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A DESIGN-AID AND COST ESTIMATE MODEL FOR SUPPRESSIVE
SHIELDING STRUCTURES

Richard S.K. Pei

December 1975

Final Report

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SAFETY ENGINEERING GRADUATE PROGRAM
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FOREWORD

The research discussed in this report was accomplished as part of the Safety Engineering Graduate Program conducted jointly by the USAMC Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Department of the Army.

This report has been reviewed and is approved for release. For further information on this project contact Dr. George D. C. Chiang, Intern Training Center, Red River Army Depot, Texarkana, Texas 75501.

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Director, ITC.

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and the total effective thickness of plates. Cost output variables include: material, fabrication, welding, and total costs of panels, frame, door, and foundation of a cubical suppressive structure. A description of the model and its construction details are reviewed in the report. A user's guide which includes step by step instructions in data inputs is also provided.

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CHAPTER I

INTRODUCTION

Suppressive shielding is a relatively new concept in safeguarding personnel and property in case of an accidental explosion during manufacturing, transporting, and storing of explosives.

A suppressive structure (sometimes called a suppressive shield) is an enclosure of a hazardous operation so that if an accidental explosion occurs, primary damage will be to the enclosed space. It can also be used in storing or transporting ammunitions and explosives of various strengths.

Conventional safeguarding of hazardous operations and ammunitions is through the use of concrete barriers. These barriers can either be barricades or cubical - types structures where one or more sides and/or the roof of the structures are of frangible construction or open to atmosphere. The design concept of these concrete barriers is to vent pressure and fragments to the side(s) where minimum damage can result in the event of an accidental explosion. In most cases, pressure and fragments resulting from explosions causes serious injuries and property damage due to the presence of unprotected sides that are of frangible construction or open to the atmosphere. Suppressive structures, on the other hand, provide more complete protection than concrete barriers.

Their usual design is to contain all primary fragments

inside the structure and to allow controlled venting of blast pressure resulting from an explosion.

Most suppressive structures basically consist of four major structural components: frame, panel, door, and foundation. Except for the foundation which is made of reinforced concrete, all the other parts are made from structural steel. Primary fragments are to be stopped by thickness of the steel. Pressure venting is done by using perforated plates and air spaces between structural elements such as angle bars, W beams, pipes, etc. (see Appendix B)

The economic value of suppressive structures must be determined before they can replace the concrete barriers. An economic feasibility analysis was conducted by the U.S. Army Material Systems Analysis Agency at Aberdeen Proving Ground in June 1974 (1)*. This study distinguished the effects of different levels of protection and inherent differences in costs between suppressive structures and concrete wall structures. Saving-to-investment ratios (S/I) are computed in this study upon foregoing walls and installing suppressive walls for the modernization of 105mm melt-pour complex at the Lone Star Army Ammunition Plant. Results of this study indicated that suppressive structures are economically more attractive than concrete barriers. Therefore, it is recommended that the technological

* Numbers in parenthesis refer to numbered references in the List of References.

development of suppressive structures should be continued and that value engineering of suppressive structures should be accomplished concurrent with testing of suppressive structures.

Value engineering is the systematic application of recognized techniques which identify the function of a product or service, establish a monetary value for that function, and provide the necessary function reliably at the lowest overall cost (2). The most opportune time to apply value engineering is during research and development so that any cost savings can be realized throughout the complete life cycle of the end product (3).

The basic objectives in applying value engineering during research and development are to reduce the high cost of development, the subsequent cost of production, and the consequent costs related to operation and maintenance (3). Since suppressive structures are still in the development stage, now is the best time for the application of value engineering.

Research work in this area has been conducted and the groundwork for value engineering in development of suppressive structures was reported (3). This research project, as part of the value engineering study for suppressive structures, has been introduced in reference 3 earlier. The objective of this research project and its role in value engineering of suppressive structure will be discussed in Chapter II.

CHAPTER II

A COST MODEL FOR SUPPRESSIVE STRUCTURES

The importance of value engineering in the development stage of suppressive structures has been mentioned. A cost model is developed to serve as an important base of the value engineering study for a suppressive structure. This cost model consists of functional requirement parameters, material parameters, geometric parameters, and economic parameters.

FUNCTIONAL REQUIREMENT PARAMETERS (3)

The functional requirement parameters in a cost model are generally specified values from an analysis of the entire suppressive structure conducted before the actual design stage. These parameters are generated from the four basic requirements; safety, prevention of mechanical failure, environment and logistic support.

The primary parameters which are associated with safety requirements are the safe distance and pressure from the explosive charge to the person, structures, and equipment outside the suppressive structure. Other parameters such as degree of fire, chemical effects, etc., from any hazards produced by an explosion will also be considered.

The plastic yield strength of structural members and penetration of fragments are the basic design parameters which relate to the fracture failure mode.

Temperature, humidity, noise, and degree of ventilation

are required environmental parameters.

Time between inspections, maintenance time (painting, joining), etc., are logistic support parameters.

These functional requirement parameters are primarily influenced by factors external to the structure, and, depending on which particular structure and its application, these parameters can possibly be dependent upon each other.

GEOMETRIC PARAMETERS (3)

Geometric parameters of the cost model include the following:

1. Geometric dimensions from selected configurations of steel angles, Z beams, W beams, tubes and panels which consist of single, stiffened, multibay and yawed shapes.

2. Geometric dimensions of frame, foundation and supporting structures such as doors, etc.

3. Spacing between panels, size and distribution of holes in panels, etc. The geometry of an element of suppressive structures can always be uniquely defined by specifying certain independent geometric parameters.

MATERIAL PARAMETERS (3)

Weight, density, yield strength, ultimate strength, elastic modulus, Poisson's ratio, toughness, unit cost, and temperature coefficient may be considered as the important material parameters. In conducting a design study, the selection of a material for a structural element will be, in general, based primarily on the material parameters which

are explicitly defined. These parameters are mostly dependent on each other and on chemical and physical structures in available materials.

ECONOMIC PARAMETERS (3)

The economic parameters for a suppressive shield include the following:

1. The cost of structural steel shapes at the fabrication shop. The base price of the shapes varies with prices charged by the mills according to the size, weight, shape, quantity of steel required, and the cost of transporting the steel to the shop.

2. The cost of preparing drawings for use by the shop in fabricating the steel. The total cost of the drawings is charged to the steel supplied for a job. The cost per unit weight of steel will vary with the total cost of drawings and the quantity of steel supplied.

3. The cost of handling and fabricating the steel shapes into finished members. It will vary considerably with the operation performed, the sizes and shapes of the members, and the extent to which the operations are duplicated on similar members. For welded connections, the fabricating operations may include cutting, some punching for temporary bolt connections, milling, beveling, and shop welding.

4. The cost of shop painting, if required. The approximate costs of applying a coat of paint to structural

steel for various types of members and structures and of the labor are included.

5. The cost of shop overhead, sales, and profits.

6. The cost of transporting structural steel. It will vary with the quantity of steel, the method of transporting, and the distance from the shop to the job site.

7. The cost of erection, including equipment, labor, bolts, rivets, or welding.

8. The cost of field painting the steel structure.

9. The cost of job overhead, general overhead, insurance, taxes, and applications.

THE COST EQUATION

The cost parameters described above are closely related to design variables and parameters of a suppressive shield. With these cost parameters, a cost equation (3) is given as below:

$$\text{Cost (\$)} = f \left[\begin{array}{cc} \left(\begin{array}{c} \text{Functional} \\ \text{requirement} \\ \text{parameters} \end{array} \right) & , & \left(\begin{array}{c} \text{Material} \\ \text{parameters} \end{array} \right) \\ \left(\begin{array}{c} \text{Geometric} \\ \text{parameters} \end{array} \right) & , & \left(\begin{array}{c} \text{Economic} \\ \text{parameters} \end{array} \right) \end{array} \right]$$

This equation is used as the design-aid and cost estimate model in this report. The design-aid portion of this model will include most parameters of the functional requirement parameters, the material parameters, and the geometric parameters while the cost estimate portion handles the economic parameters of the cost equation.

THE MODEL

The computerized model can be separated into two parts, i.e., the design-aid model and the cost estimate model. Figure 1 is a flow chart of the use of the model (3). According to a specific suppressive shielding application, some application requirements are established and a donor system can be prescribed. From this donor system, weight and speed of primary fragments (4,5,6), blast pressure loading (4,5,6), and venting requirements (4,5) are obtained. A suppressive shielding structure is designed and its structural elements are checked against their response to dynamic loading and functional design requirements. Detailed evaluations of the technical requirements are made and their effect on total performance is determined. Through design review some design alternatives are chosen, the evaluation of alternatives and cost effectiveness analysis are followed to produce a cost effective suppressive shield (3).

The objective of the design-aid model (a computer aided design of a suppressive structure) is to assist the designer of a suppressive structure by rapidly changing quantities of various design variables and parameters in order to achieve an economic design and to satisfy design requirements. Rather than manually calculating various design variables and parameters, existing design equations are programmed in a computer language and results are obtained.

The same approach is proposed for the cost estimation

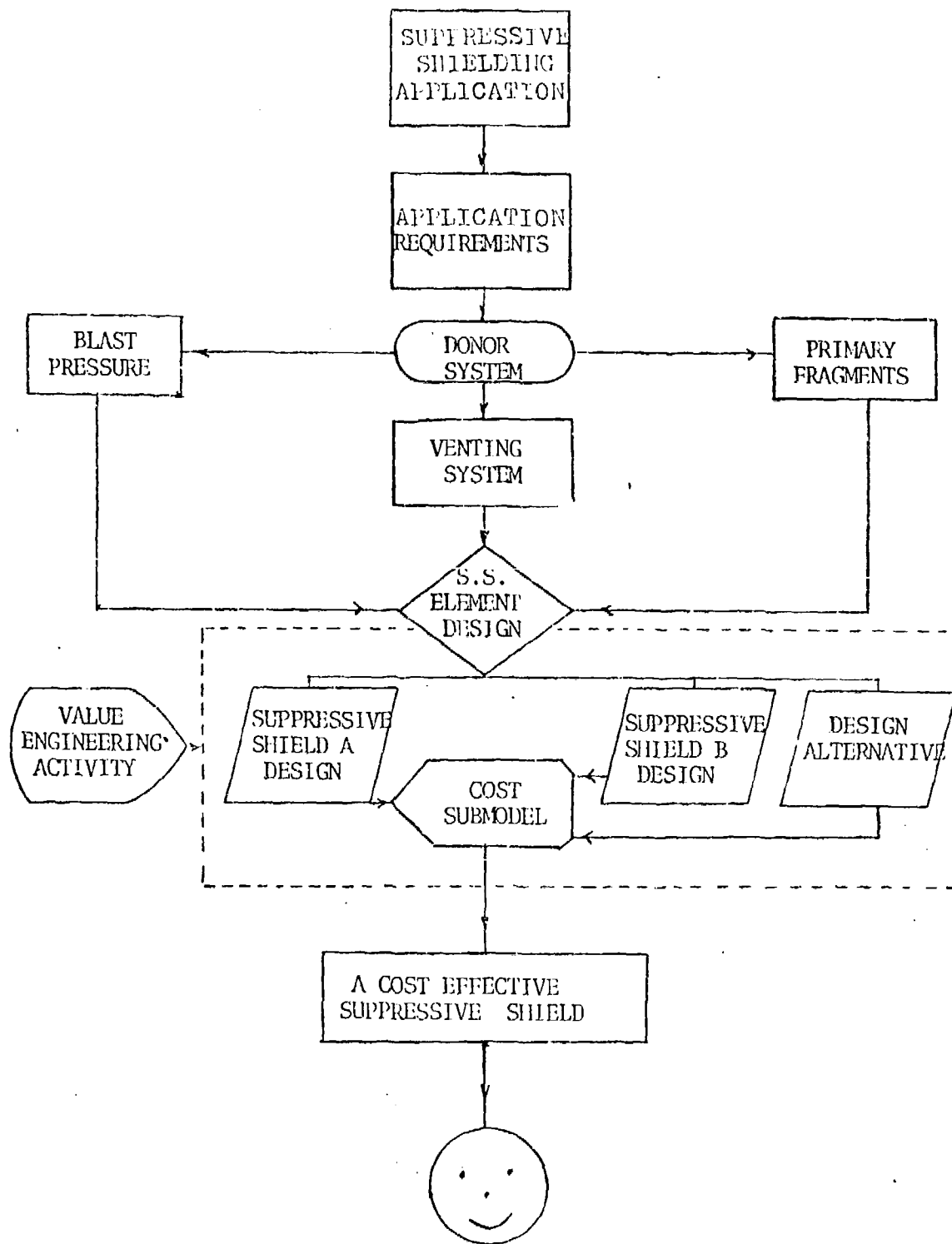


FIGURE 1 - A COST MODEL OF SUPPRESSIVE STRUCTURES

of suppressive structures. The conventional method of cost estimation is a mostly manual method. Such cost estimating processes are being used in estimating costs of various suppressive structures (7, 8, 9 & 10). This process (3) is:

1. According to the drawings (blue prints) of a suppressive structure, its major components, i.e., panel, door, frame, and foundation are formed. All structural elements of each substructure together with their materials, major characteristics and geometric dimensions are listed on a table. The primary measuring quantities associated with these elements are dimensions, volume, material density, and weight from which the material cost can be priced.

2. The manufacturing costs related to making structural elements are estimated from suggested manufacturing processes of each structural element by reliable sources and references (11, 12, 13, 14). The most important quantities in estimating manufacturing costs are processing time, and use of equipment. These costs are obtained from experienced personnel and some reliable references for each measuring quantity.

Making use of the similarities between suppressive structures, a programmed cost estimate model is developed based on the cost information obtained from the results of the conventional method. This cost estimate model is combined with the design-aid model to form the general value cost model for suppressive structures. This model

serves as an important tool for a value engineering study. Hopefully, through the use of this model, the designers of suppressive structures can save some of their valuable time for decision making rather than performing repeated manual calculation of cost and design quantities.

MODEL TESTING

The validity of a computer model must be tested before it can be used confidently. Testing can be done by comparing results computed by use of the model to existing data. The design-aid model and the cost estimate model were tested separately against design and cost estimate results of the Categories III and IV suppressive shields obtained from references 9, 16 and 17. A comparison of computer model results and analytic results are shown in table 1 for the design-aid model, and table 2 for the cost estimate model. Result of comparison shows that the model outputs are, in most cases, in excellent agreement with analytic data.

DESIGN-AID MODELCATEGORY III

<u>Variables</u>	<u>(Symbol)</u>	<u>Analytic</u>	<u>Computer Model</u>
1. Venting Coefficient	e	0.0263	0.02629
2. Thickness (Impulsive realm)	hd	0.404 in.	0.4349 in.
3. Thickness (Quasi-static realm)	hq	0.335 in.	0.3545 in.
4. Effective thickness/plate	hep	0.131 in.	0.1215 in.
5. Fragment Penetration	P	0.13 in.	0.10 in.
6. Plastic yield moment x Area	(M) x AB	3800.0 lb.-in. ³	3793.5 lb.-in. ³
7. Plastic bending moment x Area	(Mp) x AB	730.0 lb.-in. ³	830.9 lb.-in. ³

CATEGORY IV

1. Venting Coefficient	e	0.0263	0.0264
2. Thickness (Impulse)	hd	0.160 in.	0.1717 in.
3. Thickness (Quasi-static)	hq	0.178 in.	0.1874 in.
4. Effective thickness/plate	hep	0.055 in.	0.0528 in.
5. Plastic yield moment x Area	(M) x AB	79000.0 lb.-in. ³	87002.0 lb.-in. ³
6. Plastic bending moment x Area	(Mp) x AB	1200.0 lb.-in. ³	1024.0 lb.-in. ³

TABLE I. COMPARISON OF CALCULATIONS OF
CATEGORY III AND IV DESIGNS

COST MODELCATEGORY IV

<u>ELEMENT</u>	<u>PARAMETERS</u>	<u>ESTIMATED VALUES (\$)</u>	<u>COMPUTER MODEL VALUES (\$)</u>
Panel	Material	14508	14577
	Welding	22540	16908
	Fabrication	7714	5685
Door	Material	1340	1350
	Welding	1293	1566
	Fabrication	291	526
Frame	Material	6381	6501
	Welding	2034	7541
	Fabrication	1578	2535
Foundation	Material	314	343
	Fabrication	100	33
Whole Structure	Material	22554	22772
	Welding	25867	26018
	Fabrication	9684	8881
	GRAND TOTAL	58106	57672

TABLE II. COMPARISON OF COST ESTIMATING FOR
CATEGORY IV SUPPRESSIVE STRUCTURE

CHAPTER III

MODEL DESCRIPTION

The computer model is formed by a main program and ten subroutines written in FORTRAN IV computer language (see Appendix A). The main program contains the input and the output portions of the model. It coordinates the proper sequence of calculations by calling the appropriate subroutines. The proper sequence of calculations the program will execute depends on the options specified. The three options in the model are described below. Necessary inputs of each option and their formats are discussed in Chapter IV.

OPTIONS

A. OPTION #1

This option will print a list of W beams, angle bars, and steel pipes, designated by beam type numbers 1, 2, and 3 (see figures 3, 4 and 5). These beams are tested in the model so that all the beams on the list are strong enough to withstand input pressure loading. These beams that are listed are standard size beams selected from reference 15. The advantages of using standard size beams in steel construction are that they are readily available and are more economical than non-standard size beams. With the list provided by this option, the designer can choose the beam(s) after reviewing the economical and technical aspects of its usage in a suppressive structure.

The computer procedures for option number 1 are summarized as follows:

1. A deck of data cards containing dimensions for standard sized beams are inputted and stored.
2. Required inputs are read.
3. Plastic yield moment and plastic bending moment of each beam are calculated and compared (see description of subroutine BMDSN on page
4. The beams whose plastic yield moment is greater than or equal to its plastic bending moment are listed.

B. OPTION #2

This option is used when direct cost estimation of a cubical suppressive structure is desired. Required inputs are the overall dimensions of the structure to be estimated, type of panel configuration of the structure, and cost parameters associated with each type of panel configuration. Cost quantities that will be calculated are listed below:

1. Material cost, fabrication cost, and welding cost for each component, i.e. frame, panel, door, and foundation.
2. Total material cost, total welding cost, and total fabrication cost.
3. Total frame cost, total panel cost, total door cost, total foundation cost, and total cost.

These cost quantities are calculated by the cost estimate model to be described later in this chapter.

C. OPTION #3

This option includes both suppressive shielding panel design and cost estimation. The design-aid model is first used to calculate design parameters such as venting coefficient (effective venting area ratio), plastic yield moment and plastic bending moment of beams, effective thickness of perforated plates required for both the quasi-static pressure and the impulsive pressure, and length of fragment penetration. These values are then used as inputs to the cost estimation model for cost estimation of the same cost quantities described in option #2.

Steps and calculation executed in this option are as follows:

1. Read the required input quantities.
2. Calculate venting coefficient required (call subroutine VENT).
3. Calculate and compare plastic yield moment and plastic bending moment of beams (call subroutine BMDSN).
4. Calculate effective thickness of perforated plates required and number of holes required for proper pressure venting (call subroutine PLDSN).
5. Calculate length of fragment penetration in steel (call subroutine FRGPN).
6. Set total thickness of perforated plates to the larger of effective thickness of perforated plates from step 4 and length of fragment penetration calculated in

step 5.

