SUMMARY OF CHANGES AND AVAILABILITY OF THE REVISED TM5-1300 NAVFAC P-397, AFM 88-22 "DESIGN OF STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS"

Paul M. LaHoud, P.E.
Huntsville Division, Corps of Engineers
106 Wynn Drive, Huntsville Alabama 35807

ABSTRACT

Design of hardened structures to resist the effects of accidental explosions must comply with specific criteria defined in Department of Defense explosive safety regulations, DoD 6055.9.Std. The implementation these criteria in structural design were first formalized in 1969 in the Tri-Service Design Manual, "Structures to Resist the Effects of Accidental Explosions" (TM 5-1300, NAVFAC P-397, AFM 88-22). This manual has been under revision for several years and the status of that revision effort has been reported at previous DDESB Seminars. The Manual is now officially released and available for government and public use. This paper summarize and highlights significant changes from the original manual and discusses the availability of both the hardcopy and microcomputer software version.

INTRODUCTION

Design of structures to resist blast effects produced by accidental detonation of explosives and propellants represents a specialized field of structural engineering. Methods for determination of loading functions, material properties and acceptable deformation are not defined by structural engineering building codes. In 1969 formal criteria was officially defined for explosive safety design applications through the release of the technical manual "Design of Structures to Resist the Effects of Accidental Explosions" (Reference 1). The release of this manual was significant in that it provided for the first time, Department of Defense Explosive Safety Board (DDESB) approved analysis procedures and criteria which could be used to design structures to provide protection for personnel, equipment and facilities. Explosive safety protection requirements in processing, manufacturing, transporting and storing explosives are more stringent than in for military combat applications. Figure 1 highlights the area of application of TM5-1300 in the overall arena of hardened structures within the Army. Figure 2 shows the specific Army and Air Force safety regulations requiring application of the manual.

The 1969 version of the manual received world wide distribution and application for over twenty-five years and is still widely used. Even though its primary application was for reinforced concrete structures, it provided the first consistent standardized guidance for determination of loads,

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1992**	2. REPORT TYPE	3. DATES COVERED **00-00-1992 to 00-00-1992**

4. TITLE AND SUBTITLE **Summary of Changes and Availability of the Revised TM5-1300 NAVFAC P-397, AFM 88-22--Design of Structures to Resist the Effects of Accidental Explosions**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,Huntsville Division,106 Wynn Drive,Huntsville,AL,35807**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA261116, Volume IV. Minutes of the Twenty-Fifth Explosives Safety Seminar Held in Anaheim, CA on 18-20 August 1992.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**18**	

TM5-1300 DESIGN APPLICATIONS

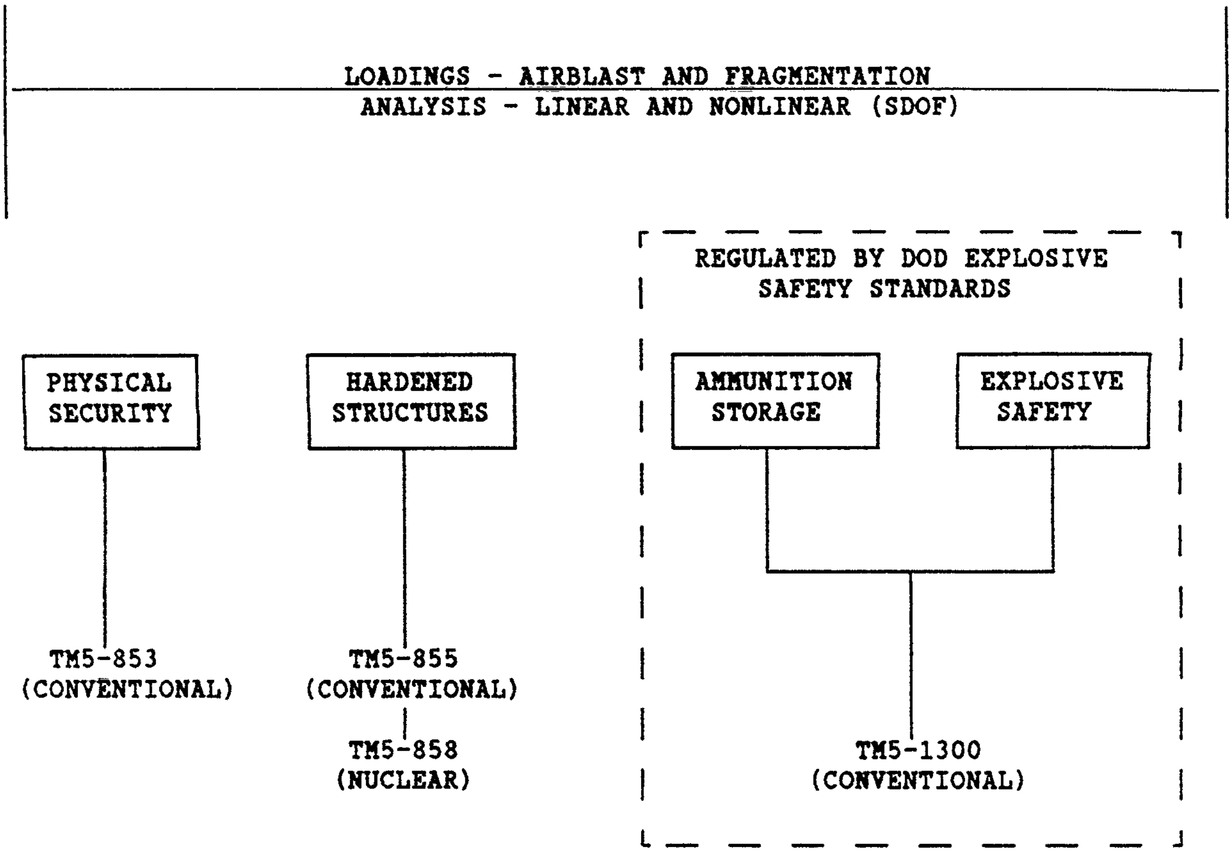
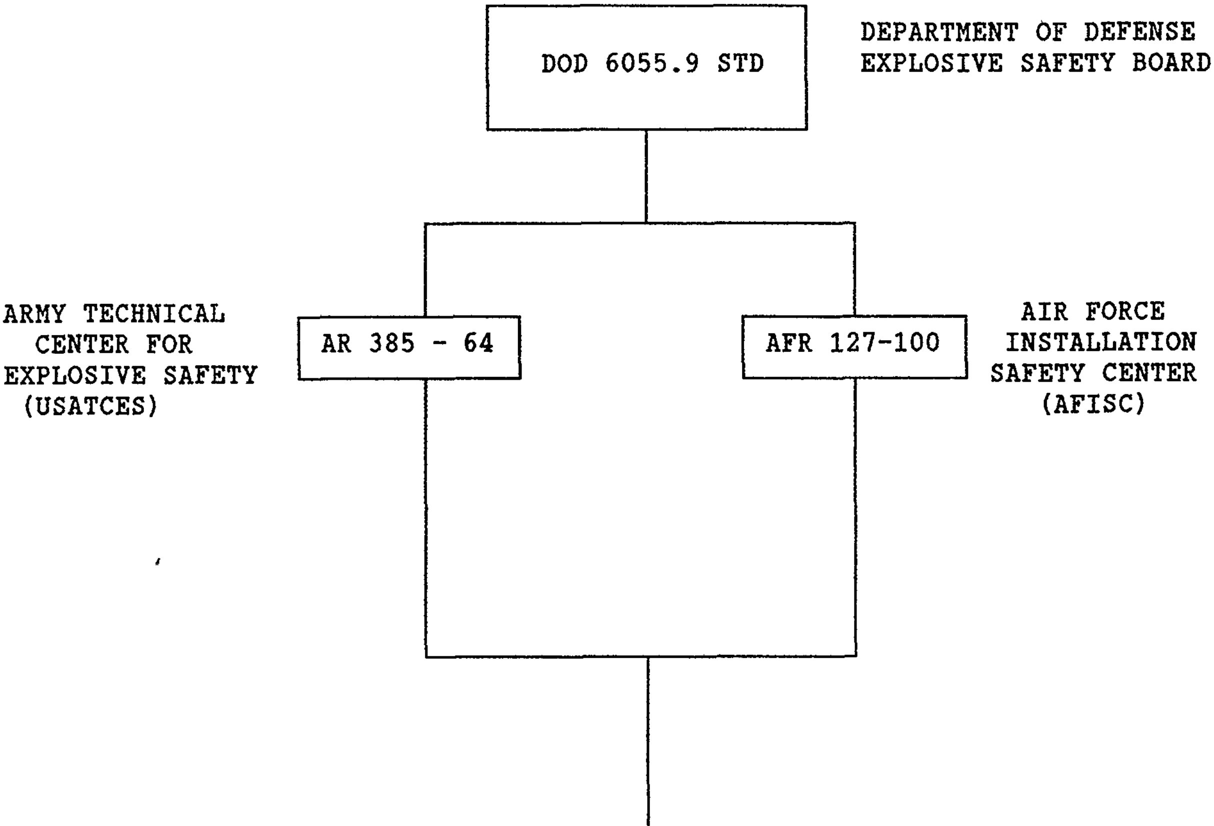


