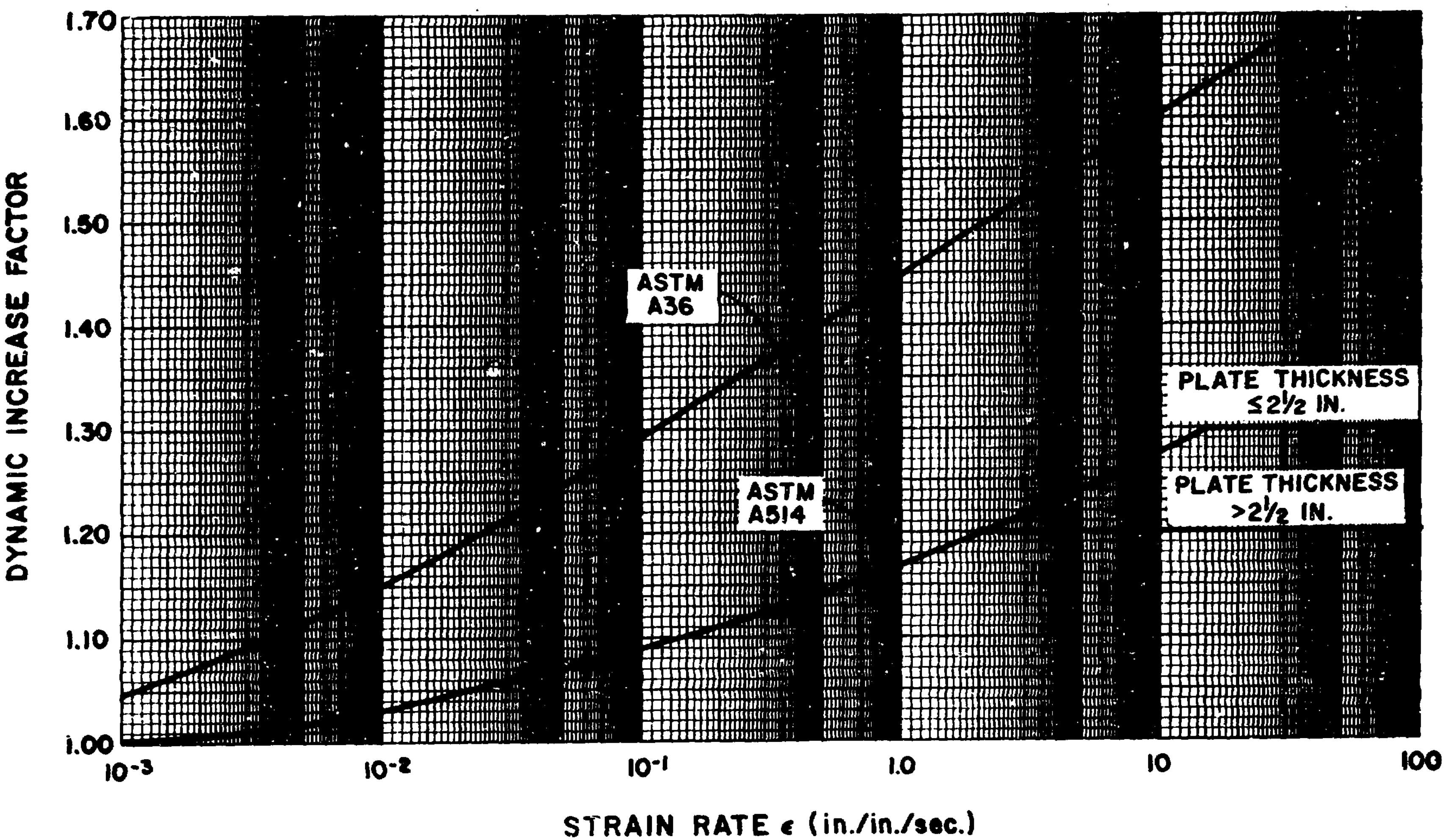
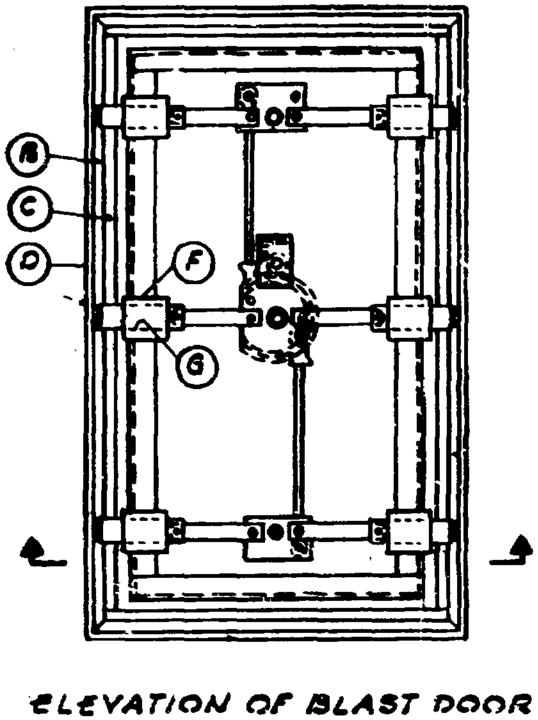
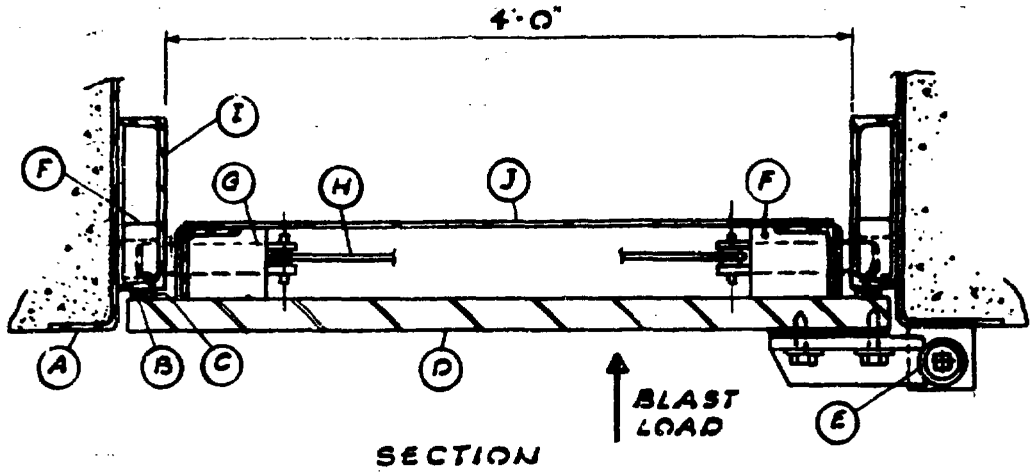