7. Calculate thickness of each perforated plate.

8. Estimate cost of structure using quantities from steps 1, 2, 3 and 7 (call subroutine COSTM).

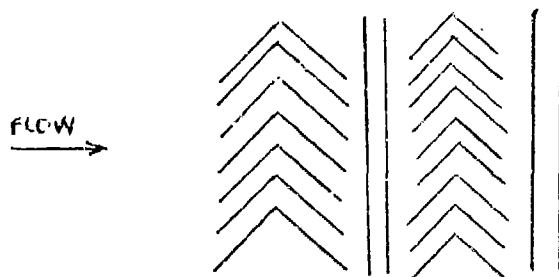
Four types of panel configurations are programmed for use in options #2 and #3 (see figure 2). They are made of combinations of fragment stopping and pressure venting elements such as angle bars, W beams, pipes, and perforated plates.

Subroutines in the model are constructed for calculations of design and cost variables. They can be divided into two groups: The design-aid subroutines and the cost estimate subroutines. The design-aid subroutines are coordinated by the main program to form the design-aid model. The cost estimate subroutines themselves constitutes the cost estimate model.

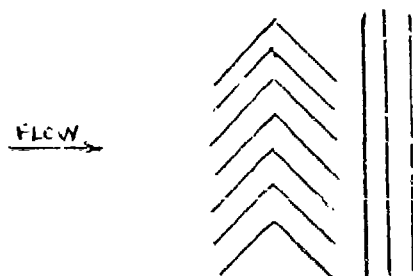
The design-aid subroutines include: BMDSN (beam design), PLDSN (plate design), VENT (venting), FRGPN (fragment penetration), and RTPOL (root of polynomials). Except for the subroutine RTPOL which is adopted from the scientific subroutine package of the IEM 1130 computer, all the other design-aid subroutines are developed from design equations obtained primarily from reference 4 and 20.

The cost estimate subroutines are: COSTM (cost model), FRAME (frame costs), PANEL (panel costs), DOOR (door costs), and FNDTH (foundation costs). These subroutines are based

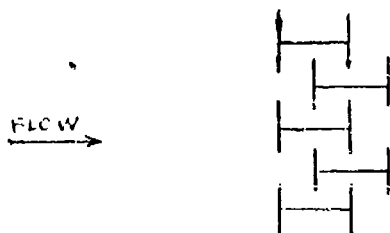
Panel Configuration #1 - Angles, Plate, Plate, Angles, Plate, Plate.



Panel Configuration #2 - Angles, Plate, Plate, Plate



Panel Configuration #3 - W Beams, W Beams



Panel Configuration #4 - Pipes, Pipes

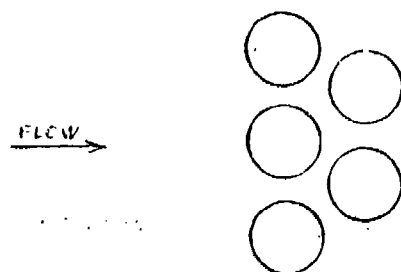


FIGURE 2 - PANEL CONFIGURATIONS

on estimates obtained from reference 6.

THE DESIGN-AID SUBROUTINES

A. SUBROUTINE BMDSN

This subroutine calculates, compares, and returns the plastic yield moment and the plastic bending moment of beams or bars of a suppressive panel. An error code of 0 will be returned if plastic yield moment of the beam is larger or equal to the plastic bending moment of the beam. Otherwise an error code of 1 will be returned. Equations for calculating plastic bending moment (M_p) and plastic yield moment (M_{py}) are given as follows * (4):

$$M_p = \frac{i_r^2 b^2 L^2 S_f}{16N A_B W_o \rho} \quad (1)$$

$$M_{py} = 1.05 \times 41600.0 \times \frac{I_B}{C_B} \quad (2)$$

Three types of beams are considered in this subroutine. Their dimensions and the formula (21) for their moment of inertia (I_B), cross-sectional area (A_B), and section modulus (C_B) are shown in figures 3, 4 and 5. The correct formula

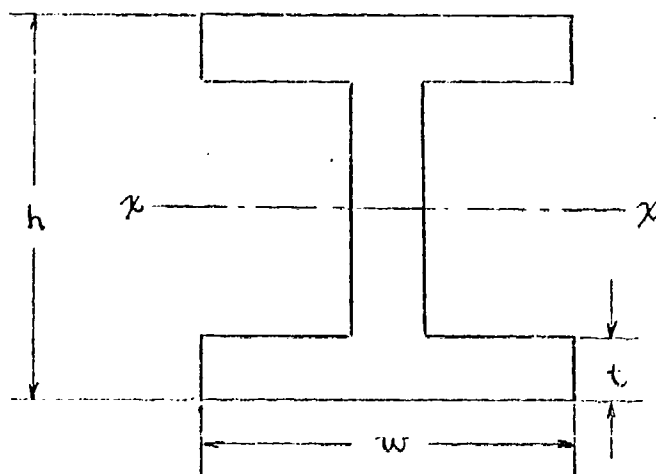
* All symbols used in equations in this chapter and their corresponding variable name used in the model are listed and explained in table 3.

<u>SYMBOL</u>	<u>EXPLANATION</u>	<u>MODEL NAME</u>	<u>DIMENSION</u>
A_B	Cross-section area of beams	AREA	in ²
b	Stacking distance between beams	B	in
C_B	Section modulus of beams	C	in
e	Total venting coefficient	VCOEF	
e_p	Venting coefficient per plate	VCPPL	
h_d	Thickness for impulsive loading		in
h_{min}	Minimum thickness of plates	HMAX	in
h_{ep}	Effective thickness for plates	HEFF	in
i_r	Impulsive pressure	AI	psi-sec
I_B	Moment of inertia of beams	MINTA	in ⁴
L	Length of beam	BEAML, L	in
M_f	Weight of primary fragment	WPPAG	lb.
M_r	Weight of residual fragment	WRPAG	lb.
M_p	Plastic bending moment of beams	MOMTP	in-lb.
M_{py}	Plastic yield moment of beams	MOMNT	in-lb.
N	Support coefficient	SCOEF	
n	Number of plates per panel	NOP	
N_{hole}	Number of holes on plates	NHOLE	
P	Penetration of fragments	PENTH	in
P_q	Quasi-static pressure	PQ	psi
P_s	Side on safety pressure	PSON	psi
ρ	Mass density of steel	DNSTYM	lb.-sec ² /in ⁴

TABLE III. SYMBOLS FOR EQUATIONS

<u>SYMBOL</u>	<u>EXPLANATION</u>	<u>MODEL NAME</u>	<u>DIMENSION</u>
R	Safety distance to personnel	R	Ft.
S_f	Safety factor	SF	
V_f	Velocity of primary fragment	VPFAG	ft/sec
V_r	Residual velocity of fragment	VRFAG	ft/sec
W_o	Center deflection of beam	WC	in
W_c	Weight of charge	WGTC	lb.
X	Length of suppressive shield	LS	ft.
Y	Height of suppressive shield	HSS	ft.
σ_y	Yield strength of steel	YS	psi

TABLE III. SYMBOLS FOR EQUATIONS (CONTINUED)

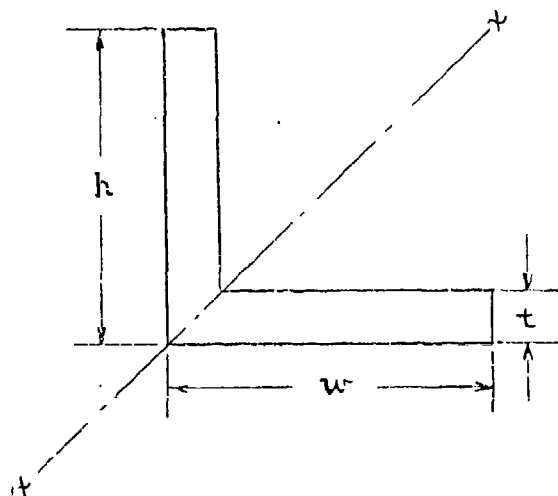


$$A_B = wh - (h - 2t)(w - t)$$

$$I_B = I_{xx} = 2 \left[\frac{wt^3}{12} + (wt) \left(\frac{h-t}{2} \right)^2 + \frac{t \left(\frac{h-2t}{2} \right)^3}{12} \right]$$

$$C_B = \frac{h}{2}$$

FIGURE 3 - TYPE I BEAM - I BEAM



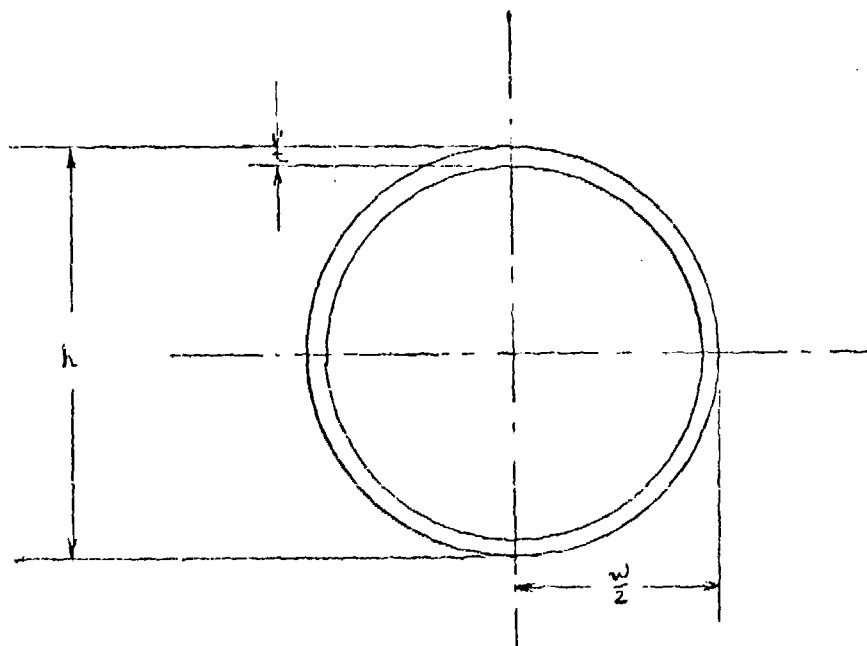
$$A_B = hw - (w-t)(h-t)$$

$$I_B = I_{xx}$$

$$= (0.70711)^2 \frac{2}{3} (h^3 t + wt^3) - \frac{w^2 h^2 t}{4 (h+w)}$$

$$C_B = \frac{w}{1.414}$$

FIGURE 4 - TYPE II BEAM - ANGLE BAR



$$A_B = \frac{3.1416}{2} h^2 - (h-2t)^2$$

$$I_B = \frac{3.1416}{64} h^4 - (h-2t)^4$$

$$C_B = \frac{h}{2}$$

FIGURE 5 - TYPE III BEAM - PIPE

for l_B , A_B , and C_B will be used when type of beam is specified.

The symbol b , in equation 1 stands for the stacking distance between two panel beams (see figures 6, 7, and 8). It is related to the venting area ratio (e_p) and the demension of the beam. Formulas are found for all three types of beams (5,19).

1. Type I - I beams (figure 6)

$$b = a + 1. \quad (3)$$

$$C_p = \frac{a}{2b}. \quad (4)$$

Substituting equation 4 into 3

$$b = 2 e_p b + 1. \quad (5)$$

Solving for b

$$b = \frac{1}{1-2e_p}. \quad (6)$$

2. Type II - Angle bars (figure 7)

$$b = 1.414 (t + a). \quad (7)$$

$$e_p = \frac{a}{b}. \quad (8)$$

Combining equations 7 and 8

$$b = 1.414 t + 1.414 e_p b. \quad (9)$$

Solving for b

$$b = \frac{1.414 t}{1 - 1.414 e_p}. \quad (10)$$

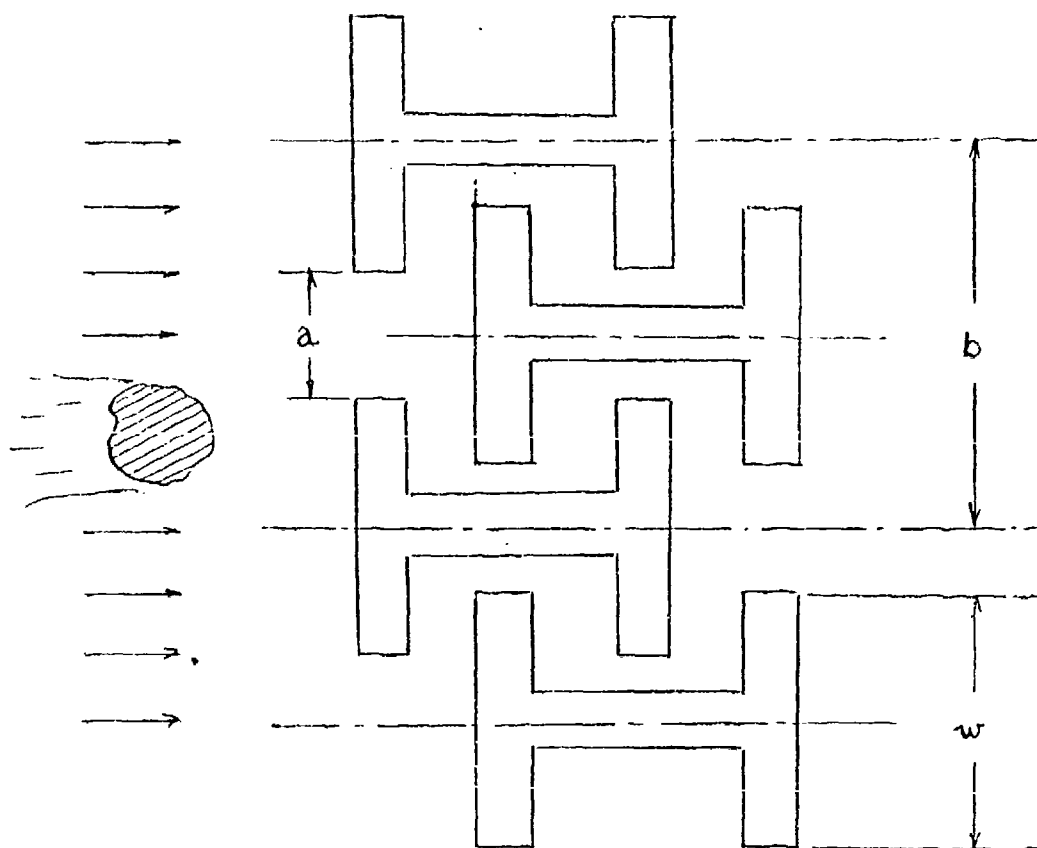


FIGURE 6 - TYPE I PANEL BEAMS

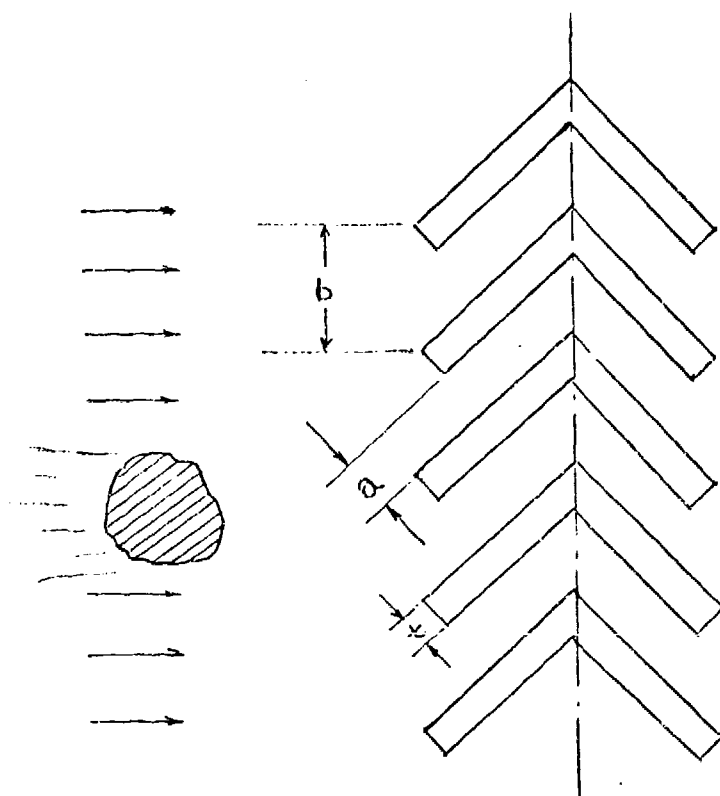


FIGURE 7 - TYPE II PANEL BEAMS

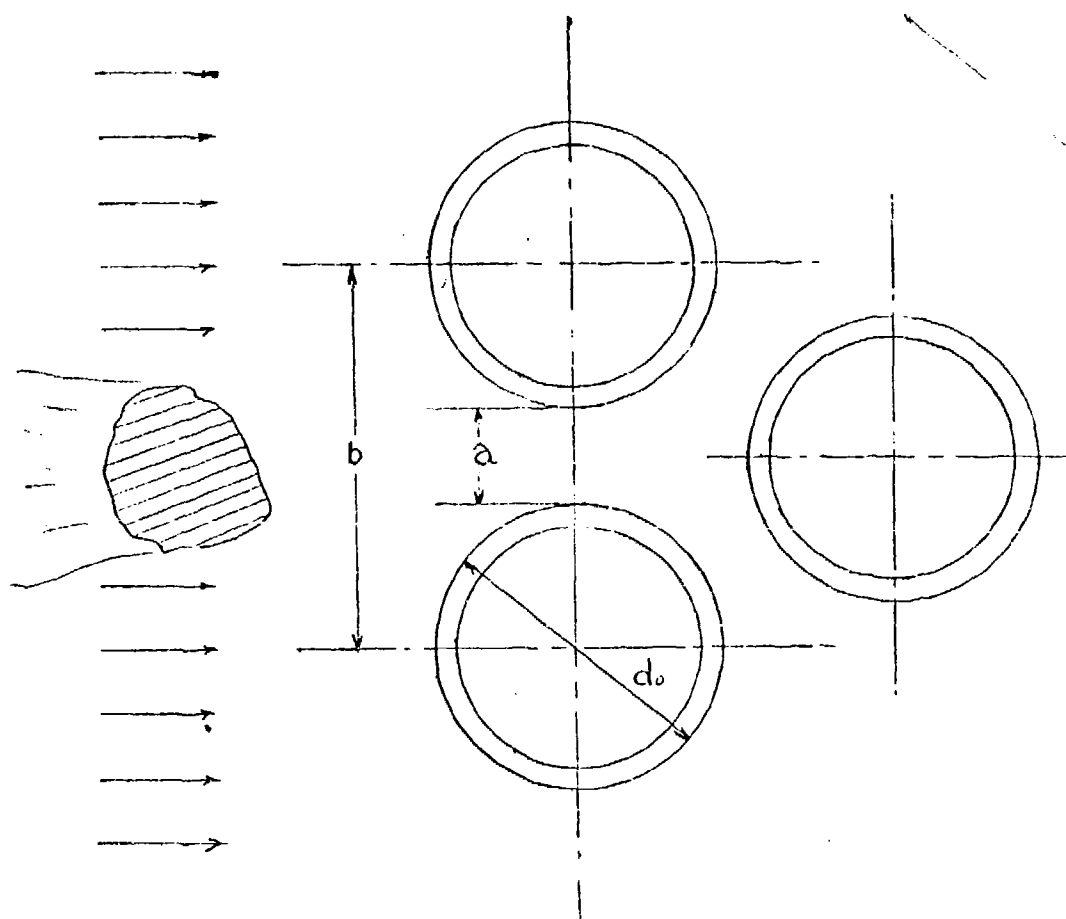


FIGURE 8 - TYPE II PANEL BEAMS

3. Type III- Pipes (figure 8)

$$e_p = \frac{a}{b}. \quad (11)$$

$$b = d_o + a. \quad (12)$$

Combining equations 11 and 12:

$$b = d_o + b e_p \quad (13)$$

$$b = \frac{d_o}{1 - e_p}. \quad (14)$$

B. SUBROUTINE PLDSN

Minimum effective thickness of perforated plates required to withstand blast pressure loading and number of holes necessary for pressure venting requirement are the output variables.