FIGURE 1

GOVERNING EXPLOSIVE SAFETY STANDARDS



USE OF ANALYSIS PROCEDURES, STRUCTURAL RESPONSE, DAMAGE CRITERIA AND PERSONNEL EXPOSURE TO BLAST LOADING IN ACCORDANCE WITH TM5-1300 IS <u>PRESCRIPTIVE</u>

MANDATORY

FIGURE 2

material properties and acceptable deformation criteria for structures exposed to blast loads. As a consequence it has been used as guidance for all types of structures. In 1981 a revision was initiated to capture a large accumulation of research and experimental work that had occurred since the original publication. This revision effort was extensive and has been discussed in previous DDESB Seminars.

The revision effort to the manual was initially guided by a steering committee with subcommittees for blast technology and design applications. In 1987 with most of the research completed and the draft manual released for technical review, the management structure was streamlined to a combined management/technical steering group. Figure 3 shows the historical evolution of the committee. The current steering group, will continue to manage the manual and provide periodic revisions.

The revision to "Structures to Resist the Effects of Accidental Explosions" presents an enormous amount of improved technical data in loading prediction, material properties, deformation criteria, and analytical procedures. This is reflected in the physical size of the new hardcopy of the manual as depicted in Figure 4. One of the most popular features of the original manual was the detailed example design problems. The new manual provides the same type of examples throughout, demonstrating both original and new material. This paper will briefly highlight the changes in content of the new manual.

CHAPTER 1 - Introduction

The material contained in Chapter I consists of an expanded discussion of the topics contained in Chapters 1, 2, and 3 of the original manual. Significant additional data and discussion are provided on the topics of human tolerance to blast overpressures, ground shock and fragments. New discussion is provided on tolerances of explosives to blast effects. New data is also provided on equipment response to blast forces. Figure 5 shows an example of information on human tolerance to overpressure. Extensive information on safe separation distance for numerous types of munitions is also included. The contents expands from 7 pages in the original manual to 42 pages in the new manual. The number of source material technical references provided increases from 8 to 17.

CHAPTER 2 - Blast, Fragment, and Shock Loads

This Chapter replaces Chapter 4 of the original manual and reflects the abundance of new data incorporated in the revision. Technical discussion provided on blast, fragment and shock loading increases from 65 pages in Chapter 4 of the original manual to over 500 pages in this chapter. Source technical references increase from 25 to 138. A significant new topic discussed is the effect of explosive source geometry on blast pressure and impulse. This is an important concern in estimating the energetic output of explosive processing and manufacturing operations. Figure 6 shows examples of source geometries. Figure 7 is one example of 32 pages of new data on this topic obtained from various references.