FIGURE 28 DYNAMIC INCREASE FACTORS FOR YIELD STRESSES FOR VARIOUS STRAIN RATES

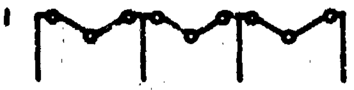
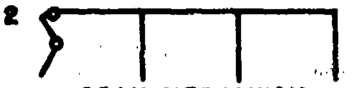
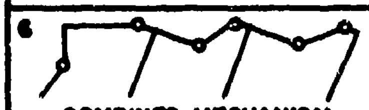


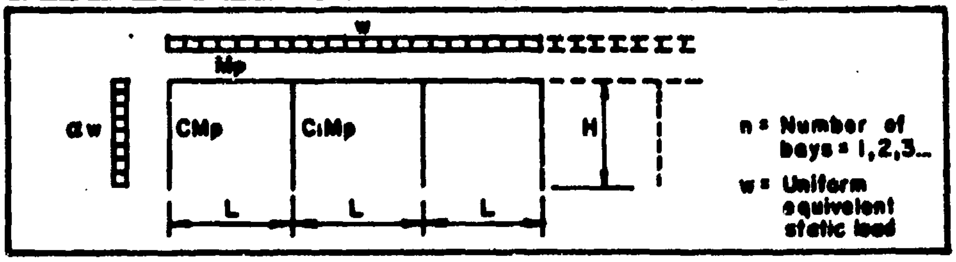


LEGEND:

- (A) - Steel Frame Embedded in Concrete.
- (B) - Continuous Gasket
- (C) - Bearing Block
- (D) - Blast Door Plate
- (E) - Door Hinge
- (F) - Reversal Bolt Housing
- (G) - Reversal Bolt
- (H) - Bar Connected to Closure Mechanism
- (I) - Steel Frame Equipped with Blast Door
- (J) - Light Gage Cover Plate

FIGURE 29 STEEL PLATE BLAST DOOR

Collapse Mechanism	Plastic Moment M_p	
	Pinned Bases	Fixed Bases
1  BEAM MECHANISM	$\frac{wL^2}{16}$	$\frac{wL^2}{16}$
2  BEAM MECHANISM	$\frac{\alpha w H^2}{4(2C+1)}$	$\frac{\alpha w H^2}{4(3C+1)}$
3a  PANEL MECHANISM	$\frac{\alpha w H^2}{2} \cdot \frac{1}{2+(n-1)C_1}$ $(C_1 \leqq 2)^*$	$\frac{\alpha w H^2}{4} \cdot \frac{1}{1+(n-1)C_1+C}$ $(C_1 \leqq 2)^*$
3b  PANEL MECHANISM	$\frac{\alpha w H^2}{4n}$ $(C_1 \geqq 2)^*$	$\frac{\alpha w H^2}{2} \cdot \frac{1}{2(n+C)+(n-1)C_1}$ $(C_1 \geqq 2)^*$
4  COMBINED MECHANISM	$\frac{w}{8n}(\alpha H^2 + \frac{n}{2}L^2)$	$\frac{w}{2} \cdot \frac{\alpha H^2 + \frac{n}{2}L^2}{2(2n+C)+(n-1)C_1}$
5a  COMBINED MECHANISM	$\frac{\frac{3}{8}\alpha w H^2}{C+\frac{1}{2}+\frac{C_1}{2}(n-1)}$ $(C_1 \leqq 2)^*$	$\frac{\frac{3}{8}\alpha w H^2}{\frac{3}{2}C+(n-1)C_1+\frac{1}{2}}$ $(C_1 \leqq 2)^*$
5b  COMBINED MECHANISM	$\frac{\frac{3}{8}\alpha w H^2}{C+(n-\frac{1}{2})}$ $(C_1 \geqq 2)^*$	$\frac{\frac{3}{8}\alpha w H^2}{\frac{3}{2}C+(n-1)\frac{C_1}{2}+(n-\frac{1}{2})}$ $(C_1 \geqq 2)^*$
6  COMBINED MECHANISM	$\frac{\frac{w}{8}\left[3\alpha H^2+(n-1)L^2\right]}{C+(2n-\frac{3}{2})}$	$\frac{\frac{w}{8}\left[3\alpha H^2+(n-1)L^2\right]}{\frac{3}{2}C+(n-1)\frac{C_1}{2}+(2n-\frac{3}{2})}$



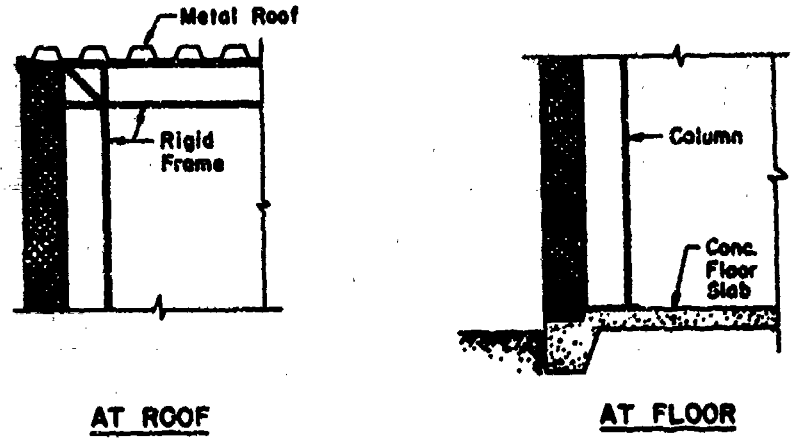
* For $C_1 = 2$ hinges form in the girders and columns at interior joints.