Minimum effective thickness (h_{ep}) is obtained by first calculating thickness for both impulsive pressure loading (h_d) and thickness for quasi-static loading (h_q). A relationship for h_d is given as below (20):

$$\left(\frac{i_r X}{\sqrt{\sigma_y} h_d} \right)^2 = \frac{\pi^{N-1}}{2N} \left[1 + \left(\frac{X}{Y} \right)^2 \right] \left(\frac{W_o}{h_d} \right) + \frac{2}{\sqrt{3}} \left(\frac{X}{Y} \right) \left(\frac{W_o}{h_d} \right) + \frac{3^{N-1} \pi^2}{16N^2} \left[1 + \left(\frac{X}{Y} \right)^2 \right] \left(\frac{W_o}{h_d} \right)^2 + \frac{2N}{\sqrt{3}} \left(\frac{X}{Y} \right) \left(\frac{W_o}{h_d} \right)^2. \quad (15)$$

Equation 15 can be simplified to:

$$A h_d^3 + B h_d^2 - C = 0 \quad (16)$$

$$\text{Where } A = \left\{ \frac{\pi^{N-1}}{2N} \left[1 + \left(\frac{X}{Y} \right)^2 \right] + \frac{2}{\sqrt{3}} \left(\frac{X}{Y} \right) \right\} W_o \rho \sigma_y,$$

$$B = \left\{ \frac{3^{N-1} \pi^2}{16 N^2} \left[1 + \left(\frac{X}{Y} \right)^2 \right] + \frac{2N}{\sqrt{3}} \left(\frac{X}{Y} \right) \right\} W_o^2 \rho \sigma_y,$$

$$C = i_r^2 X^2.$$

Roots of equation 16 are found by using subroutine RTPOL. Thickness for impulsive loading (h_q) is set equal to the largest positive root calculated by RTPOL.

As for h_q , it can be found from the following equation (20):

$$\begin{aligned} \frac{P_q}{\sigma_y} \left(\frac{X}{h_q} \right)^2 = & \frac{\pi^{2/N}}{2^{4/N^2}} \left[1 + \left(\frac{X}{Y} \right)^2 \right] + \frac{4^{2N-3}}{\sqrt{3} \pi^{2(N-2)}} \left(\frac{X}{Y} \right) \\ & + \frac{3^{N-1} 4^{N-2} \pi^{2(3-N)}}{32} \left[1 + \left(\frac{X}{Y} \right)^2 \right] \left(\frac{W_o}{h_q} \right) \\ & + \frac{2^{N-1} 4^{2N-3}}{\sqrt{3} \pi^{2(N-2)}} \left(\frac{X}{Y} \right) \left(\frac{W_o}{h_q} \right). \end{aligned} \quad (17)$$

Solving for h_q , equation 17 becomes:

$$D h_q^2 + E h_q + F = 0 \quad (18)$$

Where

$$D = \left\{ \frac{\pi^{2/N}}{2^{4/N^2}} \left[1 + \left(\frac{X}{Y} \right)^2 \right] + \frac{4^{2N-3}}{\sqrt{3} \pi^{2(N-2)}} \left(\frac{X}{Y} \right) \right\},$$

$$E = \left\{ \frac{3^{N-1} 4^{N-2} \pi^{2(3-N)}}{32} \left[1 + \left(\frac{X}{Y} \right)^2 \right] + \frac{2^{N-1} 4^{2N-3}}{\sqrt{3} \pi^{2(N-2)}} \left(\frac{X}{Y} \right) \right\} W_o,$$

$$F = - \frac{P_q X^2}{\sigma_y}.$$

The roots of quadratic equation 18 are:

$$h_q \text{ 1,2} = \frac{-E \pm \sqrt{E^2 - 4DF}}{2D} \quad (19)$$

We want h_q to be the largest positive root. Therefore:

$$h_q = \frac{-E + \sqrt{E^2 - 4DF}}{2D} \quad (20)$$

After both h_d and h_q are calculated using equations 16 and 20, minimum total thickness of panel plates ($h_{\min}$) is then set equal to the larger of h_d and h_q .

$$h_{\min} = \max [h_d, h_q] \quad (21)$$

To compensate for the effect of venting space on perforated plates, h_{ep} (minimum effective thickness of each perforated plates) is found by (5):

$$h_{ep} = \frac{h_{\min}}{n(1 - e_p)} \quad (22)$$

Number of holes required for each perforated plate is calculated by dividing venting area by area of holes:

$$N_{\text{hole}} = \frac{A_p e_p}{A_{\text{hole}}} \quad (23)$$

C. SUBROUTINE VENT

The venting coefficient (e) is calculated and returned in this subroutine. "e" is the total venting coefficient for all perforated plates or beams. For venting coefficient of each individual plate, the following formula is used (5):

$$\frac{1}{e} = \frac{1}{e_p} + \frac{1}{e_p} + \frac{1}{e_p} + \dots \quad (24)$$

And for n plates

$$\frac{1}{e} = \frac{n}{e_p} \quad (25)$$

And therefore:

$$e_p = ne. \quad (26)$$

Relationship for "e" is given by (4):

$$P_s = 976.3 \frac{W_c^{2/3} e^{1/2}}{R^{3/2} X^{1/2}} \quad (27)$$

Solving for "e", equation 27 yields:

$$e = \left(\frac{P_s R^{3/2} X^{1/2}}{976.3 W_c^{2/3}} \right)^2 \quad (28)$$

The following constraints are imposed on equations (27) and (28):

$$0.0263 \leq e \leq 0.60. \quad (29a)$$

$$0.323 \leq \frac{X}{R} \leq 1.77. \quad (29b)$$

$$4.27 \leq \frac{R}{W_c^{1/3}} \leq 17.5. \quad (29c)$$

These limits are checked in the subroutine and if they are exceeded, corresponding error messages will be returned. For design purposes, "e" is set equal to 0.0263 if its value is less than 0.0263 and is set equal to 0.6 if its value is greater than 0.6.

D. SUBROUTINE FRGPN

With weight and velocity of primary fragments as input variables, depth of fragment penetration in steel is calculated. It is the thickness of steel that would be necessary

to stop penetration of primary fragments. The equation used in its calculation is (5):

$$P = 0.112 M_f^{1/3} \cdot \frac{V_f^{4/3}}{1000} \quad (30)$$

This subroutine is also programmed to return residual velocity (V_r) and residual weight of fragment (M_r) if the thickness of steel target is specified. The value of the residual fragment velocity will be negative if the target thickness is thicker than required. Formula for these two quantities are given as (5):

$$\log_{10} (M_f - M_r) = a_0 + \sum_{i=1}^4 a_i \log_{10} X_i \quad (31)$$

$$\log_{10} (V_f - V_r) = b_0 + \sum_{j=1}^4 b_j \log_{10} X_j \quad (32)$$

Where' X_1 = Thickness of steel target.

X_2 = Weight of primary fragment.

X_3 = Secant of angle between direction of fragment and normal of the target.

X_4 = Velocity of primary fragment.

And $a_0 = -2.2776$; $b_0 = 3.9064$;

$a_1 = 0.2885$; $b_1 = 0.9496$;

$a_2 = 0.9145$; $b_2 = -0.3603$;

$a_3 = 0.1958$; $b_3 = 1.2842$;

$a_4 = 0.6394$; $b_4 = 0.1929$.

Upon solving for M_r and V_r , equations 31 and 32 become;

$$M_r = M_f - 10 \left(a_0 + \sum_{i=1}^4 a_i \log_{10} X_i \right) \quad (33)$$

$$V_r = V_f - 10 \left(b_0 + \sum_{j=1}^4 b_j \log_{10} X_j \right) \quad (34)$$

COST ESTIMATE SUBROUTINES

A. SUBROUTINE COSTM

This subroutine and the other cost subroutines constitutes the cost estimate model. It calls the other four cost subroutines (FRAME, DOOR, PANEL, and FNDTN) for material cost, welding cost, and fabrication cost of each of the four components of a cubical suppressive shield. With these cost quantities, it computes values for total welding cost, total material cost, total fabrication cost, total cost of door, total cost of frame, total cost of panels, total cost of foundation, and total cost of structure (grand total).

The cost estimate model is developed for cubical suppressive structures. Category IV suppressive shields represent a typical type of cubical suppressive structure with well defined features. Therefore, it is used as a base for the construction of the cost estimate model.

A few assumptions are made upon the construction of the cost estimate model:

1. All structures have the same basic structural components as the Category IV suppressive shield.
2. All dimensions of structural components varies

linearly with the overall dimensions of the suppressive structures.

3. Fabrication cost and welding cost of structure are linearly related to the material cost of structure.

According to a cost estimate of a Category IV suppressive shield (9), 26¢ is a reasonable figure for average cost per lb. of steel of structure which includes such cost items as base price at mill, extras and delivery to shop, drafting, shop coat paint, trucking to job site, erect and plumb, crane and minor erection equipment, and a field coat paint. This figure does not include welding cost and fabrication cost of the structure. Welding cost includes cost of weld, welding equipment, and labor cost for welding. Fabrication cost is the cost of equipment and labor for cutting, grinding, and smoothing of structural members into proper shapes and sizes. The cost estimate (9) showed that the average welding cost and the average fabrication cost (per pound of steel) are 31¢ and 11¢ respectively.

In the cost estimate subroutines, the weight of each component of the suppressive structure will first be computed. Then the material cost of each component are determined by:

$$\text{Material cost} = \text{Weight of structure} \times \text{Unit cost of steel} \quad (35)$$

where

Unit cost of steel = \$0.26 per pound.

From material cost, fabrication cost and welding cost of each component can be calculated:

$$\text{Fabrication cost} = \text{Material cost} \times \text{Fabrication cost factor} \quad (36)$$

$$\text{Welding cost} = \text{Material cost} \times \text{Welding cost factor} \quad (37)$$

where

$$\text{Fabrication cost factor} = \frac{\$.11}{\$.26} = 0.39, \quad (38)$$

and

$$\text{Welding cost factor} = \frac{\$.31}{\$.26} = 1.16. \quad (39)$$

To compensate for the effects of inflation and other economic factors that may affect the cost of the structure, values for unit cost of steel, fabrication cost factor, and welding cost factor can be changed easily.

B. SUBROUTINE FRAME

This subroutine computes and returns the material cost, the fabrication cost, and the welding cost of the frame of a cubical suppressive shield.

The frame of a cubical suppressive shield consists mainly of W beams, angle bars, and plates. Total weight of W beams constitutes approximately 49% of the total weight of frame (9). Therefore, if we can estimate the weight of W beams, then:

$$\begin{aligned} \text{Total weight of frame (lb)} &= \text{total weight of W beams} \\ &\times \frac{100}{49} \end{aligned} \quad (40)$$

Total weight of W beams is directly related to total volume of W beams:

$$\begin{aligned} \text{Total weight of W beams} &= \text{Total volume of W beams} \\ &\times \text{density of steel} \end{aligned} \quad (41)$$

where

$$\text{Density of steel} = 490 \text{ lb/cu. ft.} \quad (42)$$

Volume of W beam is calculated from length of W beam and its cross sectional area:

$$\text{Volume of W beam} = \text{Length of W beam} \times \text{cross section area.} \quad (43)$$

Fourteen vertically situated W beams account for 65.7% of total length of all W beams needed (9). Therefore, total length of W beams can be calculated by:

$$\text{Total length of W beam} = 14 \times \frac{100}{65.7} \times \text{Height of frame.}$$

By combining equations 41, 43, and 44, we have the equation for the total weight of frame.

$$\begin{aligned} \text{Total weight of frame} &= 21.7 \times \text{Height of frame} \\ &\quad \times \text{Cross sectional area} \\ &\quad \times \text{Density of steel} \\ &\quad \times \frac{100}{49} \quad (45) \end{aligned}$$

At this point, equations 35, 36, and 37 are used to calculate material cost, welding cost and fabrication cost of the frame.

C. SUBROUTINE PANEL

This subroutine is programmed to return material cost, fabrication cost, and welding cost of all the panels of a suppressive structure. Four types of panel configurations are also programmed to be consistent with the design-aid model (see figure 2).

Total weight of a panel is contributed by the following

groups of structural elements:

1. Fragment stopping and pressure venting elements - W beams, angles, steel pipes, and perforated plates.
2. Channels.
3. Miscellaneous items - bars and plates.

The kind of fragment stopping and pressure venting elements used in a panel is determined by the panel configuration chosen. Two channels are used for the frame of a panel. Miscellaneous items such as lifting eyes and reinforcement bars are needed to complete the panel.

Miscellaneous items contribute very little to the total weight of a panel. It only amounts to about 13% of the total weight of panel (9). For an estimate of its weight, we will consider it as a percentage of the weight of channel:

$$\begin{array}{rcl} \text{Weight of miscellaneous items} & & \\ + & & \\ \text{Weight of channel} & = 2.8 \times \text{Weight channel} & (46). \end{array}$$

Thus, total weight of channel can be estimated by:

$$\begin{array}{l} \text{Total weight per panel} = 2.8 \times \text{weight of channel} \\ + \text{weight of fragment stopping and} \\ \text{pressure venting elements (47).} \end{array}$$

Weight of channel is computed as follows:

$$\begin{array}{l} \text{Weight of channels} = \text{Number of channels} \\ \quad \times \text{Length of each channel} \\ \quad \times \text{Cross sectional area of channel} \\ \quad \times \text{Density of steel.} \end{array} \quad (48)$$

A reasonable estimate of cross sectional area of channel is by its width:

Cross sectional area = $0.58 \times \text{Width of channel}$. (49)

Therefore, equation 48 becomes:

$$\begin{aligned} \text{Weight of channel} = & \text{Number of channels} \\ & \times \text{Length of channel} \times 0.58 \\ & \times \text{Width of channel} \\ & \times \text{Density of steel} \end{aligned} \quad (50)$$

where

Length of channel = Height of panel.

Width of channel = Thickness of panel.

Number of channels = 2 .

Weight of fragment stopping and pressure venting element (W_{fp}) varies with the type of panel configuration specified:

1. Panel configuration #1:

W_{fp} is equal to the sum of weight of angles 1, weight of angles 2, and weight of perforated plates.

$$\begin{aligned} W_{fp} = & \text{Weight of angles 1} + \text{Weight of angles 2} \\ & + \text{Weight of perforated plates} . \end{aligned} \quad (51)$$

where

$$\begin{aligned} \text{Weight of angles 1} = & \text{Number of angles 1} \times \text{Cross section-} \\ & \text{al area 1} \times \text{Panel length} \times \text{Density} \\ & \text{of steel} . \end{aligned} \quad (52)$$

$$\begin{aligned} \text{Weight of angles 2} = & \text{Number of angles 2} \times \text{Cross section-} \\ & \text{al area 2} \times \text{Panel length} \times \text{Density} \\ & \text{of steel} . \end{aligned} \quad (53)$$

$$\begin{aligned}
 \text{Weight of perforated plates} &= \text{Number of perforated plates} \\
 &\quad \times \text{Thickness of each plate} \\
 &\quad \times \text{Panel height} \\
 &\quad \times \text{Panel length} \\
 &\quad \times \text{Density of steel} . \quad (54)
 \end{aligned}$$

2. Panel configuration #2:

In this configuration, W_{fp} equals to the weight of angles plus the weight of perforated plates.

$$W_{fp} = \text{Weight of angles} + \text{Weight of P. plates} \quad (55)$$

where

$$\begin{aligned}
 \text{Weight of angles} &= \text{Number of angles} \\
 &\quad \times \text{Cross sectional area} \\
 &\quad \times \text{Panel length} \\
 &\quad \times \text{Density of steel} , \quad (56)
 \end{aligned}$$

$$\text{Number of angles} = \text{Panel height}/b. \quad (57)$$

Number of perforated plates is computed using equation 54.

3. Panel configuration #3:

Only W beams are used in this configuration. Therefore, W_{fp} is equal to the weight of W beams.

$$\begin{aligned}
 W_{fp} &= \text{Weight of W beams} \\
 &= \text{Number of W beams} \times \text{Panel length} \\
 &\quad \times \text{Cross sectional area of W beam} \\
 &\quad \times \text{Density of steel} \quad (58)
 \end{aligned}$$

where

$$\text{Number of W beams} = 2 (\text{panel height}/b) - 1 . \quad (59)$$

4. Panel configuration #4:

Two rows of steel pipes of the same size are used for stopping fragments and venting pressure. W_{fp} for this configuration can be calculated as follows:

$$\begin{aligned}
 W_{fp} &= \text{Weight of pipes} \\
 &= \text{Number of pipes} \times \text{Panel length} \\
 &\quad \times \text{Cross sectional area of pipe} \\
 &\quad \times \text{Density of steel} \quad (60).
 \end{aligned}$$

where

$$\text{Number of pipes} = 2 (\text{panel height}/b) - 1. \quad (61).$$

Now, total weight of the panel can be computed by using equations 47, 50, and the equations of W_{fp} for all four types of panel configurations. Welding and fabrication cost of panel can be found by using equations 35, 36, and 37.

D. SUBROUTINE DOOR

This subroutine calculates the material cost, welding cost and fabrication cost of a suppressive door. The structure of a suppressive door is basically the same as a panel. It has the same basic elements: fragment stopping and pressure venting elements, channels, and miscellaneous items. Due to these similarities, equations derived for panel costs are applicable for door costs also. All equations for W_{fp} (equations 51 to 61) will be the same with panel length and panel height changed to door length and door height. Extra channels are needed for the door edges. Therefore, the equation for weight of channel becomes:

$$\begin{aligned}
 \text{Weight of channel} &= 2 (\text{door height and door length}) \\
 &\quad \times 0.58 \\
 &\quad \times \text{Door thickness} \\
 &\quad \times \text{Density of steel} . \quad (62)
 \end{aligned}$$

Special items such as trolleys and trolley tracks, changes equation 46 to:

$$\begin{aligned}
 &\text{Weight of miscellaneous items} \\
 &\quad + \quad = 2.04 \times \text{Weight of channel} \\
 &\text{Weight of channel} \quad (63).
 \end{aligned}$$

Thus

$$\text{Total weight of door} = 2.04 \times \text{Weight of channel} + W_{fp} . \quad (64)$$

Material cost, welding cost, and fabrication cost of door are then computed using equation 35, 36, and 37.

E. SUBROUTINE FNDTN

This subroutine is used to estimate material cost, welding cost, and fabrication cost of the foundation of a cubical suppressive shield. Material cost includes cost of concrete and miscellaneous items. Cost of concrete can be calculated from the total volume of concrete used:

$$\text{Cost of concrete} = \text{Volume of concrete} \times \text{Unit cost of concrete} . \quad (65)$$

where

$$\text{Unit cost of concrete} = \$28.71 \text{ per cu. yd. of concrete} .$$

Volume of concrete needed is computed by given length of foundation (l_f), width of foundation (w_f), and height of foundation (h_f). Figure 9 represents the concrete portion of the foundation and therefore:

$$\begin{aligned} \text{Volume of concrete} &= (l_f w_f h_f) - (l_f - 2t_f) \\ &\quad \times (w_f - 2t_f) \times (h_f - t_f) . \quad (66) \end{aligned}$$

Cost of miscellaneous items approximately equals to 33% of cost of concrete (9). Therefore:

$$\text{Total material cost of foundation} = 1.33 \times \text{Cost of concrete (67)}.$$

Welding cost is equal to zero since no welding is necessary. Fabrication cost of foundation is obtained by using equations 67 and 36.