MANUAL STEERING COMMITTEE

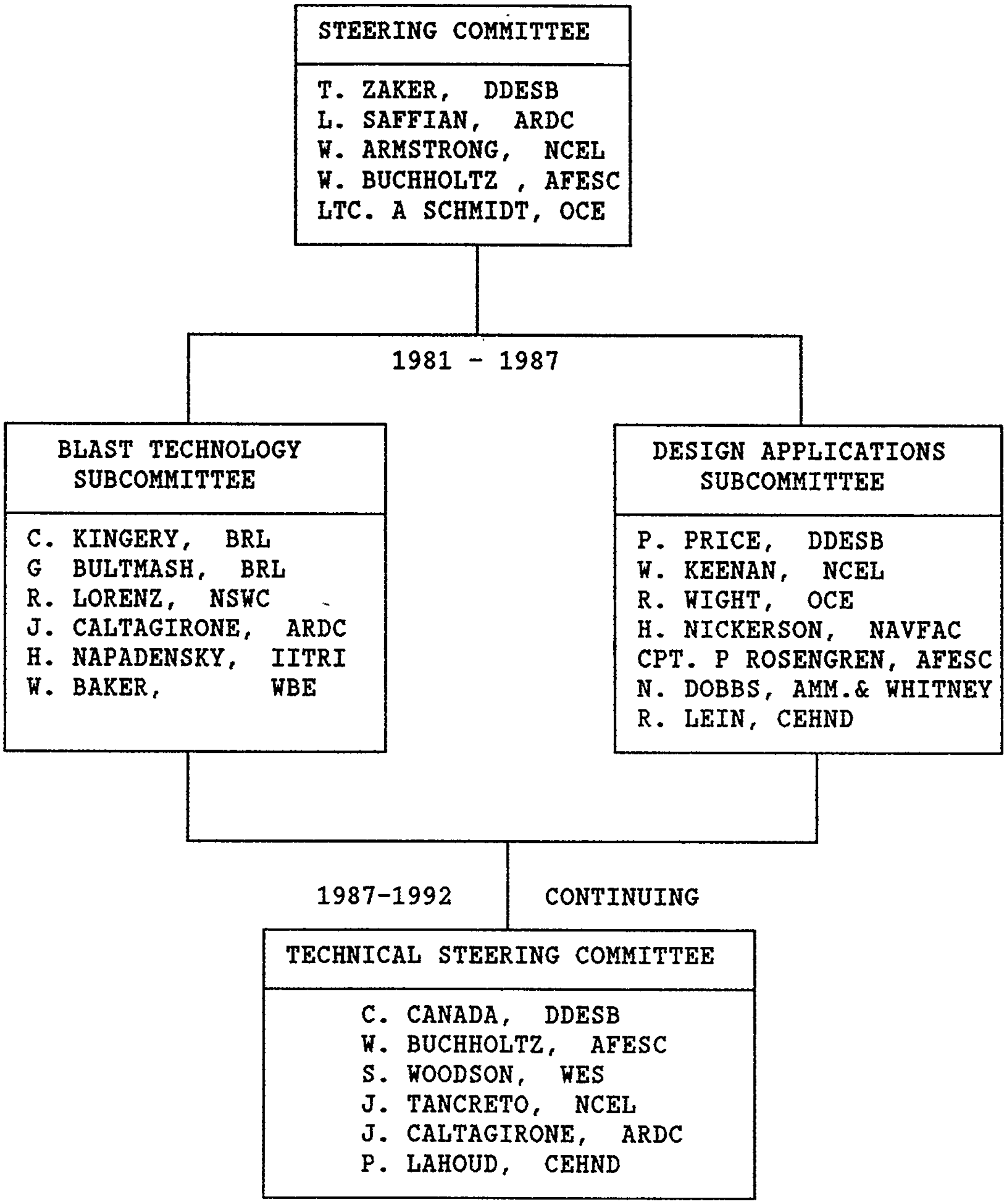


FIGURE 3

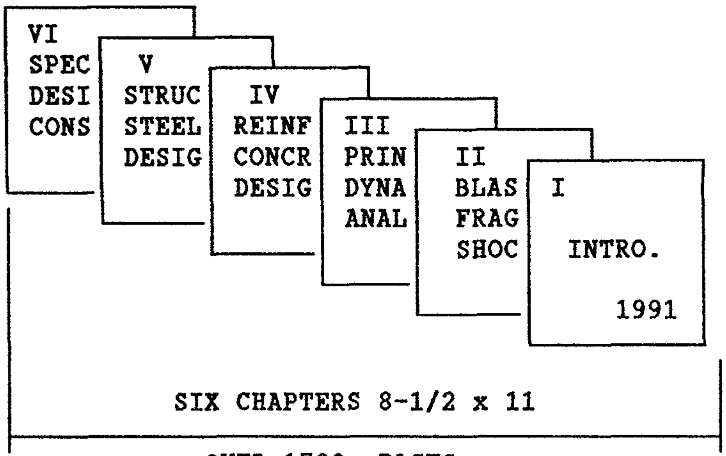
THE OLD

TM 5 - 1300

SINGLE VOLUME 11 X 17

188 PAGES 1969

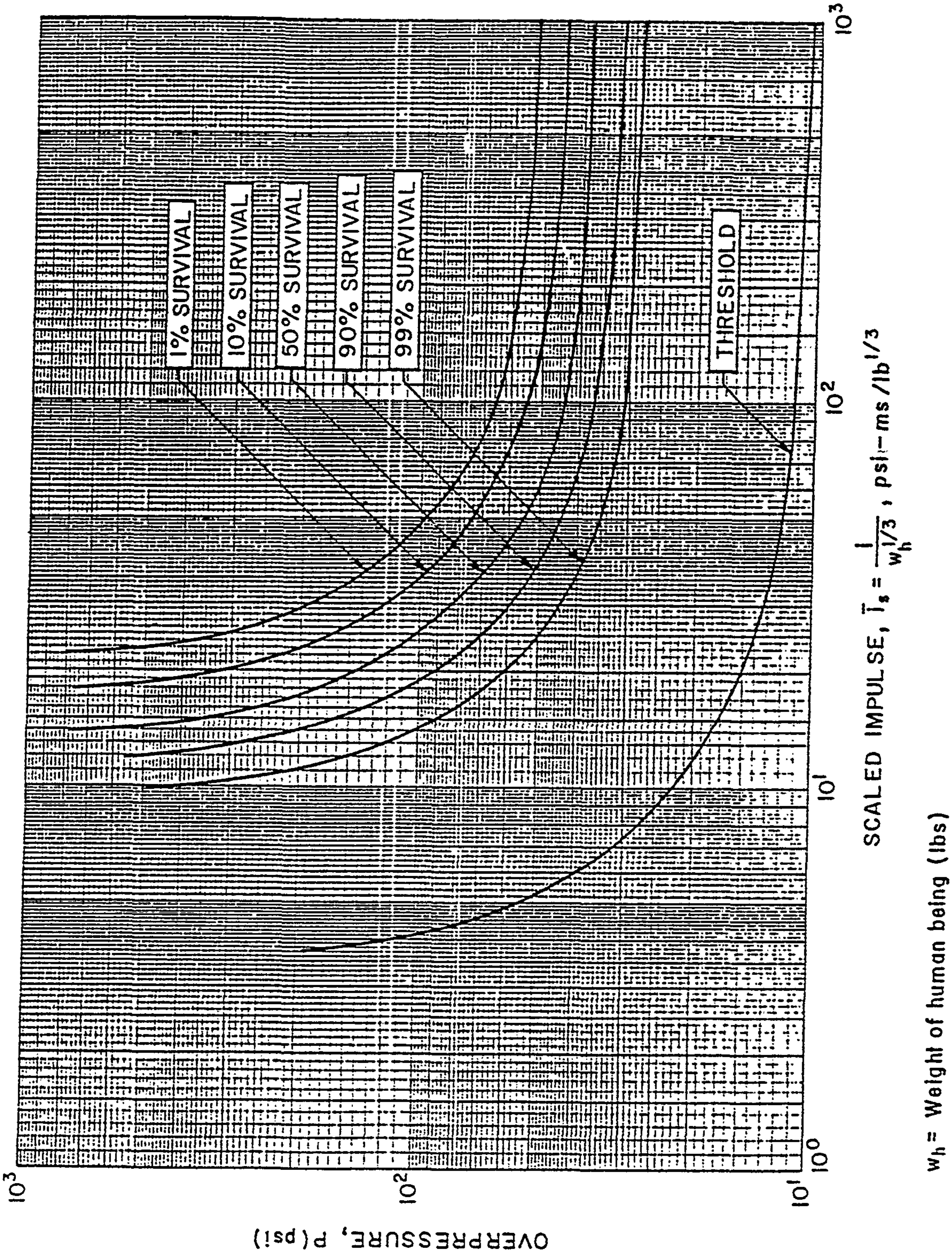
THE NEW



OVER 1700 PAGES