FIGURE 30 COLLAPSE MECHANISMS FOR RIGID FRAMES

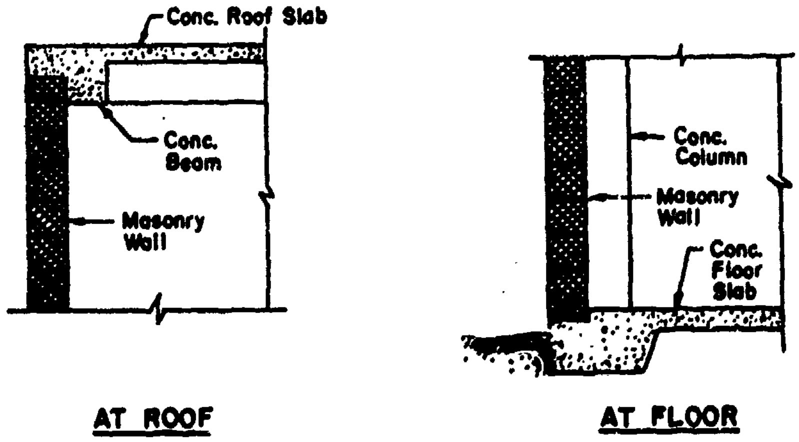
VOLUME VI
SPECIAL CONSIDERATIONS IN EXPLOSIVE FACILITY DESIGN

• MASONRY DESIGN	1.	DESIGN PROCEDURES AND CONSTRUCTION METHOD
• PRECAST CONCRETE DESIGN	1.	DESIGN PROCEDURES AND CONSTRUCTION METHOD
• SPECIAL PROVISIONS FOR PRE-ENGINEERED BUILDINGS	1.	DESIGN LOADS AND REQUIREMENTS
	2.	TYPICAL SPECIFICATIONS
• SUPPRESSIVE SHIELDING	1.	OUTLINE OF DATA CONTAINED IN "SUPPRESSIVE SHIELDS - STRUCTURAL DESIGN AND ANALYSIS HANDBOOK" (HNDM 1110-1-2)
• BLAST RESISTANT WINDOWS	1.	DESIGN PROCEDURES FOR GLAZING AND WINDOW FRAMES SUBJECTED TO BLAST LOADS
• DESIGN LOADS FOR UNDERGROUND STRUCTURES	1.	OUTLINE OF DATA CONTAINED IN "FUNDAMENTALS OF PROTECTIVE DESIGN FOR CONVENTIONAL WEAPONS"
• EARTH-COVERED ARCH-TYPE MAGAZINES	1.	INVESTIGATION, DESIGN, CONSTRUCTION AND STANDARD DRAWINGS FOR MAGAZINES
• SHOCK ISOLATION SYSTEM	1.	METHOD AND PROCEDURES FOR DESIGN OF SHOCK ISOLATION SYSTEMS ARE PRESENTED FOR BOTH PERSONNEL AND EQUIPMENT
• BLAST VALVES	1.	DISCUSS VARIOUS TYPE OF BLAST VALVES AND ASSOCIATED EQUIPMENT