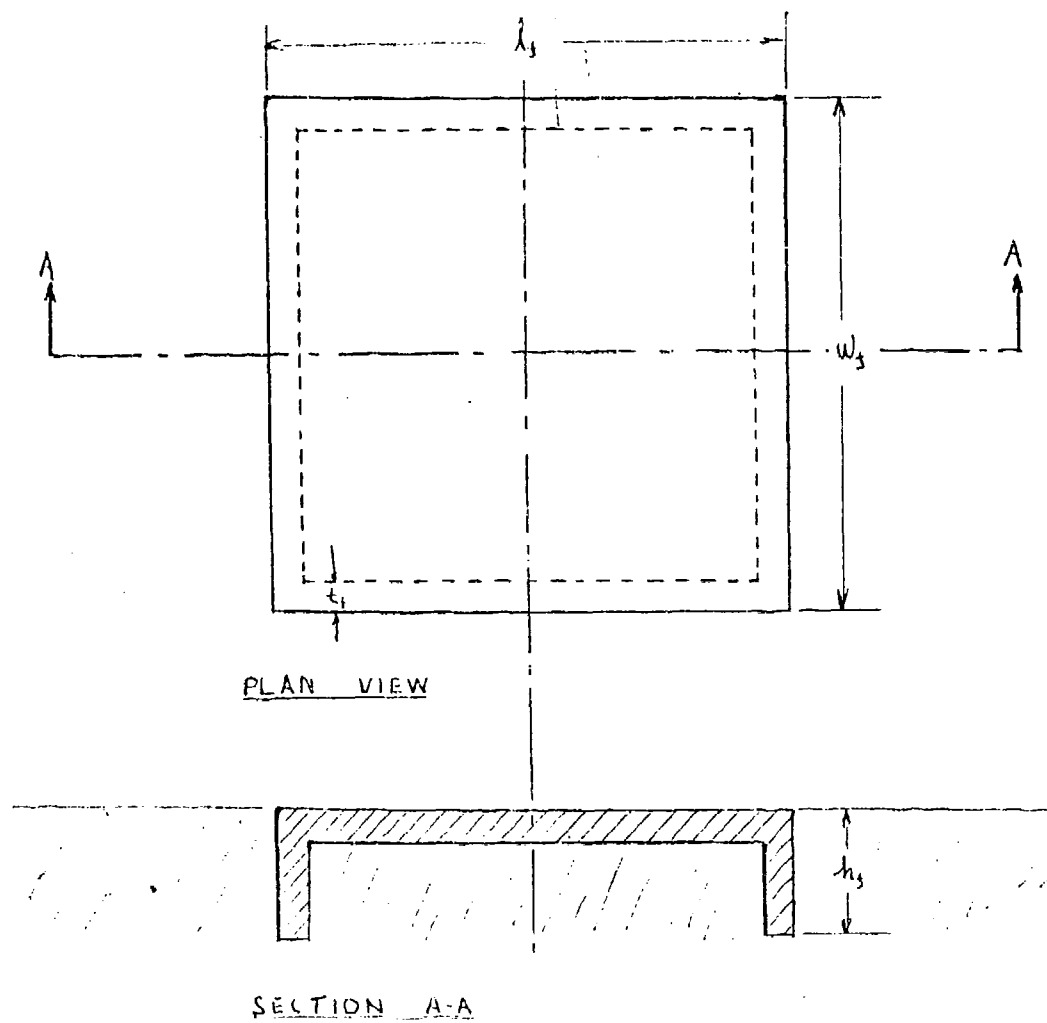


FIGURE 9 - FOUNDATION OF SUPPRESSIVE SHIELD

CHAPTER IV

USER'S GUIDE

Required data to be inputted by the user are listed below for all of the three options. Input procedures for required data will be described later in this chapter.

REQUIRED INPUTS

A. INPUTS FOR OPTION #1

1. Option number - equals to 1.
2. Length of suppressive structure - distance between corner vertical W beams of the longer side (ft.).
3. Width of suppressive structure - distance between corner vertical W beams of the shorter side (ft.).
4. Height of suppressive structure - distance between top of concrete slab and the lowest roof W beam.
5. Impulsive pressure i_p (psi-sec).
6. Quasi-static pressure p_q (psi).

B. INPUTS FOR OPTION #2

1. Option number - equals to 2.
2. Length of suppressive structure (ft.).
3. Width of suppressive structure (ft.).
4. Height of suppressive structure (ft.).
5. Type of panel configuration - 1, 2, 3, or 4 (see figure 2).

Other inputs for this option depend on the type of panel configuration specified in 5.

For panel configuration #1 only:

6. Cross-sectional area of angles 1 (sq. ft.).
7. Cross-sectional area of angles 2 (sq. ft.).
8. Thickness of perforated plates (ft.).

For panel configuration #2 only:

6. Cross-sectional area of angles (sq. ft.).
7. Thickness of perforated plates (ft.).

For panel configuration #3 only:

6. Venting coefficient per plate (c_p).
7. Cross-sectional area of W beams (sq. ft.).
8. Width of W beams (w) - see figure 3 (ft.).

For panel configuration #4 only:

6. Venting coefficient per plate (c_p).
7. Cross-sectional area of steel pipes (sq. ft.).
8. Outside diameter of pipes (d_o) in feet.

C. INPUTS FOR OPTIONS #3

1. Option number - equals to 3.
2. Length of suppressive structure (ft.).
3. Width of suppressive structure (ft.).
4. Height of suppressive structure (ft.).
5. Impulsive pressure i_r (psi-sec).
6. Quasi-static pressure P_q (psi).
7. Side on safety pressure P_s (psi).
8. Safety distance to personnel R (ft.).

9. Weight of explosive charge W_c (lb.).
10. Weight of primary fragment M_f (lb.).
11. Velocity of primary fragment V_f (ft./sec).
12. Type of panel configuration - 1, 2, 3, or 4 (see figure 2).

Other inputs are determined by type of panel configuration specified in 12.

For panel configuration #1 only:

13. Height of angles 1 (h)-see figure 4 (in.).
14. Width of angles 1 (w)-see figure 4 (in.).
15. Thickness of angles 1 (t)-see figure 4 (in.).

For panel configuration #2 only:

13. Height of angles (h)-see figure 4 (in.).
14. Width of angles (w)-see figure 4 (in.).
15. Thickness of angles (t)-see figure 4 (in.).

For panel configuration #3 only:

13. Height of W beam (h)-see figure 3 (in.).
14. Width of W beam (w)-see figure 3 (in.).
15. Thickness of W beam (t)-see figure 3 (in.).

For panel configuration #4 only:

13. Height of pipe (h)-see figure 5 (in.).
14. Width of pipe (w)-see figure 5 (in.).

15. Thickness of pipe (t)-see figure 5 (in.).

INPUT PROCEDURES

Proper input procedures for data when using the model are discussed in this section. The user must follow each

step carefully to avoid misleading results and errors.

Sample input forms for options #1, #2, and #3 are shown in figures 10 to 15. Card number, card columns, and description of the input variable are given in the input forms. The user is required to use the correct input form for the option chosen and enters the numerical values for the input variables in blank spaces on the right. The user should make certain that the numbers entered are of the same format (integer numbers or floating point numbers) and dimension as specified. Special attention must be given when filling out input forms for options #2 and #3. Notice that there are five parts of each input form. Part A should be filled out at all times before proceeding to other parts. Parts B, C, D and E are used for additional inputs for panel configurations #1, #2, #3, and #4 respectively. After completing part A, fill out the part that corresponds to the panel configuration you have chosen. Numerical values entered should be checked after the completion of the input form.

The next step is to key-punch data cards from the input form. Numerical values for input variables should be key-punched within the card columns specified on input form when decimal point is required. After key-punching, the order of these data cards should be checked, as shown in figure 16.

INPUT FORM FOR OPTION #1

CARD NUMBER	CARD COLUMNS	VARIABLE DESCRIPTION	NUMERICAL VALUE
1	3	Option number (no decimal point)	1
2	1-10	Length of suppressive shield (ft.) (decimal point required)	
2	11-20	Width of suppressive shield (ft.) (decimal point required)	
2	21-30	Height of suppressive shield (ft.) (decimal point required)	
3	1-10	Impulsive pressure (psi-sec) (decimal point required)	
3	11-20	Quasi-static pressure P_q (psi) (decimal point required)	

FIGURE 10

INPUT FORM FOR OPTION #2

PART A - FOR ALL PANEL CONFIGURATIONS

CARD NUMBER	CARD COLUMNS	VARIABLE DESCRIPTION	NUMERICAL VALUE
1	3	Option number (no decimal point)	2
2	1-10	Length of suppressive shield (ft.) (decimal point required)	
2	11-20	Width of suppressive shield (ft.) (decimal point required)	
2	21-30	Height of suppressive shield (ft.) (decimal point required)	
3	3	Type of panel configuration (no decimal point)	

PART B - FOR PANEL CONFIGURATION #1 ONLY

4	1-10	Cross-sectional area of angles 1 (sq. ft.) (decimal point required)	
4	11-20	Cross-sectional area of angles 2 (sq. ft.) (decimal point required)	
4	21-30	Thickness of perforated plates (ft.) (decimal point required)	

FIGURE 11

CONTINUATION OF INPUT FORM FOR OPTION #2

PART C - FOR PANEL CONFIGURATION #2 ONLY

4	1-10	Cross-sectional area of angles (sq. ft.) (decimal point required)	
4	11-20	Thickness of perforated plates (ft.) (decimal point required)	

PART D - FOR PANEL CONFIGURATION #3 ONLY

4	1-10	Venting coefficient per plate c_p (decimal point required)	
4	11-20	Cross-sectional area of W beam (sq. ft.) (decimal point required)	
4	21-30	Width of W beam (ft.) (decimal point required)	

PART E - FOR PANEL CONFIGURATION #4 ONLY

4	1-10	Venting coefficient per plate c_p (decimal point required)	
4	11-20	Cross-sectional area of pipe (sq. ft.) (decimal point required)	
4	21-30	Outside diameter of pipe d_o (ft.) (decimal point required)	

FIGURE 12

INPUT FORM FOR OPTION #3

PART A - FOR ALL PANEL CONFIGURATIONS

CARD NUMBER	CARD COLUMNS	VARIABLE DESCRIPTION	NUMERICAL VALUE
1	3	Option number (no decimal point)	3
2	1-10	Length of suppression shield (ft.) (decimal point required)	
2	11-20	Width of suppressive shield (ft.) (decimal point required)	
2	21-30	Height of suppressive shield (ft.) (decimal point required)	
3	1-10	Impulsive pressure i_r (psi-sec) (decimal point required)	
3	11-20	Quasi-static pressure P_q (psi) (decimal point required)	
4	1-10	Side on safety pressure P_s (psi) (decimal point required)	
4	11-20	Safety distance to personnel R (ft.) (decimal point required)	
4	21-30	Weight of explosive charge W_c (lb.) (decimal point required)	

FIGURE 13

CONTINUATION "1" OF INPUT FORM FOR OPTION #3

PART A - CONTINUED

5	1-10	Weight of primary fragment M_f (lb.) (decimal point required)	
5	11-20	Velocity of primary fragment V_f (ft./sec.) (decimal point required)	
6	3	Type of panel configuration (no decimal point)	

PART B - FOR PANEL CONFIGURATION #1 ONLY

7	1-10	Height of angles 1 (in.) (decimal point required)	
7	11-20	Width of angles 1 (in.) (decimal point required)	
7	21-30	Thickness of angles 1 (in.) (decimal point required)	

PART C - FOR PANEL CONFIGURATION #2 ONLY

7	1-10	Height of angles (in.) (decimal point required)	
7	11-20	Width of angles (in.) (decimal point required)	
7	21-30	Thickness of angles (in.) (decimal point required)	

FIGURE 14

CONTINUATION "2" OF INPUT FORM FOR OPTION #3

PART D - FOR PANEL CONFIGURATION #3 ONLY

7	1-10	Height of W beam (in.) (decimal point required)	
7	11-20	Width of W beam (in.) (decimal point required)	
7	21-30	Thickness of W beam (in.) (decimal point required)	

PART E - FOR PANEL CONFIGURATION #4 ONLY

7	1-10	Height of pipe (in.) (decimal point required)	
7	11-20	Width of pipe (in.) (decimal point required)	
7	21-30	Thickness of pipe (in.) (decimal point required)	

FIGURE 15

CHAPTER V

CONCLUSIONS

The design and cost information of a suppressive structure are the necessary backbones to support value engineering activities (3). The design-aid and cost estimate model presented in this report provides a valuable mean for obtaining such informations. The advantages of using this model have been discussed in previous chapters. However, suppressive structures are still under development. New ideas and design concepts are continuously being generated by researchers and designers of suppressive projects. Therefore, the model must be periodically revised according to new technology and developments to provide up to date design and cost information. The design-aid model could be easily modified for new design concepts. Corresponding changes in the cost estimate model could also be done to provide a complete value model.

This model is developed only for cubical suppressive structures. The model can be modified to include design and cost estimates of different types of suppressive structures.

One should clearly define desired objectives, functions, or purposes that the suppressive structures are to be accomplished when applying this model. All functional requirements essential to the attainment of desired goals must then be identified. Furthermore, various alternatives of concepts for accomplishing the functions have to be

reviewed and enhanced. A cost-effective suppressive shield should result through the use of this model and other value engineering activities outlined in reference 3.

APPENDICES

APPENDIX A
FORTRAN CODING
AND
SAMPLE OUTPUTS

THIS IS A COMPUTER AID DESIGN AND COST ESTIMATION MODEL FOR
CUBIC SUPPRESSIVE SHIELDING STRUCTURES. THREE OPTIONS AND FOUR TYPES MAIN
OF PANEL CONFIGURATIONS ARE CONSIDERED IN THIS MODEL. THE DESIGN AID MAIN
PORTION OF THIS MODEL CALCULATES VENTING COEFFICIENT, COMPARES
PLASTIC YIELD MOMENT OF BEAMS TO THE PLASTIC BENDING MOMENT EXERTED MAIN
ON THE BEAMS BY IMPULSE PRESSURE, CALCULATES TOTAL EFFECTIVE THICKNESS MAIN
OF PERFORATED PLATES AND PENETRATION OF PRIMARY FRAGMENTS, AND SETS MAIN
TOTAL THICKNESS OF THE PANEL PLATES TO THE LARGER ONE FOR COST
ESTIMATION. MAIN
THE COST ESTIMATION PORTION OF THIS MODEL COMPUTES AND OUTPUTS MAIN
MATERIAL, WELDING, AND FABRICATION COSTS OF THE FOUR BASIC UNITS OF MAIN
A CUBICAL SUPPRESSIVE STRUCTURE, NAMELY FRAME, PANEL, DOOR, AND
FOUNDATION. MAIN

INPUT VARIABLES

NBEAM - NUMBER OF BEAMS IN THE INPUT LIST
ITYPE - TYPE OF PANEL CONFIGURATION
1 AG PL PL AG PL PL
2 AG PL PL PL PL
3 WBEAM WBEAM
4 PIPE PIPE

LIST - MATRIX FOR BEAM DESIGN
ROW-BEAM NUMBER
COL-1 HEIGHT
COL-2 WIDTH
COL-3 THICKNESS
COL-4 AREA
COL-5 SECTION MODULUS(C)
COL-6 MOMENT OF INERTIA
COL-7 EQUIVALENT BEAM WIDTH

IGOUT - OPTION NUMBER
1 GIVE THE LIST OF BEAMS THAT MEETS THE PRESSURE
INPUT REQUIREMENTS.
2 COST ESTIMATION OF A CUBIC SUPPRESSIVE STRUCTURE.
3 DESIGN AND COST ESTIMATION OF A SUPPRESSIVE SHIELDING

MAIN 0
MAIN 5
MAIN 10
MAIN 15
MAIN 20
MAIN 25
MAIN 30
MAIN 35
MAIN 40
MAIN 45
MAIN 50
MAIN 55
MAIN 60
MAIN 65
MAIN 70
MAIN 75
MAIN 80
MAIN 85
MAIN 90
MAIN 95
MAIN 100
MAIN 105
MAIN 110
MAIN 115
MAIN 120
MAIN 125
MAIN 130
MAIN 135
MAIN 140
MAIN 145
MAIN 150
MAIN 155
MAIN 160
MAIN 165
MAIN 170
MAIN 175
MAIN 180

STRUCTURE WITH DIFFERENT TYP.		PANEL CONFIGURATION.	
C	41 - IMPULSIVE PRESSURE	(PSI-SEC)	MAIN 185
C	P2 - QUASI-STATIC PRESSURE	(PSI)	MAIN 190
C	PSON - SIDE ON PRESSURE	(PSI)	MAIN 195
C	R - DISTANCE FROM CHARGE TO PERSON	(FT.)	MAIN 200
C	WGTCH - WEIGHT OF CHARGE	(LB.)	MAIN 205
C	LSS - LENGTH OF STRUCTURE	(FT.)	MAIN 210
C	HSS - HEIGHT OF STRUCTURE	(FT.)	MAIN 215
C	WSS - WIDTH OF STRUCTURE	(FT.)	MAIN 220
C	WPRAS - WEIGHT OF PRIMARY FRAGMENTS	(LB.)	MAIN 225
C	VPRAS - VELOCITY OF PRIMARY FRAGMENTS	(FT/SEC)	MAIN 230
C	TYPE - TYPE OF BEAM DESIRED		MAIN 235
C	1. I BEAM, 2. ANGLE BAR, 3. PIPE	(IN.)	MAIN 240
C	DIMN - DIMENSION MATRIX FOR BEAMS		MAIN 245
C	SCUEF - SUPPORT COEFFICIENT		MAIN 250
C	1 - SIMPLY SUPPORTED		MAIN 255
C	2 - CLAMPED		MAIN 260
C	DNSTY - DENSITY OF STEEL	(LB./CU.FT.)	MAIN 265
C	DNSTVM - MASS DENSITY OF STEEL	(LB.-SEC2/IN.4)	MAIN 270
C	SF - FACTOR OF SAFETY		MAIN 275
C	E - MODULUS OF ELASTICITY	(PSI)	MAIN 280
C	YS - YIELD STRENGTH	(PSI)	MAIN 285
C	NPL - NUMBER OF PLATES IN EACH TYPE OF PANEL CONFIGURATIONS		MAIN 290
C	DNHOLE - DIAMETER OF HOLES TO BE DRILLED ON PLATES	(FT.)	MAIN 295
C	SENOG - SECANT OF THE ANGLE BETWEEN STRIKING FRAGMENT & PLATE SURFACE		MAIN 300
C	USIGN - COEFFICIENT OF DESIGN		MAIN 305
C			MAIN 310
C			MAIN 315
C			MAIN 320
C			MAIN 325
C	VCUEF - VENTING COEFFICIENT PER PANEL PLATE	(IN.)	MAIN 330
C	PEVTH - PENETRATION OF PRIMARY FRAGMENTS	(IN.-LB.)	MAIN 335
C	MONMT - PLASTIC YIELD MOMENT OF BEAM	(IN.-LB.)	MAIN 340
C	MONTP - PLASTIC BENDING MOMENT OF BEAM	(IN.-LB.)	MAIN 345
C	EEFH - EFFECTIVE THICKNESS OF PLATES WITH CONSIDERATION OF VENTING COEF.	(IN.)	MAIN 350
C			MAIN 355
C			MAIN 360
C			MAIN 365
C			MAIN 370
C			MAIN 375
C			MAIN 380