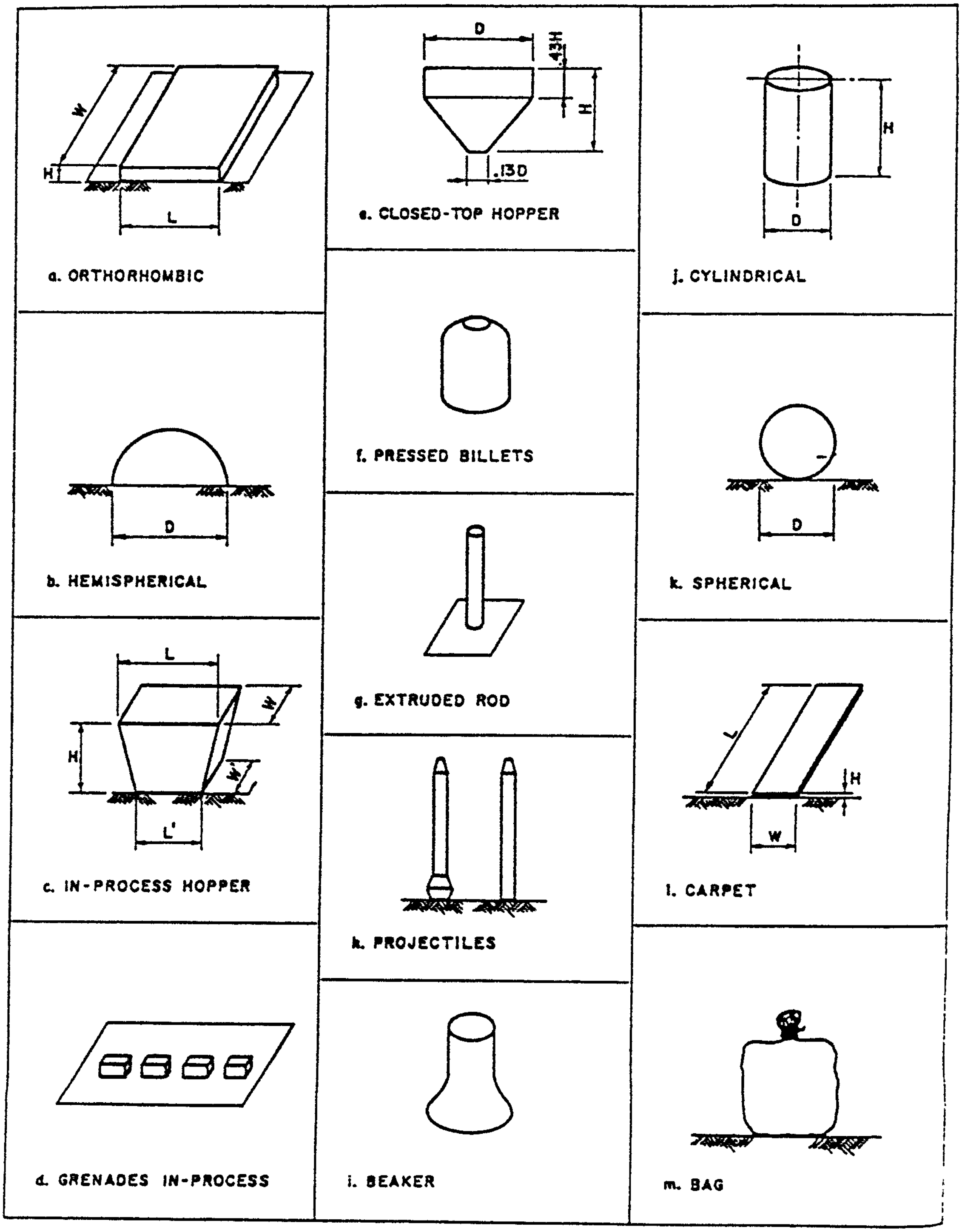
CHAPTER	1	INTRODUCTION
CHAPTER	2	BLAST, FRAGMENTATION AND SHOCK LOADS
VOLUME	3	PRINCIPLES OF DYNAMIC ANALYSIS
VOLUME	4	REINFORCED CONCRETE DESIGN
VOLUME	5	STRUCTURAL STEEL DESIGN
VOLUME	6	SPECIAL CONSIDERATIONS IN EXPLOSIVE FACILITY DESIGN