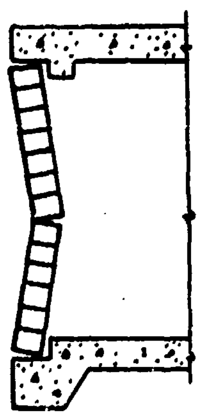
FIGURE 31



a) MASONRY WITH FLEXIBLE SUPPORT

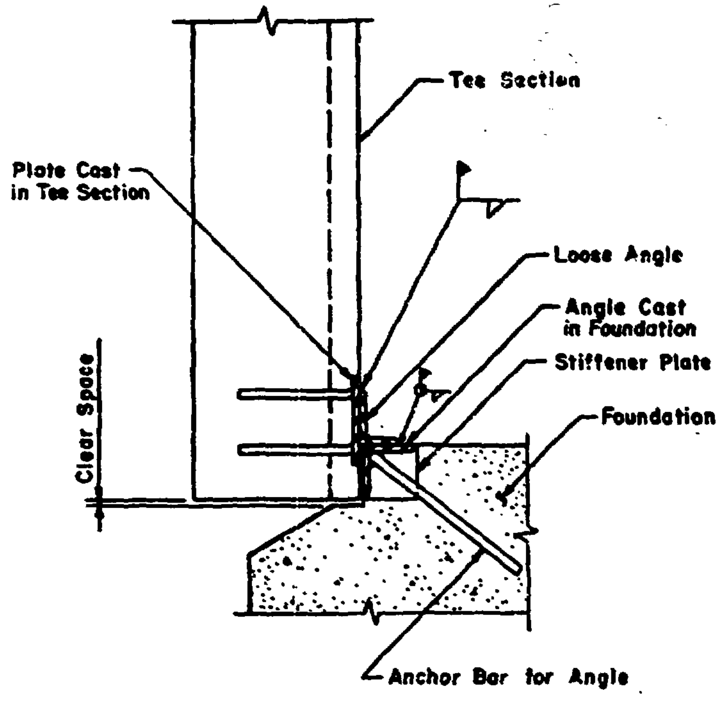


b) MASONRY WITH RIGID SUPPORT

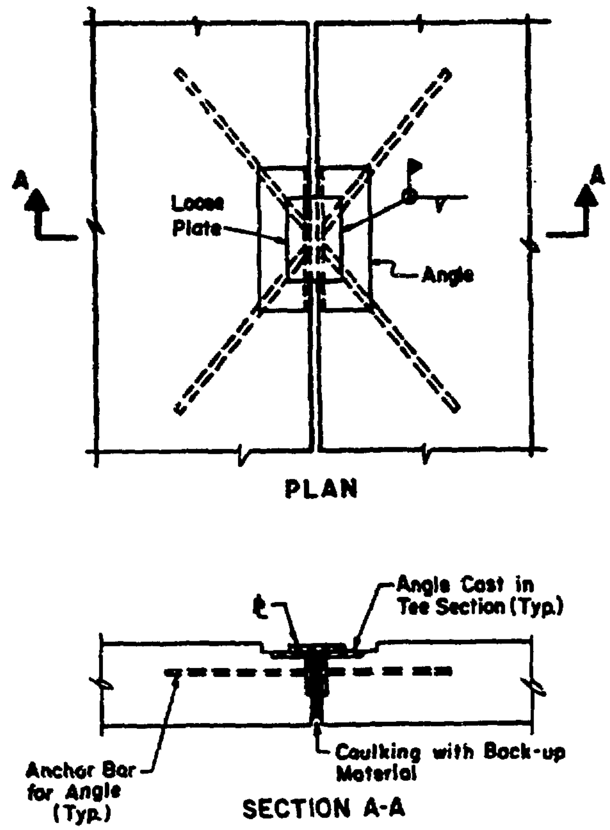


c) ARCHING ACTION OF NON-REINFORCED MASONRY WALL

FIGURE 32 MASONRY WALL CONSTRUCTION

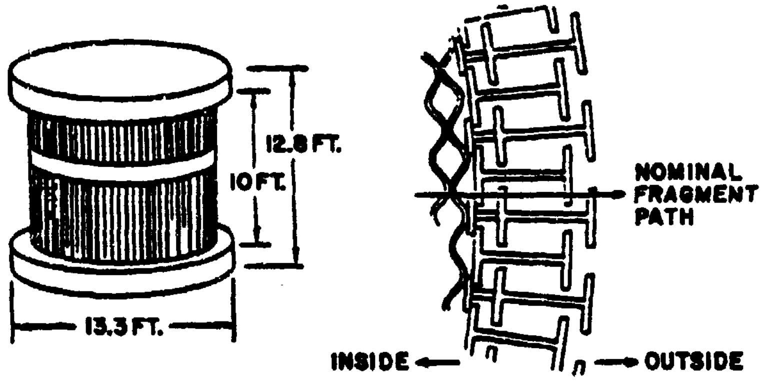