ASSUMPTIONS MADE IN THIS MODEL - SF = 1.25
 SCUEF = 1
 DNHOLE = 3/16 IN
 DNSTY = 490 LB/CU.FT.
 DNSTVM = 0.000733 LB-SEC2/IN.4


```

IF (TYPE(I).NE.1)GO TO 110
LIST(I,4) = LIST(I,2)*LIST(I,1)-2.*(LIST(I,1)-2.*LIST(I,3))*(LIST(I,3)-
*1.2)-LIST(I,3))/2.0
LIST(I,5) = LIST(I,1)/2.0
D1 = LIST(I,1)-2.*LIST(I,3)
LIST(I,6) = 2.0*(LIST(I,2)*LIST(I,3)**3/12.0+LIST(I,2)*LIST(I,3)*
*(D1+LIST(I,3))/2.0)**2)+LIST(I,3)*(D1/2.0)**3/12.
LIST(I,7) = LIST(I,2)/(1.-2*VC)
GO TO 120
90 LIST(I,4) = LIST(I,1)*LIST(I,2)-(LIST(I,2)-LIST(I,3))*(LIST(I,1)-
*LIST(I,3))
LIST(I,5) = LIST(I,2)/2.0**0.5
FR = LIST(I,1)**3*LIST(I,3)+LIST(I,2)*LIST(I,3)**3
LIST(I,6) = 0.7071**2*(2./3.*FR-LIST(I,2)**2*LIST(I,1)**2*LIST(I,3)
*)/4./(LIST(I,1)+LIST(I,2))
LIST(I,7) = LIST(I,3)/(.7071-VC)
GO TO 120
100 LIST(I,4) = 3.1416/4.*(LIST(I,1)**2-(LIST(I,1)-LIST(I,3)*2)**2)
LIST(I,5) = LIST(I,2)/2.0
LIST(I,6) = 3.1416*(LIST(I,1)**4-(LIST(I,1)-LIST(I,3)*2.0)**4)/64.
LIST(I,7) = LIST(I,1)/(1.-VC)
GO TO 120
110 WRITE (LP,130)
GO TO 140
C
C CALCULATE AND COMPARE BEAM YIELD MOMENT AND BENDING MOMENT
C
120 BEAM = LSS/4.39*12.0
WJ = BEAM*0.15
MSFC = 41**2*LIST(I,7)**2*8EAML**2/SCOE/CNSTYM/LIST(I,4)/16./WC
**SF
MYIELD = 1.05*41600.*LIST(I,6)/LIST(I,5)
IF (MYIELD.LT.MBEND)GO TO 80
WRITE (LP,150) TYPE(I),LIST(I,1),LIST(I,2),LIST(I,3),MYIELD,MBEND,
*LIST(I,4)
80 CONTINUE
30 CONTINUE
IF (ICU1.NE.2)GO TO 160
C

```

```

C INPUTS FOR OPTIONS NUMBER 2
C
  READ (CD,40) LSS,WSS,HSS
  READ (CD,20) ITYPE
  IF (ITYPE.EQ.3.OR.ITYPE.EQ.4)GO TO 170
  IF (ITYPE.EQ.2)GO TO 180
  READ (CL,40) XABR1,XABR2,TKPPL
  AREA(2) = XABR1
  AREA(4) = XABR2
  DIMN(4,3) = TKPPL

C CALL SUBROUTINE COSTIN FOR COST ESTIMATION
C
C 190 CALL COSTIN(LSS,WSS,HSS,VCDEF,IOUT)
  GO TO 140
170 CONTINUE
  IF (ITYPE.EQ.3)READ (CD,40) VCDEF,AREA(1),DIMN(1,2)
  IF (ITYPE.EQ.3)GO TO 190
  READ (CD,40) VCDEF,AREA(3),DIMN(3,1)
  GO TO 190
180 CONTINUE
  READ (CD,50) AREA(2),DIMN(4,3)
  GO TO 190
160 CONTINUE
  IF (ICUT.NE.3)WRITE (LP,200)
  IF (ICUT.NE.3)GO TO 210

C INPUTS FOR OPTION NUMBER 3
C
C  READ (CD,40) LSS,WSS,HSS
  READ (CD,50) AI,20
  READ (CD,40) P3GV,K,WTCH
  READ (CD,50) WDFAG,VCFAG
  READ (CD,20) ITYPE
  I = 2
  IF (ITYPE.EQ.3)I=1
  IF (ITYPE.EQ.4)I=3
  NOP = 2
  IF (ITYPE.EQ.1)NOP=4
  IF (ITYPE.EQ.2)NOP=3

```

MAIN 785
 MAIN 790
 MAIN 795
 MAIN 800
 MAIN 805
 MAIN 810
 MAIN 815
 MAIN 820
 MAIN 825
 MAIN 830
 MAIN 835
 MAIN 840
 MAIN 845
 MAIN 850
 MAIN 855
 MAIN 860
 MAIN 865
 MAIN 870
 MAIN 875
 MAIN 880
 MAIN 885
 MAIN 890
 MAIN 895
 MAIN 900
 MAIN 905
 MAIN 910
 MAIN 915
 MAIN 920
 MAIN 925
 MAIN 930
 MAIN 935
 MAIN 940
 MAIN 945
 MAIN 950
 MAIN 955
 MAIN 960
 MAIN 965
 MAIN 970
 MAIN 975
 MAIN 980

65

```

C      CALCULATE PENETRATION OF PRIMARY FRAGMENTS
C
      EFFHT = EFFH*NDP+2*DIMN(1,3)*12.0
310 CALL PROPC(EFFHT,VPFAG,SEMGD,VPFAG,VRFAG,WRFAG,PENTH)
      PENPL = PENTH*LSIGN
      IF (PENPL.GT.EFFHT.AND.1.NE.2)GO TO 340
      IF (PENPL.GT.EFFHT)GO TO 350
      WRITE (LP,360) LPFAG,VPFAG,PENPL
      IF (1.NE.2)GO TO 190
      WRITE (LP,370) EFFH
      GO TO 380
340 WRITE (LP,390) LP,PL,EFFHT
350 WRITE (LP,360) VPFAG,VRFAG,PENPL
      WRITE (LP,400)
C
C      SET THICKNESS OF PLATES TO MAXIMUM PENETRATION OF PRIMARY FRAGMENTS
C      WHEN THICKNESS CALCULATED FOR PRESSURE LOADING IS LESS THAN
C      PENETRATION THICKNESS.
C
      EFFH = (PENPL-2*DIMN(1,3)*12.0)/NDP
380 CONTINUE
C
C      CALL SUBROUTINE COSM FOR COST ESTIMATION
C
      AREA(4) = AREA(2)
      DIM(4,3) = EFFH/12.0
      GO TO 190
140 CONTINUE
20 FORMAT(13)
40 FORMAT(3F10.0)
50 FORMAT(2F10.0)
130 FORMAT(//, ' TYPE OF BEAM IS NOT DEFINED CORRECTLY')
150 FORMAT(//,10X,12.4X,F10.5,4X,F10.5,4X,F10.5,6X,F13.2,6X,F13.2,
      *4X,F10.5)
230 FORMAT(//, ' PAVEL CONFIGURATION ',13,/,33X,'HEIGHT WIDTH
      *THICKNESS',/, ' DIMENSION FOR TYPE',13, ' BEAM IS',3F8.4)
250 FORMAT(//, ' WEIGHT OF CHARGE',17X,'=',F10.3,/, ' WIDTH OF SMAIN1365
      *STRUCTURE',15X,'=',F10.3,/, ' DISTANCE FROM CHARGE TO PERSON ',MAIN1370
      *F10.3,/, ' SIDE ON PRESSURE',17X,'=',F10.3,/, ' VENTING COEFFICMAIN1375
      *IENT IS CALCULATED AS',F10.5)
MAIN1185
MAIN1190
MAIN1195
MAIN1200
MAIN1205
MAIN1210
MAIN1215
MAIN1220
MAIN1225
MAIN1230
MAIN1235
MAIN1240
MAIN1245
MAIN1250
MAIN1255
MAIN1260
MAIN1265
MAIN1270
MAIN1275
MAIN1280
MAIN1285
MAIN1290
MAIN1295
MAIN1300
MAIN1305
MAIN1310
MAIN1315
MAIN1320
MAIN1325
MAIN1330
MAIN1335
MAIN1340
MAIN1345
MAIN1350
MAIN1355
MAIN1360
MAIN1365
MAIN1370
MAIN1375
MAIN1380

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```

290 FORMAT(' ', TYPE OF BEAM IS NOT STRONG ENOUGH TO WITHSTAND PRESSURE, MAIN1385
      #E LOADING', MAIN1390
300 FORMAT(' ', IMPULSIVE PRESSURE, 15X, '=', F10.3, /, ' EQUIVALENT MAIN1395
      #BEAM WIDTH, 12X, '=', F10.3, /, ' LENGTH OF BEAM, 19X, '=', F10.3, /, ' MAIN1400
      # TYPE OF BEAM, 21X, '=', 15, /, ' SAFETY FACTOR, 20X, '=', F5.2, /, ' MAIN1405
      # MODULUS OF ELASTICITY, 12X, '=', E15.7, /, ' PLASTIC YIELD MOMENT, MAIN1410
      # 12X, '=', F10.3, /, ' PLASTIC BENDING MOMENT, 11X, '=', F10.3, ' MAIN1415
320 FORMAT(' ', IMPULSIVE PRESSURE, 23X, '=', F10.3, /, ' QUASI-STATIC MAIN1420
      #C PRESSURE, 20X, '=', F10.3, /, ' CALCULATED VENTING COEFFICIENT PERMAIN1425
      # PLATE =, F10.6, /, ' CALCULATED EFFECTIVE THICKNESS PER PLATE =, MAIN1430
      #F10.6) MAIN1435
330 FORMAT(' ', NUMBER OF DRILLED HOLES REQUIRED IS, 19, ' GIVEN THAT TUMAIN1440
      #E DIAMETER OF HOLE IS, F10.6, ' IN. ) MAIN1445
340 FORMAT(' ', #E GIVEN - WEIGHT OF PRIMARY FRAGMENTS =, F12.2, /, 8X, MAIN1450
      #, ' VELOCITY OF PRIMARY FRAGMENT =, F10.3, /, ' THICKNESS OF PLATMAIN1455
      #E REQUIRED TO STOP ALL PRIMARY FRAGMENTS IS, F10.5, ' IN. ) MAIN1460
370 FORMAT(' ', THICKNESS OF PANEL DESIGNED IS ABLE TO CONTAIN ALL PRIMMAIN1465
      #ARY FRAGMENTS. , /, ' THICKNESS OF EACH PERFORATED PLATE IS DESIGNMAIN1470
      #E TO BE, F10.6, ' IN. ) MAIN1475
400 FORMAT(' ', THICKNESS OF PANEL DESIGNED IS UNABLE TO CONTAIN ALL PRMAIN1480
      #INARY FRAGMENTS, /, ' TOTAL THICKNESS OF PANEL IS SET EQUAL TO PENMAIN1485
      #TRATION LENGTH OF FRAGMENTS ) MAIN1490
200 FORMAT(' ', INVALID VALUE FOR IOUT ) MAIN1495
60 FORMAT(' ', OPTION NUMBER, 12, /, ' FOLLOWING IS A LIST OF BEAMS REQUESTED THAT ARE STMAIN1505
      # MAIN1510
      #ROG ENOUGH FOR PRESSURE LOADING REQUIREMENTS, /, /, ' MAIN1515
      #CX, TYPE, 5X, HEIGHT, 9X, WIDTH, 7X, THICKNESS, 11X, 'MYIELD', MAIN1520
      #13X, 'NBEND, 10X, 'AREA') MAIN1525
390 FORMAT(' ', TOTAL PENETRATION OF PRIMARY FRAGMENTS IS, F10.5, ' MAIN1530
      #, ' THEREFORE IT IS NECESSARY TO USE LARGER SIZES OF IBEAMS OR PIMAIN1535
      #ES SO AS TO STOP ALL PRIMARY FRAGMENTS. ) MAIN1540
220 FORMAT(' ', OPTION NUMBER, 12, ' - DESIGN OF BEAMS AND PLATES MAIN1545
      #OF SUPPRESSIVE SHIELDING PANELS') MAIN1550
70 FORMAT(' ', IMPULSIVE PRESSURE =, F10.5, /, ' QUASI STATIC PRESSMAIN1555
      #URE =, F10.5) MAIN1560
210 STOP MAIN1565
      END

```

```

C
C
C SUBROUTINE PLDSN(YS,VCOEF,NPL,DHOLE,EFFH,NHOLE,LSS,WSS)
C
C THIS SUBROUTINE CALCULATES MINIMUM THICKNESS OF SUPPRESSIVE PANEL
C PLATES NECESSARY TO WITHSTAND BOTH THE MAXIMUM IMPULSIVE PRESSURE AND
C THE QUASI-STATIC PRESSURE. NUMBER OF DRILLED HOLES FOR PERFORATED
C PLATES IS CALCULATED WITH GIVEN DIAMETER OF HOLE DESIRED.
C
C INPUT VARIABLES:
C
C YS - YIELD STRESS FOR THE PLATE.
C VCOEF - VENTING COEFFICIENT.
C NPL - NUMBER OF PLATES DESIRED.
C DHOLE - DIAMETER OF HOLES DESIRED.
C LSS = LENGTH OF SUPPRESSIVE STRUCTURE
C WSS = WIDTH OF SUPPRESSIVE STRUCTURE
C
C OUTPUT VARIABLES:
C
C EFFH - EFFECTIVE THICKNESS OF AN INDIVIDUAL PLATE.
C NHOLE - NUMBER OF HOLES NECESSARY TO MEET PRESSURE VENTING REQUIREMENT
C
C CALCULATING THICKNESS FOR IMPULSE REALM
C
C DIMENSION XCOF(100),COF(100),ROOTR(100),ROOTI(100)
C DIMENSION DIMN(4,3),AREA(4),C(3)
C REAL MINTA(3),LSS
C COMMON /4/ AI,PL,SCOE,C,DNSTYN
C COMMON /T/REE/ INSTY,DIMN,AREA,ITYPE
C DATA XCOF,COF,ROOTR,ROOTI/400*0.0/
C DATA LP/6/
C X = LSS
C IF (WSS.GT.LSS)X=WSS
C Y = 1.0E20
C D=DNSTYP
C WU=0.15*X
C X=X/2.0

```

PLDS	0
PLDS	5
PLDS	10
PLDS	15
PLDS	20
PLDS	25
PLDS	30
PLDS	35
PLDS	40
PLDS	45
PLDS	50
PLDS	55
PLDS	60
PLDS	65
PLDS	70
PLDS	75
PLDS	80
PLDS	85
PLDS	90
PLDS	95
PLDS	100
PLDS	105
PLDS	110
PLDS	115
PLDS	120
PLDS	125
PLDS	130
PLDS	135
PLDS	140
PLDS	145
PLDS	150
PLDS	155
PLDS	160
PLDS	165
PLDS	170
PLDS	175
PLDS	180

```

N = SCDEF
N=3
GF= 1.0+(X/Y)**2
XCOF(1)=-51**2*X**2
XCOF(2)=1.0
XCOF(3)=(4.0**((N-1)*3.1416**2/16.0/N**2*GF+2.0*N*X/1.732/Y)*WO**2*PLDS 185
*Q*YS
XCOF(4)=(3.1416**((N-1)*GF/2.0/N+2.*X/1.732/Y)*WO*D*YS
10 CALL RTPOL(XCOF,COF,N,ROOTR,ROOTI,IER)
H=ROOTR(1)
DO 20 I=1,N
IF (H-XCOF(I))30,20,20
30 H=ROOTR(1)
20 CONTINUE
HMAX=H
WRITE (LP,40) H
C
C CALCULATING THICKNESS FOR QUASI-STATIC LOADING REALM
C
XCOF(1)=-PG*X**2/YS
XCOF(2)=(3.0**((N-1)*4.0**((N-2)*3.1416**((6-2*N)*GF/32.0+2.0**((N-1)*PLDS 190
*4.0**((2*N-3)*X/1.732/3.1416**((2*N-4)/Y)*WO
XCOF(3)=3.1416**((2/N)*GF/2.0**((4/N**2)+4.0**((2*N-3)*X/Y/1.732/3.14PLDS 195
*16**((2*N-4)
H=(XCOF(2)+(XCOF(2)**2-4.0*XCOF(1)*XCOF(3))**0.5)/2.0/XCOF(3)
WRITE (LP,50) H
C
C DETERMINING MINIMUM THICKNESS REQUIRED
C
IF (HMAX=0)60,70,70
60 HMAX = H
70 HPL = HMAX/NPL
EFFH = HPL/(1.0-VCDEF)
C
C CALCULATING NUMBER OF HOLES NEEDED
C
X = DIMY(4,1)*12.0
Y = DIMY(4,2)*12.0
VENTA= X*Y*VCDEF
NHOLES= VENTA/(3.1416*(UHOLE/2.0)**2.1)
PLDS 200
PLDS 205
PLDS 210
PLDS 215
PLDS 220
PLDS 225
PLDS 230
PLDS 235
PLDS 240
PLDS 245
PLDS 250
PLDS 255
PLDS 260
PLDS 265
PLDS 270
PLDS 275
PLDS 280
PLDS 285
PLDS 290
PLDS 295
PLDS 300
PLDS 305
PLDS 310
PLDS 315
PLDS 320
PLDS 325
PLDS 330
PLDS 335
PLDS 340
PLDS 345
PLDS 350
PLDS 355
PLDS 360
PLDS 365
PLDS 370
PLDS 375
PLDS 380

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```
50 FORMAT(/, ' THICKNESS CALCULATED FOR QUASI-STATIC LOADING IS ', PLDS 385  
  *F10.5, ' IN. ') PLDS 390  
40 FORMAT(/, ' THICKNESS CALCULATED FOR DYNAMIC LOADING IS ', F10.5, PLDS 395  
  * ' IN. ') PLDS 400  
  RETURN PLDS 405  
  END PLDS 410
```

```

C
C      SUBROUTINE BMDS(B,L,TYPE,SF,E,MOMNT,MOMTP,IERR)
C
C      THIS SUBROUTINE CALCULATES AND CHECKS WHETHER THE PLASTIC YIELD
C      MOMENT FOR A BEAM SELECTED IS LARGER THAN THE PLASTIC BENDING MOMENT
C      INCUCED ON BEAM BY THE ELAST PRESSURE OF EXPLOSIVE. A SAFETY FACTOR
C      IS INCORPORATED INTO CALCULATION OF THE PLASTIC BENDING MOMENT OF
C      THE BEAM. THREE TYPES OF BEAMS ARE AVAILABLE FOR SELECTION.
C
C      INPUT VARIABLES -
C
C      R - EQUIVALENT BEAM WIDTH.
C      L - LENGTH OF BEAM.
C      TYPE - TYPE OF BEAM DESIRED.
C      SF - FACTOR OF SAFETY.
C      E - MODULUS OF ELASTICITY.
C
C      OUTPUT VARIABLES -
C
C      MOMNT - PLASTIC YIELD MOMENT OF BEAM.
C      MOMTP - PLASTIC BENDING MOMENT OF BEAM.
C
C      REAL NA,MRA
C      REAL MOMNT,MOMTP,MINTA,L
C      INTEGER LP,CD,TYPE
C      DIMENSION DIMN(4,3),AREA(4),MINTA(3),C(3)
C      COMMON /4/ AI,PC,SCOEFF,C,DNSTYX
C      COMMON /THREE/ DNSTY,DIMN,AREA,ITYPE
C      DATA LP,CD/6,5/
C      IERR = 0
C      IF (TYPE)10,10,20
C      10 WRITE (LP,30)
C      RETURN
C      20 IF (TYPE-4)40,10,10
C      40 R = DIMN(TYPE,1)*12.0
C      W = DIMN(TYPE,2)*12.0
C      TX = DIMN(TYPE,3)*12.0