FIGURE 4



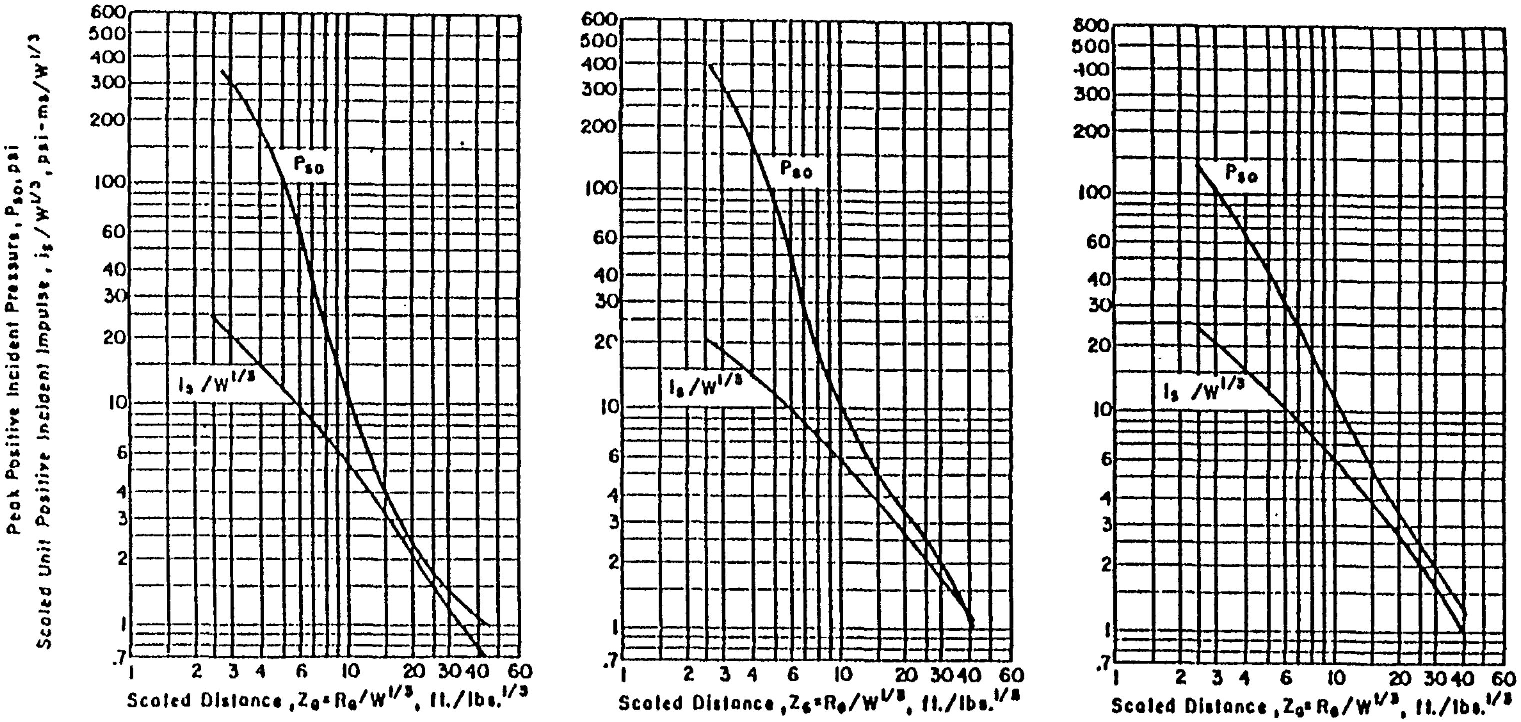
SURVIVAL CURVES FOR LUNG DAMAGE

FIGURE 5



EXPLOSIVE SHAPES

FIGURE 6



a. HMX
Orthorhombic

b. HMX
Cylindrical

c. M483 155mm ICM Projectile
Single Round

PEAK POSITIVE INCIDENT PRESSURE AND SCALED IMPULSE
FOR AN EXPLOSION ON THE SURFACE AT SEA LEVEL

FIGURE 7

Another topic which has benefitted from extensive new research is the calculation of blast loads on cubicles wall. The original manual provide charts to analyze only for impulse loads on cubicle walls with various boundary conditions. Subsequent research and experiment has shown that in many cases a pressure-time solution may be required rather than an impulse solution. Therefore in addition to the original impulse charts, 38 new charts are provided which allow the calculation of the average reflected pressure on the same cubicle walls.

Extensive Naval Civil Engineering Laboratory (NCEL) research on blast load environments in and adjacent to fully and partially vented cubicles has been incorporated in the new manual. Thirty-two additional new charts are provided which allow the estimation of gas pressures in, and shock pressures adjacent to, various configurations of cubicles.

Fragmentation prediction procedures in the original manual were limited, addressing only primary fragment effects from conventional explosive filled munitions. More detailed analytical models for primary fragmentation have been developed and incorporated in this chapter. These expanded procedures allow the estimation of primary fragment mass and velocity for many Non-cylindrical geometries. Additional experimental and analytical material on primary fragmentation from liquid filled munitions developed from the chemical weapons demilitarization program (Reference 2) have also been included. This chapter also incorporates extensive additional analytical procedures developed by the Department of Energy (Reference 3) on prediction of secondary debris from equipment and building elements.

Chapter 2 also incorporates procedures for the estimation of groundshock from accidental explosions. This data was extracted from Reference 4. Methods are presented for determining the structure motion caused by ground shock and air blast effects as well as their interaction. Other procedures are presented for determining shock spectra which may be used for evaluation of structure motion as well as the design of shock isolation systems.

Another topic which has received considerable additional treatment is the calculation of gas pressures as a contributor to total loading from internal explosions in buildings. Research and experimentation has shown that even with frangible walls or vents, gas pressure is a major contributor to total loading. This phenomena was not clearly recognized in the original manual.

Expanded methods and examples are provided for the calculation of exterior loads on structures as well as interior loads on structures due to leakage of exterior blast pressures through openings. This is very valuable in the design of shelter type structures where personnel protection from overpressure is required.

Chapter 3 - Principles of Dynamic Analysis

In the original manual basic principles of dynamic analysis were provided as sub-paragraphs of chapters 5 and 6. The new manual has reorganized this material into a single chapter and extensively supplemented and expanded the methods presented to cover a more complete range of possible structural

response situations. Material provided has increased from approximately 50 pages in the original manual to over 375 pages in this chapter.
Data for determining resistance-deflection functions and yield line locations have been significantly increased in this chapter. This new material includes the determination of elastic and elasto-plastic moment and deflection coefficients for numerous support and loading conditions, including both one and two-way elements, and flat slabs.