a) WALL PANEL-TO-FOUNDATION CONNECTION

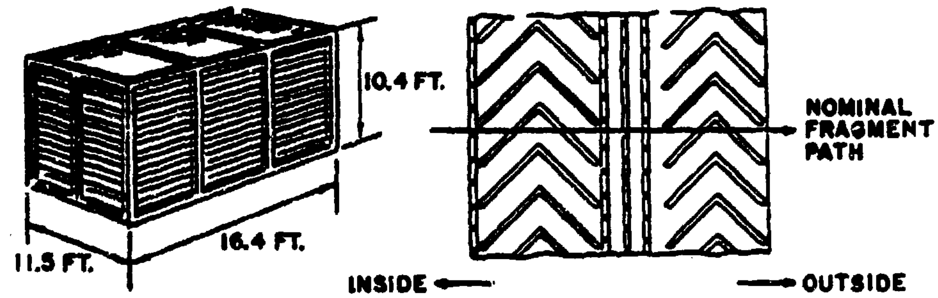


b) TYPICAL PANEL SPLICE

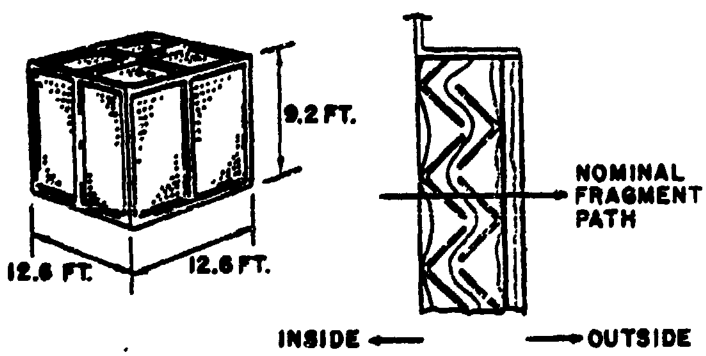
FIGURE 33 TYPICAL PRECAST PANEL CONNECTIONS



SUPPRESSIVE SHIELD GROUP 3
(GROUPS 1 & 2 ARE SIMILAR, BUT MUCH LARGER, AND HAVE THREE EXTERNAL RINGS)