```

BMDS	0
BMDS	5
BMDS	10
BMDS	15
BMDS	20
BMDS	25
BMDS	30
BMDS	35
BMDS	40
BMDS	45
BMDS	50
BMDS	55
BMDS	60
BMDS	65
BMDS	70
BMDS	75
BMDS	80
BMDS	85
BMDS	90
BMDS	95
BMDS	100
BMDS	105
BMDS	110
BMDS	115
BMDS	120
BMDS	125
BMDS	130
BMDS	135
BMDS	140
BMDS	145
BMDS	150
BMDS	155
BMDS	160
BMDS	165
BMDS	170
BMDS	175
BMDS	180

BMDS 185
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BMDS 275
BMDS 280
BMDS 285
BMDS 290
BMDS 295
BMDS 300
BMDS 305
BMDS 310
BMDS 315
BMDS 320
BMDS 325
BMDS 330
BMDS 335
BMDS 340

WO = 0.15*U
CALCULATING MOMENT OF INERTIA AND AREA OF THE BEAMS.

```

C(1) = H/2.0
BI = H-2.*TK
MINIA(1) = 2.*(K*TK**3/12.0+K*TK*((B1+TK)/2.))**2)+TK*(B1/2.))**3/12
AREA(1) = W*H-2*(H-2*TK)*(W-TK)/2.
C(2) = W/2.0**0.5
FACIR = F**3*JK+W*TK**3
MINIA(2) = .7071**2*(2.0/3.0*FACIR-W**2*H**2*TK/4/(H+W))
AREA(2) = H*W-(W-TK)*(H-TK)
C(3) = H/2.
MINIA(3) = 3.1416*(H**4-(H-TK**2)**4)/64.0
AREA(3) = 3.1416/4.*(H**2-(H-TK**2)**2)

```

CALCULATING PLATIC YIELD MOMENT AND PLASTIC BENDING MOMENT.

```

MOMTP=A1**2*B**2*L**2/SCDEF/CNSTYM/AREA(TYPE)/16./WC*SF
MOMNT=1.05*41600.*MINIA(TYPE)/C(TYPE)

```

```

DO 50 Y=1,4
50 AREA(K) = AREA(K)/144.0
IF (MOMNT-MOMTP) 60,70,70
60 WRITE (LP,80)

```

```

1 ERR = 1
30 FORMAT('... ERROR IN DEFINING TYPE OF BEAM')

```

```

80 FORMAT('... PLASTIC BENDING MOMENT IMPOSED ON BEAM BY IMPULSIVE
*PRESSURE LOADING EXCEEDS PLASTIC YIELD MOMENT OF BEAM.',//, ' IT
*IS NECESSARY TO EITHER REDUCE PRESSURE LOADING OR USE LARGER SIZE
*BEAMS.')
70 RETURN
END

```


**COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION**

```

40 WRITE (IPRIN,60) ERR1
   ERR=1
50 ERR2=X/L*(1/3)
   IF 14.27-ERR2)70,70,80
80 WRITE (IPRIN,90) ERR2
   ERR=1
70 IF (17.5-ERR2)100,110,110
100 WRITE (IPRIN,120) ERR2
110 IF 1W)130,130,140
130 WRITE (IPRIN,150) W
   ERR=1
140 IF (X)160,160,170
160 WRITE (IPRIN,180) X
   ERR=1
170 IF (PSD)190,190,200
190 WRITE (IPRIN,210) PSD
   ERR=1
200 IF (R)220,220,230
220 WRITE (IPRIN,240) R
   ERR=1
230 CONTINUE

      CALCULATE EFFECTIVE VENTING COEFFICIENT
      A=(PSD**3*RT(R)*SQRT(X))/(976.3*W**0.666))
      E=A*E
      IF (E,LT,0.0263)E=0.0263
      IF (E,GT,0.6)E=(.6

ERROR MESSAGES

30 FORMAT(10X,1***ERROR -- X/R IS LESS THAN 0.023,5X,'X/R=',F5.3,/)
60 FORMAT(10X,1***ERROR -- X/R IS GREATER THAN 1.77,5X,'X/R=',F5.3,/)
90 FORMAT(10X,1***ERROR -- R/(W**1/3) IS LESS THAN 4.27,5X,
   *      'R/(W**1/3)=',F5.2,/)
120 FORMAT(10X,1***ERROR -- R/(W**1/3) IS GREATER THAN 17.5,5X,
   *      'R/(W**1/3)=',F5.2,/)
150 FORMAT(10X,1***ERROR -- W IS LESS THAN OR EQUAL TO ZERO W=',F10.5)
160 FORMAT(10X,1***ERROR -- X IS LESS THAN OR EQUAL TO ZERO X=',F10.5)
210 FORMAT(10X,1***ERROR -- PSD IS LESS THAN OR EQUAL TO ZERO PSD=',

```

VENT 185
VENT 190
VENT 195
VENT 200
VENT 205
VENT 210
VENT 215
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VENT 225
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VENT 385
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VENT 395
VENT 400

VENT 385
VENT 390
VENT 395
VENT 400

VENT 385
VENT 390
VENT 395
VENT 400

```

SUBROUTINE FRGP(TH,WPFAG,SEMOD,VPFAG,VR,FMR,PENTH)
FRGP 0
FRGP 5
FRGP 10
FRGP 15
FRGP 20
FRGP 25
FRGP 30
FRGP 35
FRGP 40
FRGP 45
FRGP 50
FRGP 55
FRGP 60
FRGP 65
FRGP 70
FRGP 75
FRGP 80
FRGP 85
FRGP 90
FRGP 95
FRGP 100
FRGP 105
FRGP 110
FRGP 115
FRGP 120
FRGP 125
FRGP 130
FRGP 135
FRGP 140
FRGP 145
FRGP 150
FRGP 155
FRGP 160
FRGP 165
FRGP 170
FRGP 175
FRGP 180

THIS SUBROUTINE CALCULATES THE AMOUNT OF PENETRATION OF PRIMARY
FRAGMENTS IN STEEL WITH GIVEN WEIGHT AND VELOCITY OF PRIMARY FRAGMENT
IF GIVEN THICKNESS OF A CERTAIN STRUCTURE(PLATES OR BEAMS), RESIDUAL
VELOCITY AND RESIDUAL MASS OF SECONDARY FRAGMENTS CAN BE CALCULATED.

INPUT VARIABLES:
TH - THICKNESS OF STRUCTURE (IN.)
WPFAG - WEIGHT OF PRIMARY FRAGMENTS (LB.)
VPFAG - VELOCITY OF PRIMARY FRAGMENTS (FT./SEC)
SEMOD - SECANT OF THE ANGLE BETWEEN STRIKING FRAGMENT & PLATE SURFACE

OUTPUT VARIABLES:
VR - RESIDUAL VELOCITY (FT./SEC)
FMR - RESIDUAL FRAGMENT WEIGHT (LB.)
PENTH - MAXIMUM PENETRATION OF FRAGMENT (IN.)

DIMENSION BA(5),BS(5),XA(4)
DATA BA/0.9064,0.9496,-.3603,1.2842,0.1929/
DATA BS/-0.2776,0.1985,0.9145,0.1958,0.6394/
WPFAG = WPFAG*7000.0
XA(1) = TH
XA(2) = WPFAG
XA(3) = SEMOD
XA(4) = VPFAG
SUN = 0.0
SUM = 0.0
DO 10 J=1,4
SUN = SUN+XA(J+1)*ALOG(XA(J))/2.3
10 SUM = SUM+BS(J+1)*ALOG(XA(J))/2.3
VR = XA(4)-10*(BA(1)+SUM)
FMR = XA(2)-10*(BS(1)+SUN)
FMS = XA(2)/7000.0*16.

```

FRGP 185
FRGP 190
FRGP 195

PENTH = .112*FMS**((1.0/3)*(.COL*XA(1/1))**((4.0/3)

RETURN
END


```

110 XPR=X
120 YPR=Y
130 ICT=0
140 UX=0.0
150 UY=0.0
160 V=0.0
170 YI=0.0
180 XI=1.0
190 U=COF(N+1)
200 IF (N)140,150,160
210 DO 160 I=1,N
220 L=N-I+1
230 XT2=X*XT-V*YT
240 YT2=X*YT+V*XT
250 U=U+COF(L)*XT2
260 V=V+COF(L)*YT2
270 FI = I
280 UX=UX+FI*XT*COF(L)
290 UY=UY+FI*YT*COF(L)
300 XT=XT2
310 YT=YT2
320 SUMSQ=UX*UX+UY*UY
330 IF (SUMSQ)170,180,170
340 DX=(V*UY-U*UX)/SUMSQ
350 X=X+DX
360 DY=-(U*UY+V*UX)/SUMSQ
370 Y=Y+DY
380 IF (ABS(DY)+ABS(DX)-1.0E-05)200,210,210
390 ICT=ICT+1
400 IF (ICT-500)130,220,220
410 IF (IF1)200,230,200
420 IF (IN-51100,240,240
430 ICR=3
440 DO 10 50
450 DO 200 L=1,NXX
460 YT=XI-L+1
470 TEMP=XCOF(MT)
480 XCOF(MT)=COF(L)
490 COF(L)=TEMP
495 ITEMP=N

```

```

N=NX
NX=ITERP
IF (IFIT)260,120,260
120 IF (IFIT)270,100,270
270 X=XOR
Y=YPR
260 IFIT=0
IF (X)290,290,280
280 IF (ABS(Y)-ABS(X)*1.0E-04)300,290,290
290 ALPHA=X+X
SUMSQ=X*X+Y*Y
N=N-2
GO TO 310
150 X=C.0
NX=NX-1
NXY=NXY-1
300 Y=0.0
SUMSQ=0.0
ALPHA=X
N=N-1
310 LI=1
L2=2
COF(L2) = COF(L2)+ALPHA*COF(L1)
IF (N.EQ.0)GO TO 320
330 DO 340 L=2,N
340 COF(L+1)=COF(L+1)+ALPHA*COF(L)-SUMSQ*COF(L-1)
320 RCOF(L+2)=Y
RCOFR(N2)=X
N2=N2+1
IF (SUMSQ)350,360,350
350 Y=-Y
SUMSQ=0.0
GO TO 320
360 IF (N)50,50,90
END
RTP0 385
RTP0 390
RTP0 395
RTP0 400
RTP0 405
RTP0 410
RTP0 415
RTP0 420
RTP0 425
RTP0 430
RTP0 435
RTP0 440
RTP0 445
RTP0 450
RTP0 455
RTP0 460
RTP0 465
RTP0 470
RTP0 475
RTP0 480
RTP0 485
RTP0 490
RTP0 495
RTP0 500
RTP0 505
RTP0 510
RTP0 515
RTP0 520
RTP0 525
RTP0 530
RTP0 535
RTP0 540
RTP0 545
RTP0 550
RTP0 555

```

```

C      SUBROUTINE COSTM(LSS,WSS,HSS,VCOEF,IOUT)
C
C      THIS SUBROUTINE CALCULATES AND OUTPUTS MATERIAL , WELDING, AND
C      FABRICATION COST OF THE FRAME, PANELS, DOOR, AND FOUNDATION
C      OF A CURB SUPPRESSIVE SHIELDING STRUCTURE.
C
C      INPUT VARIABLES
C
C      LSS - LENGTH OF SUPPRESSIVE STRUCTURE.
C      WSS - WIDTH OF SUPPRESSIVE STRUCTURE.
C      HSS - HEIGHT OF SUPPRESSIVE STRUCTURE.
C      VCOEF - WELDING COEFFICIENT.
C      IOUT - OPTION NUMBER
C      COST - COST MATRIX FOR ALL 4 SUBUNITS.
C      DIMN - DIMENSION MATRIX FOR BEAMS AND PLATES.
C      AREA - AREA VECTOR FOR BEAMS.
C      WELDF - WELDING COST FACTOR
C      FABDFF - FABRICATION COST FACTOR
C      CUBST - COST PER LB. OF STEEL
C      CCYDC - COST PER CU.YD. OF CONCRET
C      ITYPE - TYPE OF PANEL CONFIGURATION
C
C      OUTPUT VARIABLES
C
C      TMATC - TOTAL MATERIAL COST
C      TWELC - TOTAL WELDING COST
C      TFABC - TOTAL FABRICATION COST
C      TFRMC - TOTAL FRAME COST
C      TPANL - TOTAL PANEL COST
C      TDORC - TOTAL DOOR COST
C      TFNDCC - TOTAL FOUNDATION COST
C      GTOTL - TOTAL COST OF SUPPRESSIVE SHIELDING STRUCTURE
C
C      ASSUMPTIONS OF THIS SUBROUTINE -

```

WLDCE = 1.16
 FARCF = 0.36
 CLBST = 0.26 \$/LB.
 CCYDC = 28.71

REAL LSS
 DIMENSION COST(4,3), DIMN(4,3), AREA(4)
 COMMON/ONE/WLDCE, FARCF, CLBST, CCYDC
 COMMON/TWO/ COST
 COMMON/THREE/IDISTY, DIMN, AREA, ITYPE
 DATA LP, IC076, 5/

FMTEC = 0.0
 FMUDC = 0.0
 FMABC = 0.0
 FMKMC = 0.0
 FMPLC = 0.0
 FMKAC = 0.0
 FMKDC = 0.0
 WLDCE = 1.16
 FARCF = 0.36
 CLBST = 0.26
 CCYDC = 28.71
 DO 10 I=1,3
 DO 20 J=1,4

10 COST(J,I) = 0.0
 PANTN = LSS/4.34
 PAKHT = FAS/2.208
 PANTK = 0.8333
 ORLWH = LSS/4.34
 ORKST = FAS/1.255
 ORTHK = 0.8333
 FOUNN = LSS/0.89
 FOUNH = FAS/0.552
 FOUNT = 2.2
 NSTEN = FAS/1.125
 CALL FRT1(WGTEF)
 CALL PANEL(PANTN, PAKHT, PANTK, VCOEF)
 CALL CURF(ORLWH, ORKST, ORTHK, VCOEF)
 CALL FRT2(FOUNN, FOUNH, FOUNT)
 WRITE (LP,20) IC076, ITYPE

COST 185
 COST 190
 COST 195
 COST 200
 COST 205
 COST 210
 COST 215
 COST 220
 COST 225
 COST 230
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 COST 315
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 COST 325
 COST 330
 COST 335
 COST 340
 COST 345
 COST 350
 COST 355
 COST 360
 COST 365
 COST 370
 COST 375
 COST 380

```

IF (ITYPE,LT,3)WRITE (LP,30) LSS,WSS,HSS
IF (ITYPE,GE,3)WRITE (LP,40) LSS,WSS,HSS,VCOEFF
WRITE (LP,50) ENSTY,CLUST,WLDCF,FAECF
WRITE (LP,60)
WRITE (LP,70) COST(1,1),COST(1,2),COST(1,3)
WRITE (LP,80)
WRITE (LP,90) COST(2,1),COST(2,2),COST(2,3)
WRITE (LP,90)
WRITE (LP,70) COST(3,1),COST(3,2),COST(3,3)
WRITE (LP,100)
WRITE (LP,70) COST(4,1),COST(4,2),COST(4,3)
DO 110 I=1,4
  INTLC = INTLC + COST(1,1)
  INTLDC = INTLDC + COST(1,2)
  TFAEC = TFAEC + COST(1,3)
110 CONTINUE
DO 120 I=1,3
  TFERC = TFERC + COST(1,1)
  TPVLC = TPVLC + COST(2,1)
  TDORC = TDORC + COST(3,1)
  TFNCC = TFNCC + COST(4,1)
120 CONTINUE
GTOTL = INTLC + INTLDC + TFAEC
WRITE (LP,130) TFERC,TFERC,TPVLC,TDORC
WRITE (LP,140) INTLC,INTLDC,TFAEC,GTOTL
RETURN
60 FORMAT(' ',///,' FRAME COSTS')
80 FORMAT(' ',///,' PANEL COSTS')
90 FORMAT(' ',///,' DOOR COSTS')
100 FORMAT(' ',///,' FOUNDATION COSTS')
20 FORMAT('1',///,' OPTION NUMBER ',12,' - COST ESTIMATION OF SUPPRESSCO
AVE SHIELDING STRUCTURE',///,' TYPE OF PANEL CONFIGURATION IS ',12COST 540
*)
40 FORMAT(' LENGTH OF SUPPRESSIVE STRUCTURE = ',F10.5,/, ' WIDTH OF COST 550
SUPPRESSIVE STRUCTURE = ',F10.5,/, ' HEIGHT OF SUPPRESSIVE STRUCTUCOST 555
SE = ',F10.5,/, ' VENTING COEFFICIENT FOR PANEL = ',F10.5) COST 560
30 FORMAT(' LENGTH OF SUPPRESSIVE STRUCTURE = ',F10.5,/, ' WIDTH OF COST 565
SUPPRESSIVE STRUCTURE = ',F10.5,/, ' HEIGHT OF SUPPRESSIVE STRUCTUCOST 570
SE = ',F10.5,/)
70 FORMAT(' 8X, MATERIAL',5X, ' WELDING ',3X, 'FABRICATION',/,3F1COST 580