As in the original manual, and most other widely used hardened structures design references, the new manual utilizes single-degree-of-freedom (SDOF) methods to estimate the maximum response of structures subjected to blast loads. Only two design charts were provided in the original manual for determining structure response to blast overpressures. One chart pertained to structure response to direct loading while the second was used to determine rebound forces. The number of design charts furnished in this chapter have been increased to 216 and covers maximum elastic response to triangular loads, rectangular loads, gradually applied loads, triangular pulse loads, and sinusoidal loadings. The new charts also cover maximum response to elasto-plastic systems for triangular loads, rectangular loads, gradually applied loads, triangular pulse loads, and bilinear-triangular loads as well as rebound forces.

Other beneficial new additions to Chapter 3 are procedures for performing numerical integration analyses. These include both the average-acceleration-method and the acceleration-impulse-extrapolation-method. Procedures are presented for including damping in a system as well as for analyzing two-degree-of-freedom systems. These procedures are attractive with the availability of microcomputer spreadsheets with graphics, such as LOTUS 123, and they provide a very flexible analysis tool.

Chapter 4 - Reinforced Concrete Design

The technical data from chapters 5 through 9 of the original manual have been combined in this chapter. The original manual was concerned primarily with the design of laced reinforced concrete walls to resist the effects of close-in detonations. A considerable amount of new data has been added to address other types of concrete elements. Less than 90 pages of material in the original manual has been increased to over 250 pages in this chapter. Source references cited have increased from 38 to 77. This additional data will facilitate the design of a wider range of reinforced concrete structures.

The new manual provides much better guidance for the estimation of the dynamic capacity of both concrete and reinforcing steel. Based on recent research and testing, the dynamic increase factors for both concrete and reinforcing steel are presented as a function of the actual response 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 steel that is furnished by steel producers. Finally, the procedures for the determination of shear capacity have been significantly revised (Reference 5)

New material has been provided for small deflections (less than 2 degrees support rotation) design of slabs reinforced with single-leg stirrups rather than lacing. This type of shear reinforcement will greatly simplify construction and result in considerable cost savings.

This volume also provides greatly expanded design procedures for conventionally reinforced 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 includes, not only one and two-way slabs of various support conditions, but also flat slabs. When support conditions permit, tension membrane action of the slabs is incorporated in the design. The recognition of membrane action permits the slab to attain relatively large deflections at reduced strength, thereby achieving greater economy in design.

Data on spalling of concrete has been increased to more realistically predict the need for costly structural steel spall plates. In addition, material on structural response to primary and secondary fragment impact is expanded.

The last part of this chapter greatly expands the number of typical design details provided. These details include information acquired from numerous blast resistant construction projects. Detailing procedures are provided for laced concrete elements, conventionally reinforced concrete, flat slabs, beams columns, and foundations. Figures 8 and 9 are typical of details provided.

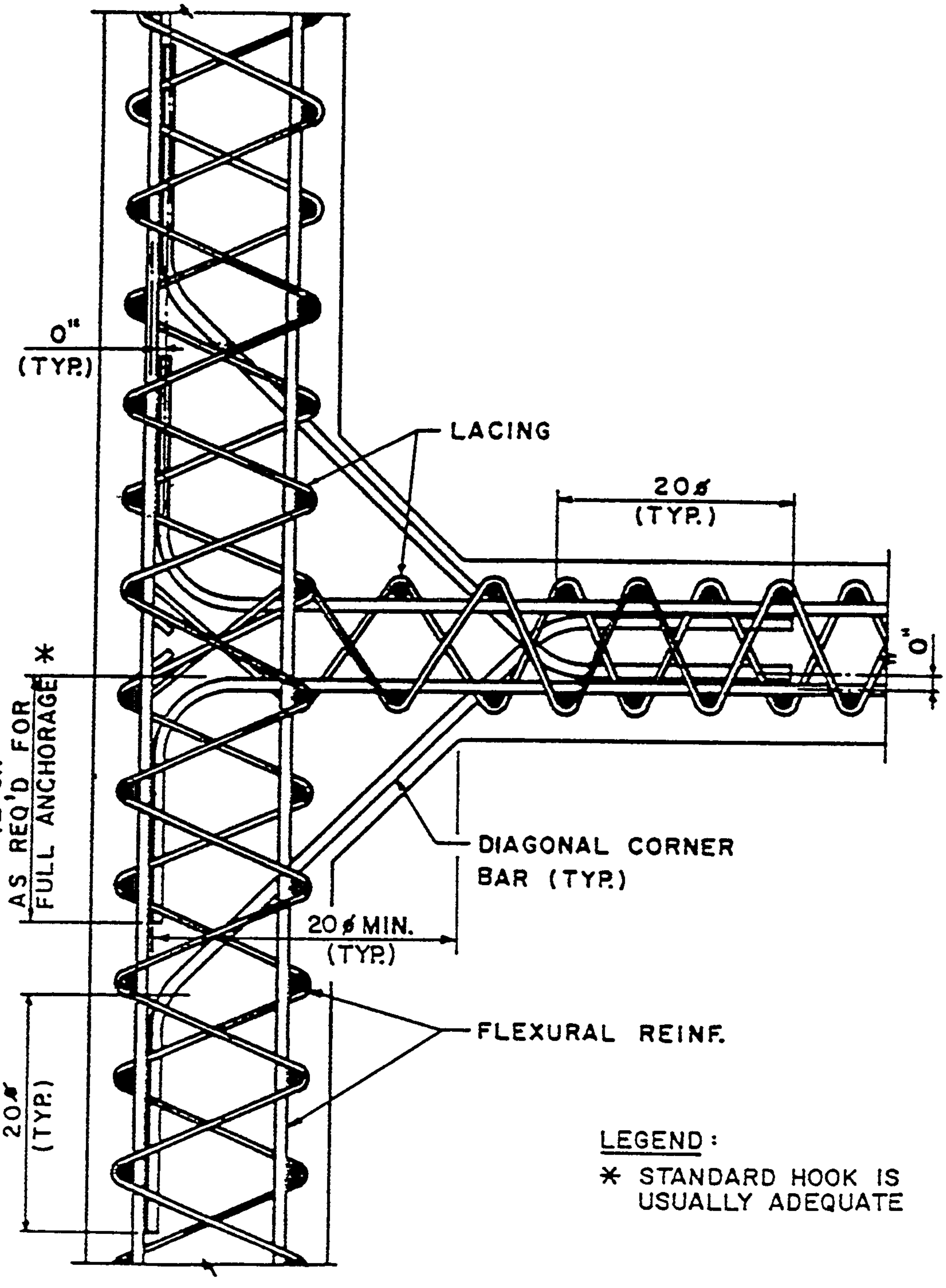
Chapter 5 - Structural Steel Design

The material provided in this chapter is entirely new since the original manual did not address structural steel at all. References 6 and others provided are the sources of the procedures in this volume. The design procedures for response of steel structures follow from the SDOF analysis procedures provided in Chapter 3. Material properties of structural steel elements are presented, along with recommended dynamic design stresses, acceptable maximum displacement, and plastic deformations within the broad range of steels available. The structural steels for plastic design covered by the AISC Specifications are discussed with regard to their uses in protective structures subjected to blast loads.