SUPPRESSIVE SHIELD GROUP 4



SUPPRESSIVE SHIELD GROUP 5

FIGURE 34 EXAMPLES OF SUPRESSIVE SHIELDS

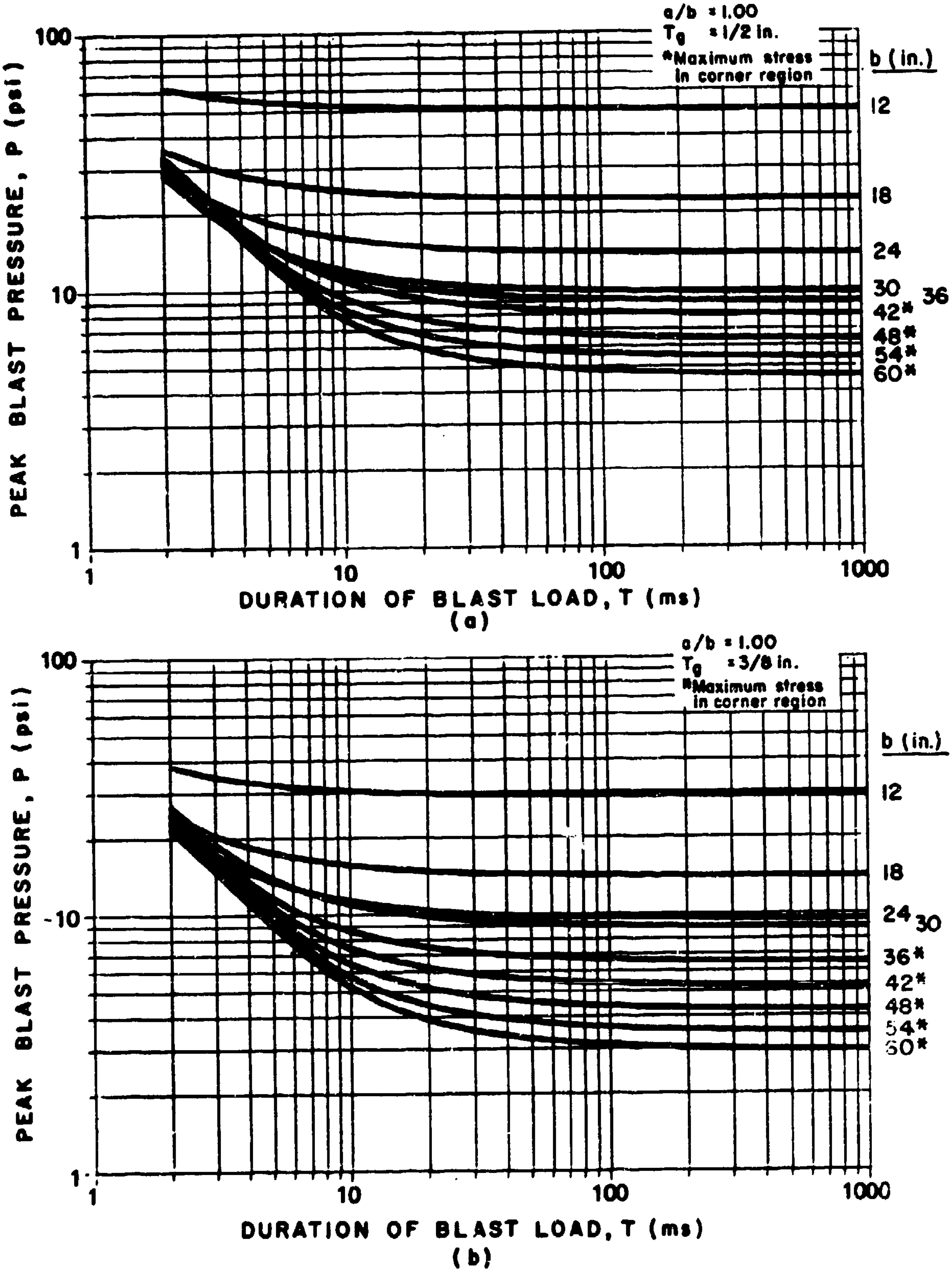


FIGURE 35 PEAK BLAST PRESSURE CAPACITY FOR TEMPERED GLASS PANES: L/H = 1.00, Tg = 1/2 AND 3/8 INS.