```

```

25.2)
140 FORMAT(//,13X,'TOTAL MATERIAL',5X,'TOTAL WELDING',7X,'TOTAL FABRI',COST 585
#7X,'TOTAL COST',/,17X,'COST',13X,' COST ',8X,'CATION COST',7XCOST 590
#10X,STRUCTURE',//,5X,4(4X,F15.2))
130 FORMAT(//,13X,'TOTAL COST OF',7X,'TOTAL COST OF',6X,'TOTAL COST OCOST 600
#6X,'TOTAL COST OF',/,15X,'FOUNDATION',12X,'FRAME',14X,'PANELS',COST 610
#12X,'DOOR',//,5X,4(4X,F15.2))
50 FORMAT(//,12X,'DENSITY OF STEEL =',F15.2,' LB/CU.FT',/,7X,'COSCOST 615
#1 PER LB. OF STEEL =',F15.2,' $ / LB.',/,9X,'WELDING COST FACTOCOST 620
#2 =',F15.3,/,5X,'FABRICATION COST FACTOR =',F15.3)
END COST 630
COST 635

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C
C SUBROUTINE PANEL(PANLN,PANHT,PANTK,PANVC,VCOEF)
C
C THIS SUBROUTINE CALCULATES MATERIAL, WELDING, AND FABRICATION COST OF
C THE PANEL PORTION OF A CUSC SUPPRESSIVE SHIELDING STRUCTURE.
C
C DIMENSION COST(4,3),DIMN(4,3),AREA(4),
C CUMVCL/CNE/WLUCF,FACCF,CLEST,CCYDC
C COMMON/TAU/COST
C COMMON/THREE/ DNSTY,DIMN,AREA, ITYPE
C IF (ITYPE.EQ.2)GO TO 10
C IF (ITYPE.EQ.3)GO TO 20
C IF (ITYPE.EQ.4)GO TO 30
C WAB1 = 42.*(AREA(2)*PANLN)*DNSTY
C WAB2 = 54.*(AREA(4)*PANLN)*DNSTY
C KGPPL = 4.0*(DIMN(4,3)*PANHT*PANLN)*DNSTY
C KGCPL = 2.0*(PANHT*PANTK*0.58)*DNSTY/12.0
C TWCPL = (KGCPL*100.0/36.0)+WGPPL+WAB1+WAB2
C TWCPL = TWCPL*24.
C
C CALCULATING COSTS OF PANEL CONSTRUCTION
C
C COST(2,1) = TWCPL*CLCST
C COST(2,2) = COST(2,1)*WLDCF
C COST(2,3) = COST(2,1)*FACCF
C RETURN
C
C VCPPL = 0.55
C DIMN(2,3) = 0.25
C B = DIMN(2,3)/(1.414/2.0-VCPPL)
C NARR = 2*WAB1/B
C WAB1 = NARR*(AREA(2)*PANLN)*DNSTY
C WAB2 = 0.0
C VGPPL = 3.0*(DIMN(4,3)*PANHT*PANLN)*DNSTY
C GO TO 40
C
C VCPPL = VCOEF*2
C B = DIMN(1,2)/(1.-2.*VCPPL)

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PANE 5
 PANE 10
 PANE 15
 PANE 20
 PANE 25
 PANE 30
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 PANE 75
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 PAVE 85
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 PAVE 100
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 PANE 115
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 PAVE 140
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PANE 185
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 PANE 245
 PANE 250
 PANE 255

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NIRM = (PANT/R)*2.-1.
WIRM = NIRM*PANELN*ART4(1)*DNSTY
WGAB1 = WIRM
WGAB2 = 0.0
WGPP1 = 0.0
GO TO 40
30 VCPPL = 2.*VCOEF
R = CIRM(3,1)/(1.-VCPPL)
NPIPE = (PANT/R)*2.-1.
NPIPE = NPIPE*AREA(3)*PANELN*DNSTY
WGAB1 = NPIPE
WGAB2 = 0.0
WGPP1 = 0.0
GO TO 40
END