A method for performing preliminary blast load plastic design of structural steel frames is presented. The analytical procedures can consider both single and multi-bay arrangements for both rigid and braced frames. Based on the results of the preliminary analysis, a final frame analysis can be performed. This chapter also provides recommended methods of detailing connections for structural steel.

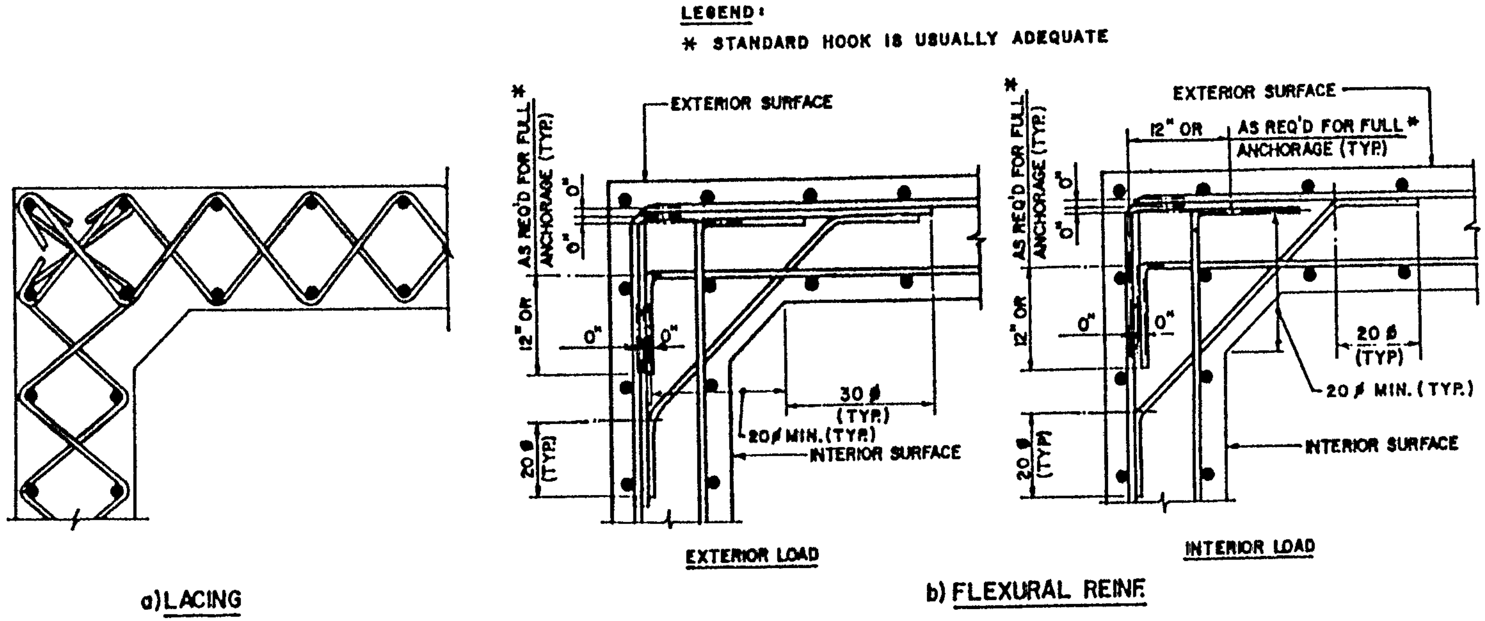
Chapter 6 - Special Considerations in Explosive Facility Design

Chapter 10 of the original manual discussed several miscellaneous topics related to explosive safety protective construction. This chapter includes that data and other new data on a wide list of topics including: (1) masonry design; (2) precast concrete design; (3) pre-engineered buildings;



INTERSECTION OF CONTINUOUS AND DISCONTINUOUS
LACED WALLS WITHOUT EXTENSIONS

FIGURE 8



CORNER DETAILS FOR LACED WALLS WITHOUT WALL EXTENSIONS

FIGURE 9

(4) suppressive shielding; (5) blast resistant windows; (6) design loads for underground structures; (7) earth-covered arch-type magazines; (8) blast valves; and (9) shock isolation systems.

Masonry Design - This section provides procedures for design of masonry walls subjected to blast overpressures. Included in the design procedures are methods for calculating the ultimate strength of masonry walls as well as resistant-deflection functions. Criteria is presented for allowable deflections.

Precast Concrete Design - Described in this section are the procedures used for design of precast elements subjected to blast overpressures. Methods are included for design of precast concrete slabs, beams and columns. The procedures include methods for calculating ultimate resistance and resistance-deflection functions as well as deflection criteria.

Special Provisions for Pre-Engineered Buildings - Standard pre-engineered buildings are usually provided by a performance specification and designed by the supplier for conventional loads (live, snow, wind loads, etc.). These buildings are very vulnerable to blast overpressures. Blast resistant pre-engineered buildings are designed in the same manner as standard structures. However, the performance specification must require considerably higher conventional loads to provide the equivalent blast resistance. This section presents the magnitude of these larger conventional loads as well as present details of both the main frame members and foundations which must be incorporated into the building design. To assist the design a template specification for hardened pre-engineered buildings is provided.

Suppressive Shielding - Presented is a summary of design and construction procedures which are outlined in the design Manual, titled "Suppressive Shields - Structural Design and Analysis Handbook" HNDM 1110-1-2, (Reference 7). This section describes the application of suppressive shielding as well as design criteria and procedures. Methods of designing equipment penetrations through walls, as well as blast doors to be used with suppressive shielding, are discussed.