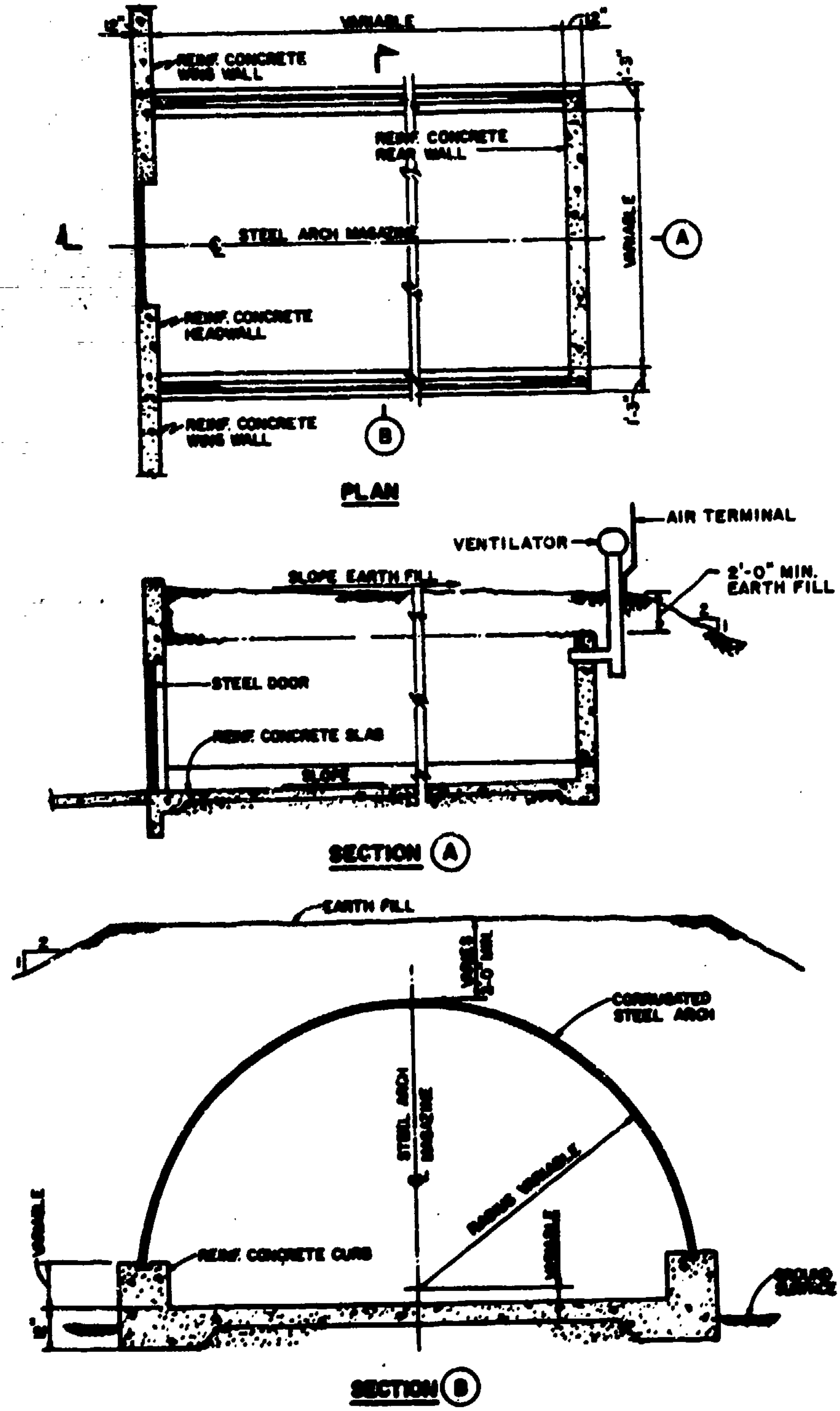
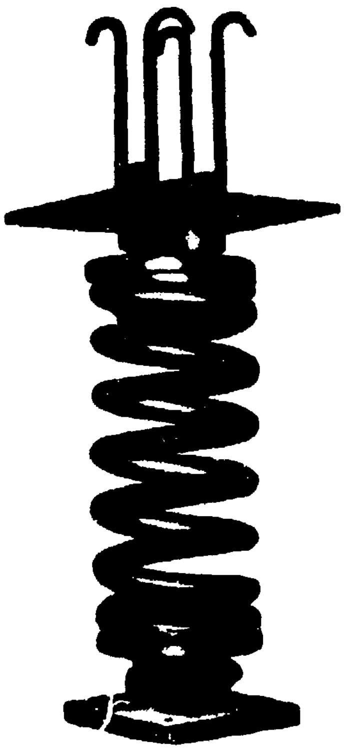
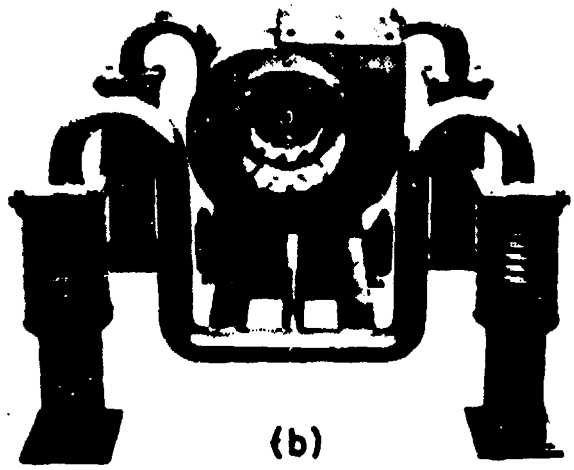


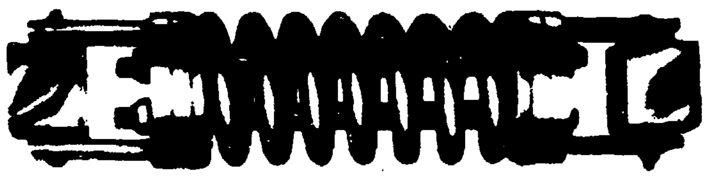
FIGURE 36 TYPICAL EARTH-COVERED STEEL-ARCH MAGAZINE



VERTICAL
SHOCK MOUNT



CENTER OF GRAVITY MOUNT PREVENTS
ROCKING UNDER SHOCK



HORIZONTAL SHOCK MOUNT

FIGURE 37 HELICAL COMPRESSION SPRING MOUNTS

END

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