Blast Resistant Windows - Historically, explosion effects have produced airborne glass fragments from failed windows which are a risk to life and property. Guidelines are presented for the design, evaluation, and certification of windows to safely survive a prescribed blast environment. Design criteria is presented for both glazing and window frames. The design procedures include a series of design charts for both the glazing and frames.

Design Loads for Underground Structures - This section is a summary of the data presented in the design Manual, "Fundamentals of Protective Design for Conventional Weapons" (TM 5-855-1). The data contained in this Manual pertains primarily to effects produced by explosions on or below the ground surface and the blast pressures they produce on below ground structures. Procedures are presented for evaluating blast loads acting on the structure surface as well as structure motions caused by explosions.

Earth Covered Arch-Type Magazines - This provides information on typical earth-covered magazines which are used for storage of explosives. Included are requirements for both metal arch and reinforced concrete arch magazines, including semicircular and oval types. Discussed are the investigations performed in connection with magazines, general design procedures, construction, and standard designs. Additional information is available from Reference 8.

Shock Isolation Systems - Data presented for shock isolation systems has been greatly expanded from that given in the present Manual. The data given in the original manual was basically qualitative rather than quantitative. Although a full discussion of the subject is beyond the scope of this chapter an introduction to isolation system design is presented. Included are various methods of achieving shock isolation for both equipment and personnel. Typical designs for equipment supports are presented.

Blast Valves - This section discusses several types of blast valves that are available commercially including sand filters, hardened louvers, and poppet valves. Also presented are the advantages and disadvantages of blast-actuated vs remote-actuated blast valves, the effect of plenum chambers, and a typical specification for the design, testing, and installation of a poppet valve.

COMPUTER ANALYSIS PROCEDURES

TM5-1300 is recognized and applied worldwide. One of the main objectives of the steering committee was to assure that the new manual provided complete methods suitable for hand calculations. This resulted in the large number of new charts and graphs for direct design. However many valuable Micro-computer codes have been developed to solve segments of the analysis procedures in the manual. Computer codes which are currently approved by the DDESB as equivalent to methods in this manual are described briefly.

TM5-1300 PC VERSION - This is an impressive piece of software written by David Hyde of the Corp of Engineers Waterways Experiment Station (CEWES). The entire text of the manual as well as all figures and tables have been committed to a microcomputer program. The text can be called up, reviewed, printed, and key word or phrase searches conducted. All graphs and tabular data are accessible for viewing, and a "cross-hair" function allows the user to accurately pick graphical data points. Many numerical calculation procedures in the manual have also been automated.

CBARCS/PCBARCS - This is a structural analysis code which performs nonlinear analysis of rectangular reinforced concrete slabs. It was developed by the Naval Civil Engineering Laboratory (NCEL). The program can compute blast shock and gas pressures based on the type of explosive. It calculates structural properties, slab resistance using yield line theory and then determines the dynamic response of the slab. It is primarily applicable to pressure-time loadings.

SHOCK - This is a program that calculates shock pressures and impulses on arbitrary rectangular surfaces. It was also developed by NCEL.

FRANGE - This program calculates the gas pressure-time history inside a room resulting from an explosion. The program also computes the time required for a frangible panel to blow away from a wall and allow full venting. Program also written by NCEL.

SOLVER - This program calculates the dynamic response of a user defined single-degree-of-freedom system and loading. It predicts nonlinear response based on user defined resistance deflection function. It was also written by NCEL.

TRAJECT - This program calculates fragment and debris trajectories based on user defined velocity, launch angles, drag and mass characteristics. This Code was written by Naval Surface Warfare Center.

Each of the three services will maintain repositories which contain the computer programs described above:

(1) Department of the Army, Commander, U.S. Army Waterways Experiment Station, P.O. Box 631 Vicksburgh Miss, 39180-0631 Attn: WESKA

(2) Department of the Navy, Commanding Officer, Naval Civil Engineering Laboratory, Port Hueneme, California 93043 Attn: Code L51

(3) Department of the Air Force, Aerospace Structures, Information Analysis Center, Wright Patterson AFB, Ohio 45433 Attn: AFFDL/FBR

The TM5-1300 steering committee will continue to evaluate new codes and requirements for revisions to existing codes. These programs will be periodically updated or revised as required.

SUMMARY

The new version of TM5-1300 is now available for general use. The manual is greatly respected worldwide and many nations use it as a basis for their own explosive safety guidance. Within the United States numerous other government agencies direct its application including DOE and NASA. The manual is available from both The Defense Technical Information Center (DTIC) and the National Technical Information Center (NTIC). The Hard copy version can be ordered as AD A243272. The PC version is AD M000097.

REFERENCES

1. Structures to Resist the Effects of Accidental Explosions; Department of the Army Technical Manual, TM 5-1300; Department of the Navy Publication, P-397; and Department of the Air Force Manual, AFM 88-22, June 1969.

2. A Manual to Predict Blast and Fragment Loadings from accidental Explosions of Chemical Munitions Inside an Explosive Containment Structure, Prepared by Southwest Research Institute under contract DACA87-81-C-0099, to the Huntsville Division for the Program Managers Office for the Chemical Weapons Stockpile Disposal Program, April 1983.

3. Prediction of Blast and Fragmentation Loading on Structures, DOE/TIC 11268, prepared by Southwest Research Institute, San Antonio Texas, under contract DACA87-79-0091, to the Huntsville Division for the Department of Energy, Amarillo Area Office, September 1980.

4. Fundamentals of Protective Design for Conventional Weapons, TM 5-855-1, prepared by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, for Office, Chief of Engineers, U.S. Army, Washington, D.C.

5. Changes to TM5-1300 Governing Shear Reinforcing Requirements for Blast Resistant Reinforced Concrete Structures, Ross, B., Zehrt W., Huntsville Division, presented at the 24th DDESB Safety Seminar August 1990.

6. Design of Steel Structures to Resist the Effects of HE explosions, TR 4837, prepared by Ammann & Whitney, New York, NY; for Picatinny Arsenal, Dover New Jersey, August 1975.

7. Suppressive Shields - Structural Design and Analysis Handbook, HNDM 1110-1-2, U.S. Army Corps of Engineers, Huntsville Division, Huntsville, AL, 18 November 1977.

8. Explosive Safety Siting of Corps of Engineers Standard Igloo Designs, Williams, E., Farsoun, A., Watanabe, W., Huntsville Division, presented at the 24th DDESB Safety Seminar, August 1990.