```



```

NIBV = NIP*CRU*VH*AREA(I)*DNSTY
RCAP1 = NIBV
RCAP2 = 0.0
RCAPL = 0.0
DO 10 I=1
30 VCCPL = 2.0*VCCOF
S = CRU*(V1)/(1.-VCCPL)
V1P2 = (CRU*GT/102.-1.
NIP1 = NIP*AREA(I)*CRU*VH*DNSTY
V1P2 = NIP*2
V1P2 = 0.0
RCAP1 = 0.0
RCAPL = 0.0

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DOOR 185
DOOR 190
DOOR 195
DOOR 200
DOOR 205
DOOR 210
DOOR 215
DOOR 220
DOOR 225
DOOR 230
DOOR 235
DOOR 240
DOOR 245
DOOR 250

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C
C
C SUBROUTINE FNDT (FONLN,FONVH,FONHT)
C
C THIS SUBROUTINE CALCULATES MATERIAL, WELDING, AND FABRICATION COST OFFNDT
C THE FOUNDATION PORTION OF A CURIC SUPPRESSIVE SHIELDING STRUCTURE.
C
C
C DIMENSION COST(4,3),DIMN(4,3),AREA(4),
C CORRCL/ONE/WLDCI,FACCF,CLBST,CCYDC
C CORRCL/100/ COST
C CORRCL/THREE/ ISTY,DIMN,AREA,ITYPE
C FOTHK = 0.57
C
C CALCULATING VOLUME AND COST OF CONCRETE NEEDED
C
C
C VOLVC = (FONVH*FONVH*FONHT-(FONLN-2.*FOTHK)
C # * (FONLN-2.*FOTHK))*(FONHT-FOTHK))/27.0
C CCNCT = VOLVC * CCYLC
C
C CALCULATING COSTS OF THE SLAB
C
C
C COST(4,1) = CCNCT * 100./75.
C COST(4,2) = 0.0
C COST(4,3) = COST(4,1)*FACCF
C RETURN
C END
FNDT 5
FNDT 10
FNDT 15
FNDT 20
FNDT 25
FNDT 30
FNDT 35
FNDT 40
FNDT 45
FNDT 50
FNDT 55
FNDT 60
FNDT 65
FNDT 70
FNDT 75
FNDT 80
FNDT 85
FNDT 90
FNDT 95
FNDT 100
FNDT 105
FNDT 110
FNDT 115
FNDT 120
FNDT 125

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* 2.8750, 3.5000, 4.0000, 4.5000, 5.5630, 6.6250, 8.6250, DATA 185
* 10.7750, 0.8430, 1.2150, 1.9000, 2.3750, 2.8750, 3.5000, DATA 190
* 4.0000, 4.5000, 5.5630, 6.6250, 8.6250, 1.0500, 1.3150, DATA 195
* 1.9000, 2.3750, 2.8750, 3.5000, 4.5000, 5.5630, 6.6250, DATA 200
* / DATA 205
* DATA 210
* DATA 215
* DATA 220
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* DATA 370
* DATA 375
* DATA 380

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DATA (LIST(J,1),J=113,150) /

* 8.6250, /

* 3750, /

DATA (LIST(J,2),J=1,28) /

* 11.5000, 7.5000, 7.5000, 8.7500, 8.7500, 11.7500, 9.2500, DATA 230

* 18.2500, 9.0000, 13.0000, 9.0000, 9.0000, 12.0000, 14.0000, DATA 235

* 16.0000, 10.0000, 16.0000, 16.0000, 16.0000, 14.5000, 14.5000, DATA 240

* 12.0000, 10.0000, 8.0000, 6.7500, 12.0000, 12.0000, 10.0000, DATA 245

* / DATA 250

DATA (LIST(J,2),J=29,56) /

* 8.0000, 6.5000, 10.0000, 10.0000, 8.0000, 5.7500, 8.0000, DATA 255

* 6.0000, 5.5000, 5.2500, 7.0000, 8.5000, 1.0000, 1.0000, DATA 260

* 1.0000, 1.2500, 1.2500, 1.5000, 1.5000, 1.7500, 1.7500, DATA 265

* 2.0000, 2.0000, 2.0000, 2.5000, 2.5000, 2.5000, 2.5000, DATA 270

* / DATA 275

DATA (LIST(J,2),J=57,84) /

* 3.0000, 3.0000, 3.0000, 3.0000, 3.5000, 3.5000, 3.5000, DATA 280

* 6.0000, 4.0000, 4.0000, 4.0000, 5.0000, 5.0000, 5.0000, DATA 285

* 9.0000, 6.0000, 6.0000, 6.0000, 8.0000, 8.0000, 8.0000, DATA 290

* 8.4000, 8.4000, 8.4000, 1.0500, 1.6600, 1.9000, 2.3750, DATA 295

* / DATA 300

DATA (LIST(J,2),J=85,112) /

* 2.3750, 3.5000, 4.0000, 4.5000, 5.5630, 6.6250, 8.6250, DATA 310

* 10.7750, 0.8430, 1.2150, 1.9000, 2.3750, 2.8750, 3.5000, DATA 315

* 4.0000, 4.5000, 5.5630, 6.6250, 8.6250, 1.0500, 1.3150, DATA 320

* 1.9000, 2.3750, 2.8750, 3.5000, 4.5000, 5.5630, 6.6250, DATA 325

* / DATA 330

DATA (LIST(J,3),J=1,28) /

* 0.7950, 0.6950, 0.4950, 0.9110, 0.860, 0.8310, 0.7400, DATA 335

* 0.5220, 0.7750, 0.9250, 0.5750, 0.5820, 0.7750, 1.1350, DATA 340

* 0.9400, 0.6700, 3.0330, 2.0930, 1.0630, 1.0630, 0.6880, DATA 345

* 0.7700, 0.6400, 0.5280, 0.3830, 1.7360, 0.6060, 0.5760, DATA 350

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* /
DATA (LIST(I,J),J=29,56) /
* 0.5160, 0.4000, 1.2480, 0.5590, 0.4330, 0.3400, 0.9330,
* 0.4330, 0.3980, 0.3090, 0.4260, 0.6450, 0.1250, 0.1875,
* 0.2500, 0.1250, 0.2500, 0.1250, 0.2500, 0.2500,
* 0.1250, 0.1875, 0.2500, 0.3750, 0.1875, 0.2500, 0.5000
* /
DATA (LIST(I,J),J=57,84) /
* 0.1875, 0.2500, 0.3750, 0.5000, 0.2500, 0.3750, 0.5000,
* 0.2500, 0.3750, 0.5000, 0.3750, 0.8750, 0.5000, 0.3100,
* 0.3100, 0.5000, 0.7500, 1.0000, 0.5000, 0.7500, 1.0000,
* 0.2600, 0.0800, 0.0910, 0.1130, 0.1400, 0.1450, 0.1540
* /
DATA (LIST(I,J),J=85,112) /
* 0.2030, 0.2160, 0.2260, 0.2370, 0.2580, 0.2800, 0.3220,
* 0.3050, 0.1470, 0.1760, 0.2000, 0.2180, 0.2760, 0.3000,
* 0.3120, 0.3370, 1.9130, 0.4320, 0.5000, 0.3080, 0.3580,
* 0.4000, 0.4360, 0.5520, 0.5000, 0.6740, 0.7500, 0.8640
* /
DATA (LIST(I,J),J=113,150) /
* 1.0000,
* 37.0 /
DATA (LIST(I,J),I=1,150), J=4,7) / 600*0./
END

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DATA 385
DATA 390
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DATA 500

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Sample Computations:

OPTION NUMBER 2 - COST ESTIMATION OF SUPPRESSIVE SHIELDING STRUCTURE

TYPE OF PANEL CONFIGURATION IS 1

LENGTH OF SUPPRESSIVE STRUCTURE = 16.41660
 WIDTH OF SUPPRESSIVE STRUCTURE = 11.51000
 HEIGHT OF SUPPRESSIVE STRUCTURE = 10.40620

DENSITY OF STEEL = 490.00 LB/CU.FT
 COST PER LB. OF STEEL = 0.25 \$ / LB.
 WELDING COST FACTOR = 1.160
 FABRICATION COST FACTOR = 0.390

FRAME COSTS

MATERIAL	WELDING	FABRICATION
6501.61	7541.86	2535.63

PANEL COSTS

MATERIAL	WELDING	FABRICATION
14577.11	16909.44	5685.07

DOOR COSTS

MATERIAL	WELDING	FABRICATION
1350.74	1566.86	526.79

FOUNDATION COSTS

MATERIAL	WELDING	FABRICATION
343.15	0.00	133.63

TOTAL COST OF FOUNDATION	TOTAL COST OF FRAME	TOTAL COST OF PANELS	TOTAL COST OF DOOR
-----------------------------	------------------------	-------------------------	-----------------------

476.97	16579.09	37171.61	3444.40
TOTAL MATERIAL COST	TOTAL WELDING COST	TOTAL FABRI CATION COST	TOTAL COST OF STRUCTURE
22772.60	26018.16	8881.31	57672.06

OPTION NUMBER 3 - DESIGN OF BEAMS AND PLATES OF SUPPRESSIVE SHIELDING PANELS

PANEL CONFIGURATION 1

DIMENSION FOR TYPE 2 BEAM IS 3.0000 3.0000 0.2500

WEIGHT OF CHARGE = 12.700
 WIDTH OF STRUCTURE = 11.510
 DISTANCE FROM CHARGE TO PERSON = 9.950
 SIDE ON PRESSURE = 8.820

VENTING COEFFICIENT IS CALCULATED AS 0.03134

IMPULSIVE PRESSURE = 0.210
 EQUIVALENT BEAM WIDTH = 0.814
 LENGTH OF BEAM = 44.875
 TYPE OF BEAM = 2
 SAFETY FACTOR = 1.25
 MODULUS OF ELASTICITY = 0.3000000E 08
 PLASTIC YIELD MOMENT = 37963.1780
 PLASTIC BENDING MOMENT = 648.254

THICKNESS CALCULATED FOR DYNAMIC LOADING IS 0.16887 IN.

THICKNESS CALCULATED FOR QUASI-STATIC LOADING IS 0.06837 IN.

IMPULSIVE PRESSURE = 0.210
 QUASI-STATIC PRESSURE = 70.000
 CALCULATED VENTING COEFFICIENT PER PLATE = 0.125345
 CALCULATED EFFECTIVE THICKNESS PER PLATE = 0.048268

NUMBER OF DRILLED HOLES REQUIRED IS 11520 GIVEN THAT THE DIAMETER OF HOLE IS 0.187500 IN.

GIVEN - WEIGHT OF PRIMARY FRAGMENTS = 7000.00
 VELOCITY OF PRIMARY FRAGMENT = 1500.000

THICKNESS OF PLATE REQUIRED TO STOP ALL PRIMARY FRAGMENTS IS 0.363451N.

THICKNESS OF PANEL DESIGNED IS ABLE TO CONTAIN ALL PRIMARY FRAGMENTS.

THICKNESS OF EACH PERFORATED PLATE IS DESIGNED TO BE 0.048268 IN.

OPTION NUMBER 3 - COST ESTIMATION OF SUPPRESSIVE SHIELDING STRUCTURE

TYPE OF PANEL CONFIGURATION IS 1

LENGTH OF SUPPRESSIVE STRUCTURE = 16.41680
 WIDTH OF SUPPRESSIVE STRUCTURE = 11.51000
 HEIGHT OF SUPPRESSIVE STRUCTURE = 10.40620

DENSITY OF STEEL = 490.00 LB/CU.FT
 COST PER LB. OF STEEL = 0.26 \$ / LB.
 WELDING COST FACTOR = 1.160
 FABRICATION COST FACTOR = 0.390

FRAME COSTS

MATERIAL	WELDING	FABRICATION
6501.61	7541.86	2535.63

PANEL COSTS

MATERIAL	WELDING	FABRICATION
12766.19	14808.78	4978.81

DOOR COSTS

MATERIAL	WELDING	FABRICATION
1214.78	1409.15	473.76

FOUNDATION COSTS

MATERIAL	WELDING	FABRICATION
343.15	0.00	133.83

TOTAL COST OF FOUNDATION	TOTAL COST OF FRAME	TOTAL COST OF PANELS	TOTAL COST OF DOOR

475.97	16579.09	32553.78	3097.69
TOTAL MATERIAL COST	TOTAL WELDING COST	TOTAL FABRI CATION COST	TOTAL COST OF STRUCTURE
20925.72	23759.78	8122.02	52707.53

OPTION NUMBER 1

FOLLOWING IS A LIST OF BEAMS REQUESTED THAT ARE STRONG ENOUGH FOR PRESSURE LOADING REQUIREMENTS

TYPE	HEIGHT	WIDTH	THICKNESS	MYIELD	MBEND	AREA
IMPULSIVE PRESSURE = 2.00000						
QUASI STATIC PRESSURE = 500.00000						
1	16.00000	11.50000	0.79500	5910878.00	886162.00	29.74109
1	18.00000	7.50000	0.69500	3950952.00	510255.10	21.96896
1	18.00000	7.50000	0.49900	2906352.00	701970.10	15.96902
1	18.00000	8.75000	0.91100	5849329.00	497307.30	30.68073
1	18.00000	8.75000	0.68600	4528252.00	651706.80	23.41199
1	18.00000	11.75000	0.83100	7173219.00	831094.30	33.10547
1	21.00000	8.25000	0.74000	5453088.00	508367.90	26.65491
1	21.00000	6.25000	0.52200	3936892.00	712754.70	19.03015
1	21.00000	9.00000	0.79500	6330666.00	542753.40	29.74109
1	21.00000	13.00000	0.86500	9756595.00	860065.50	39.15881
1	24.00000	9.00000	0.87500	8033636.00	458337.60	35.21875
1	24.00000	9.00000	0.58200	5491869.00	679191.80	23.76660
1	24.00000	12.00000	0.77500	9465765.00	797163.80	35.99890
1	24.00000	14.00000	1.13500	15573470.00	692012.60	56.44385
1	24.00000	14.00000	0.90000	12616280.00	854535.10	45.18018
1	27.00000	10.00000	0.63600	7517950.00	695225.10	29.08313

1	14.00000	16.00000	3.03300	18773240.00	421210.10	121.11980
1	14.00000	16.00000	2.09300	15094340.00	582939.00	87.51585
1	14.00000	16.00000	1.06300	9016923.00	1093890.00	46.63806
1	14.00000	14.50000	1.06300	8182429.00	964333.10	43.44910
1	14.00000	14.50000	0.68800	5610537.00	1453112.00	28.63733
1	14.00000	12.00000	0.77800	5195569.00	1012115.00	28.35352
1	14.00000	10.00000	0.64300	3667833.00	947390.60	21.03514
1	14.00000	8.00000	0.52800	2467549.00	834567.20	15.29246
1	14.00000	6.75000	0.38300	1553710.00	866781.60	10.23913
1	12.00000	12.00000	1.73600	8146322.00	508194.20	56.46861
1	12.00000	12.00000	0.60600	3497352.00	1361235.00	21.08160
1	12.00000	10.00000	0.57600	2794356.00	1121565.00	17.76946
1	12.00000	8.00000	0.51600	2034612.00	916546.20	13.91554
1	12.00000	6.50000	0.40000	1316595.00	869809.30	9.68004
1	10.00000	10.00000	1.24800	4251817.00	580582.60	34.32500
1	10.00000	10.00000	0.55800	2211057.00	1235464.00	16.11732
1	10.00000	8.00000	0.43300	1415851.00	1171933.00	10.88307
1	8.00000	8.00000	0.93300	2071647.00	617607.60	20.65103
1	16.00000	7.00000	0.42800	2068364.00	782846.30	12.47566
1	16.00000	8.50000	0.64500	3647752.00	703972.80	20.45297

2	2.50000	2.50000	0.18750	19740.98	13492.31	0.90234
2	2.50000	2.50000	0.25000	26462.05	18212.94	1.18750
2	2.50000	2.50000	0.50000	54854.52	38449.54	2.25000
2	3.00000	3.00000	0.18750	28367.28	11162.78	1.08984
2	3.00000	3.00000	0.25000	37963.79	15045.47	1.43750
2	3.00000	2.00000	0.37500	57548.93	23069.73	2.10938
2	3.00000	3.00000	0.50000	77857.94	31458.71	2.75000
2	3.50000	3.50000	0.25000	51556.80	12816.50	1.68750
2	3.50000	3.50000	0.37500	77938.44	19587.50	2.48438
2	3.50000	3.50000	0.50000	105043.00	26618.91	3.25000
2	4.00000	4.00000	0.25000	67240.94	11162.77	1.93750
2	4.00000	4.00000	0.37500	101464.60	17018.65	2.85938
2	4.00000	4.00000	0.50000	136412.30	23069.73	3.75000
2	4.00000	4.00000	0.87500	248011.30	42496.81	6.23438
2	5.00000	5.00000	0.87500	379758.60	52182.43	7.98438
2	5.00000	5.00000	0.50000	211696.30	18212.94	4.75000
2	5.00000	5.00000	0.31000	130269.30	11070.59	3.00391
2	6.00000	6.00000	0.31000	187318.00	9176.53	3.62392
2	6.00000	6.00000	0.50000	303710.30	15045.47	5.75000
2	6.00000	6.00000	0.75000	460391.00	23069.73	8.43750

2	6.00000	6.00000	1.00000	522863.80	31459.71	11.00000
2	8.00000	8.00000	0.50000	537927.80	11162.77	7.75000
2	8.00000	8.00000	0.75000	811717.00	17018.64	11.43750
2	8.00000	8.00000	1.00000	1091299.00	23069.73	15.00000
3	5.56300	5.56300	1.81300	727410.30	228143.20	21.35892
3	8.62500	8.62500	0.50000	1070768.00	917790.10	12.76275
3	5.56300	5.56300	0.75000	529193.00	429693.80	11.34039
3	6.62500	6.62500	0.86400	874691.30	441955.40	15.63733
3	8.62500	8.62500	1.00000	1793659.00	489986.30	23.95470

APPENDIX B

CATEGORY DEFINITION AND ILLUSTRATIONS OF SUPPRESSIVE STRUCTURES

Suppressive structures are divided into seven categories according to the specific hazard parameters present. Table IV shows the definition of these seven categories and their representative operations.

Pictures and blue prints of suppressive structures included in this appendix are obtained from Edgewood Arsenal, Aberdeen Proving Ground, Maryland. They illustrate two different applications of suppressive shielding concept and construction details of suppressive shield components. Figures 16, and 17 show the Chemical Agent Munition Disposal Suppressive Shield (CAMD) which was constructed and tested at Dugway Proving Ground, Utah. As we can see, CAMD has the four basic components of all cubical suppressive shields, i.e. frame, panel, door, and foundation. Figures 18 and 19 show the inside wall of CAMD after testing. Arrows show where fragments hit the panels.

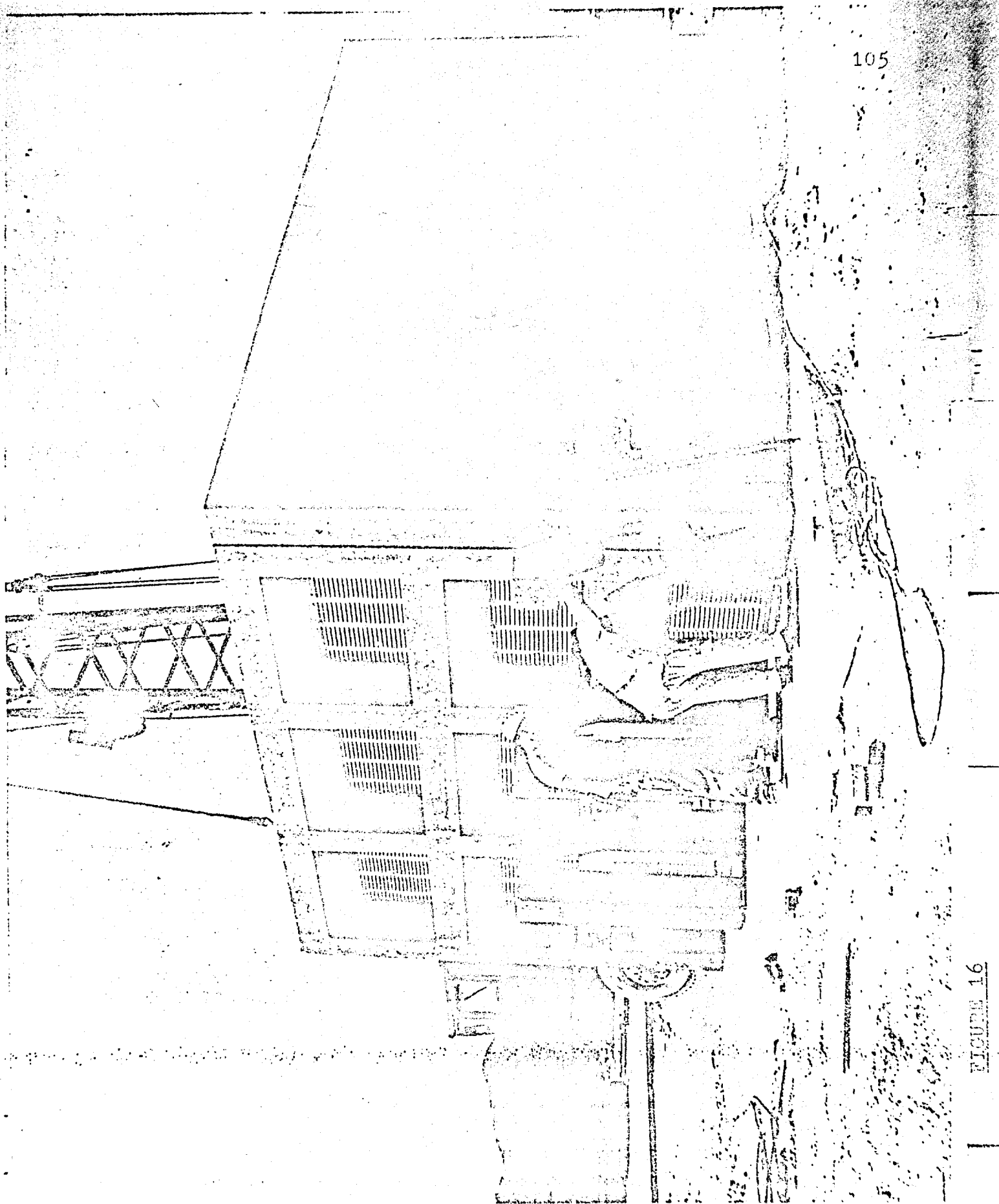
Figures 20 and 21 illustrates another type of suppressive structure - the Explosive Ordnance Disposal Transportable Suppressive Shield (EOD). It was also constructed at Dugway Proving Ground and its testing was successful. Blue prints

of test fixture assembly of Category 1 suppressive shield are shown in figures 22 and 23. A typical frame design of cubical suppressive shields is also shown in figure 24.

SUPPRESSIVE SHIELD CATEGORY DEFINITIONS

<u>Category</u>	<u>Hazard Parameters</u>	<u>Representative Operations</u>
1	Extreme blast pressure (500-1200 psi)* Severe fragmentation	Melt loading (2500# batch) Major caliber projectile processing Bulk loading operations
2	High blast pressures (200-500 psi) Moderate to severe fragmentation	Mini melt applications High explosives processing (boosters, bursters, etc.) High explosives bulk to 500 lbs.
3	High blast pressures (200-500 psi) Light fragments	Munition components, detonators, fuzes
4	Moderate blast pressures (50-200 psi) Moderate to severe fragmentation	Processing of rounds with limited bay capacity Smaller explosives bulk approximately 200 lbs in conventional cubicles Large bulk operation (to 500 lbs) in larger process rooms/areas
5	Light blast pressures (less than 50 psi) Light to moderate fragmentation Flame propagation potential	Bulk propellant processing Bulk pyrotechnic processing Light metal or plastic HE components Limited numbers of HE rounds
6	Ultra high blast pressure (500-2000 psi) Light to moderate fragmentation	Close in protection of small quantities explosive laboratory, handling and transportation
7	Moderate blast pressure (500-200 psi) Severe fragmentation	Chemical munitions Pyrotechnics

TABLE IV



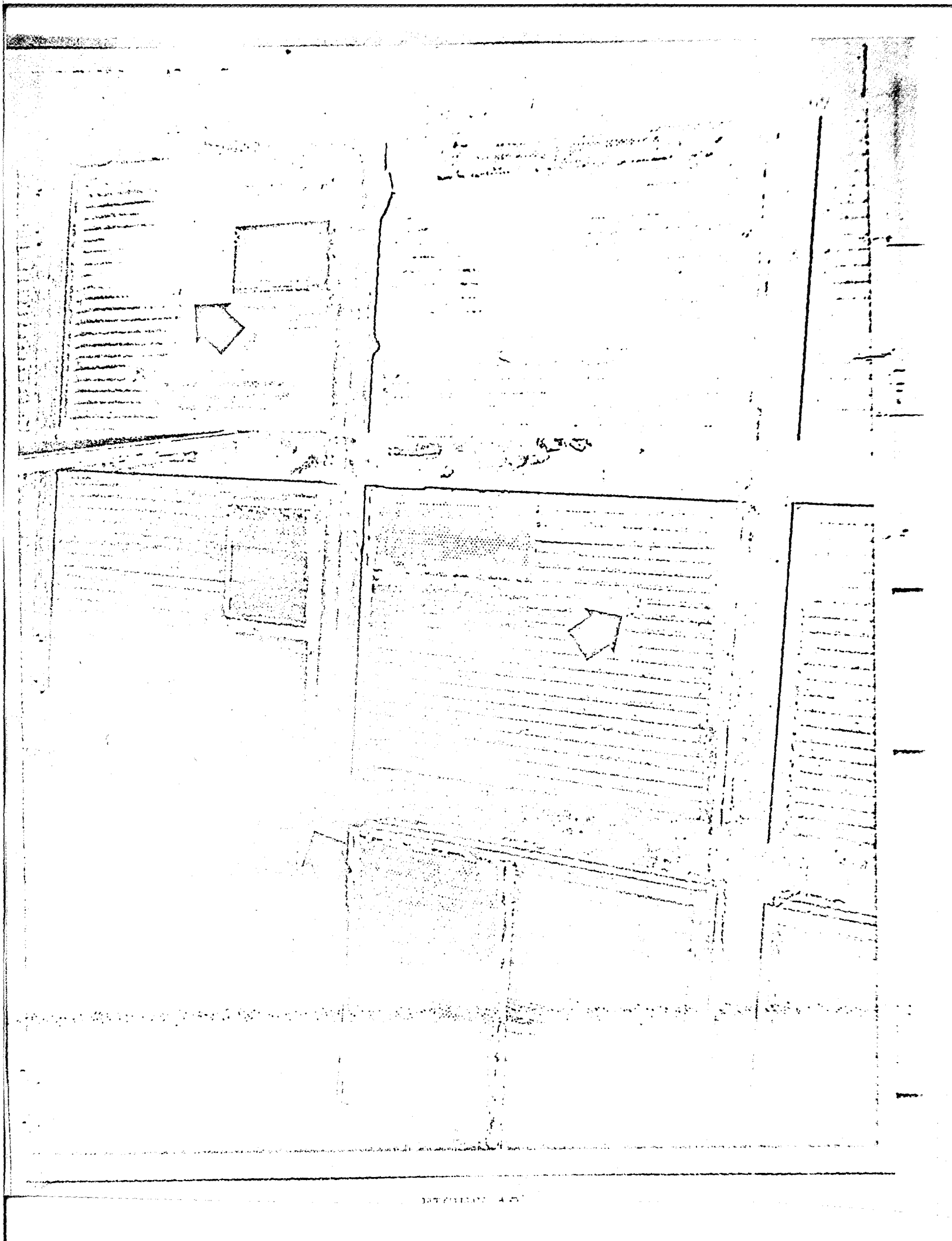




FIGURE 12

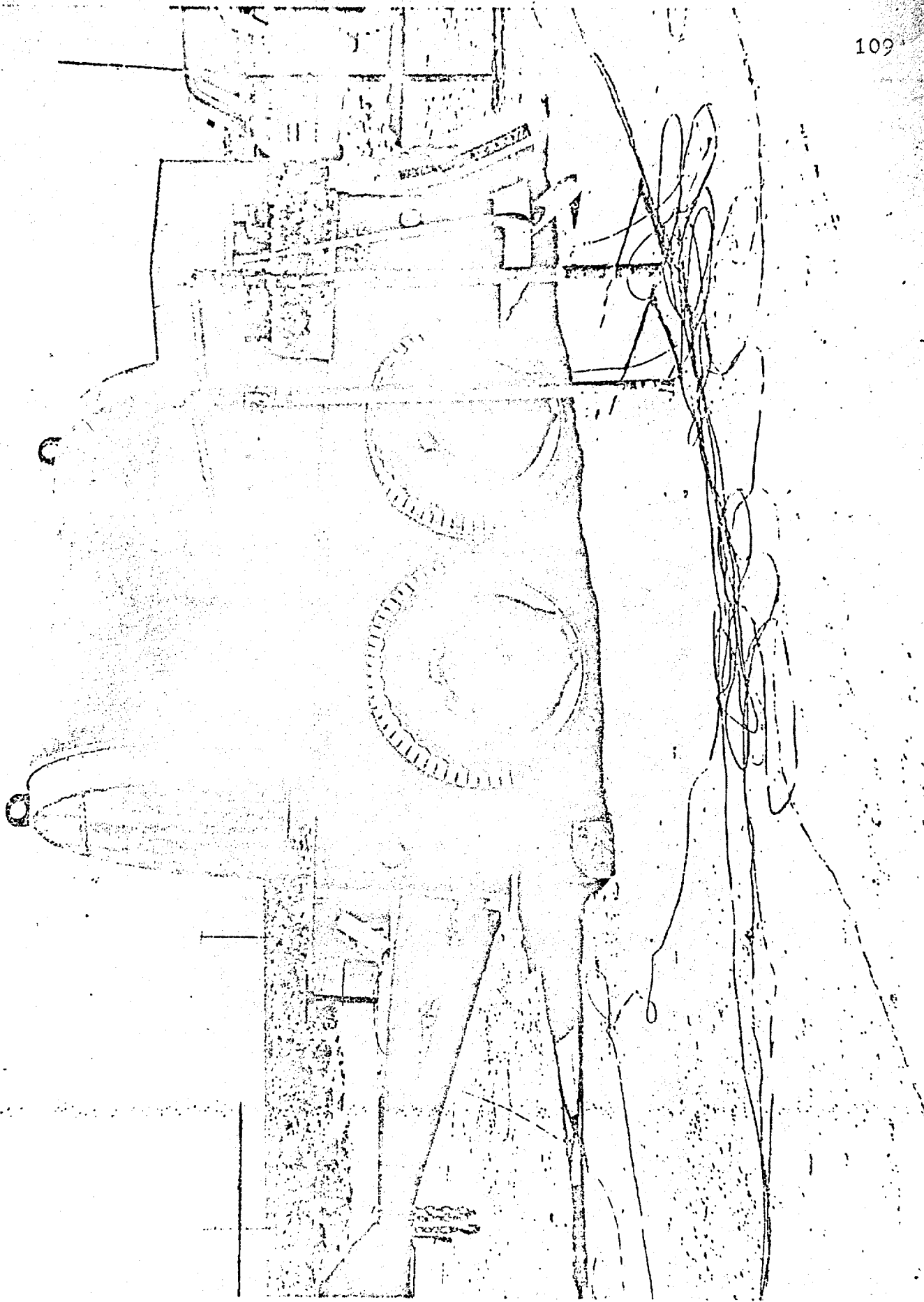
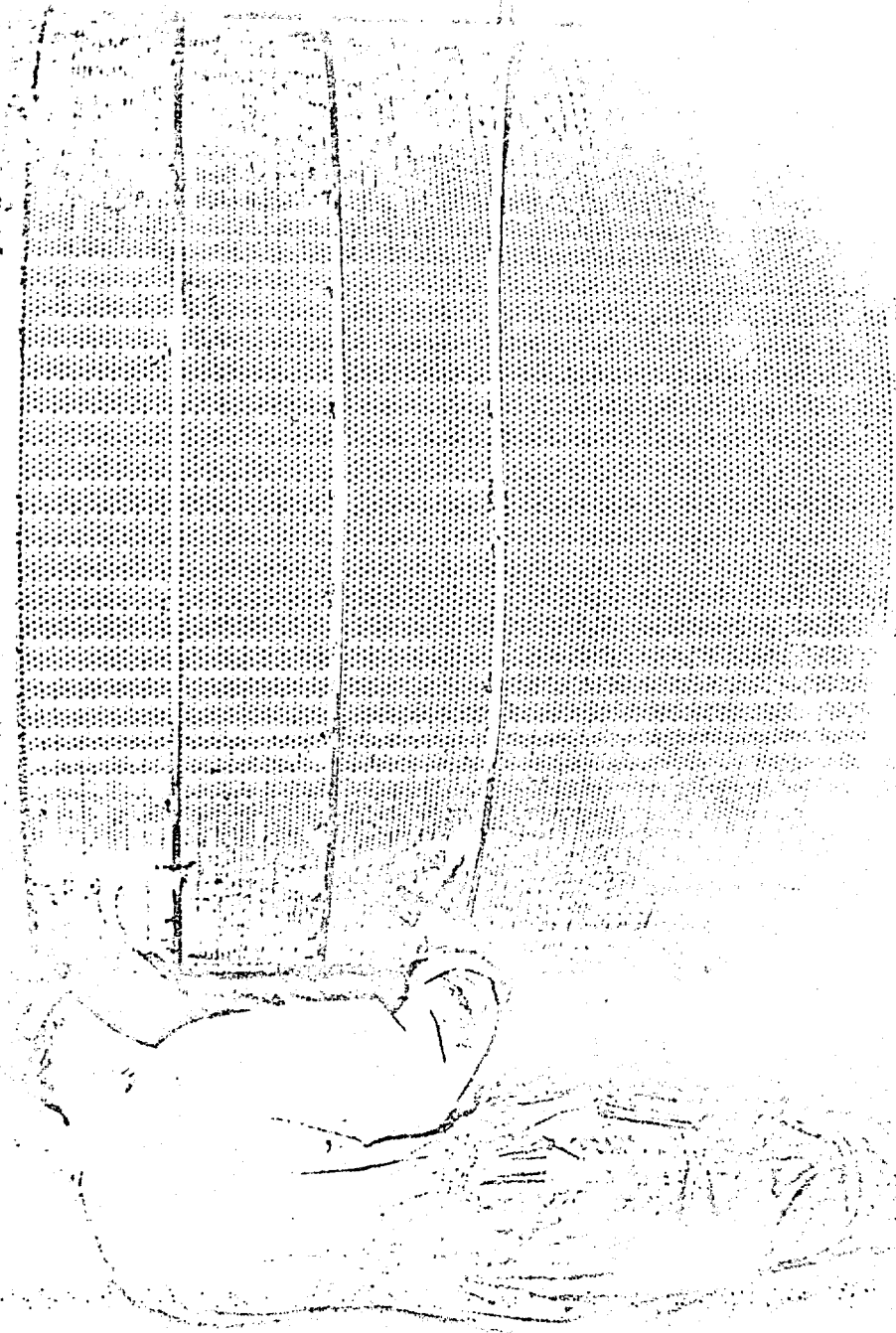
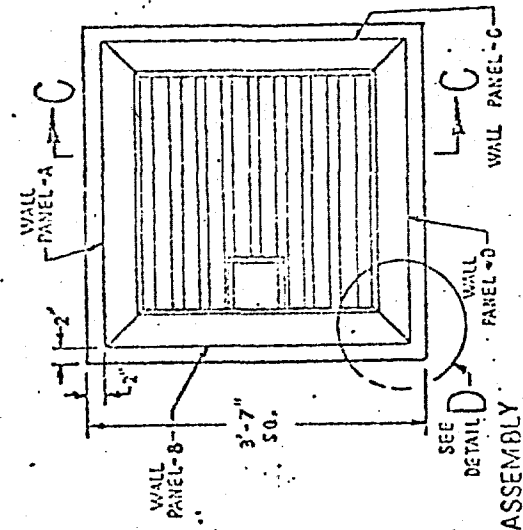


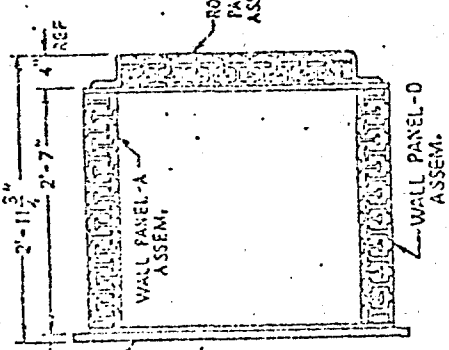
FIGURE 20



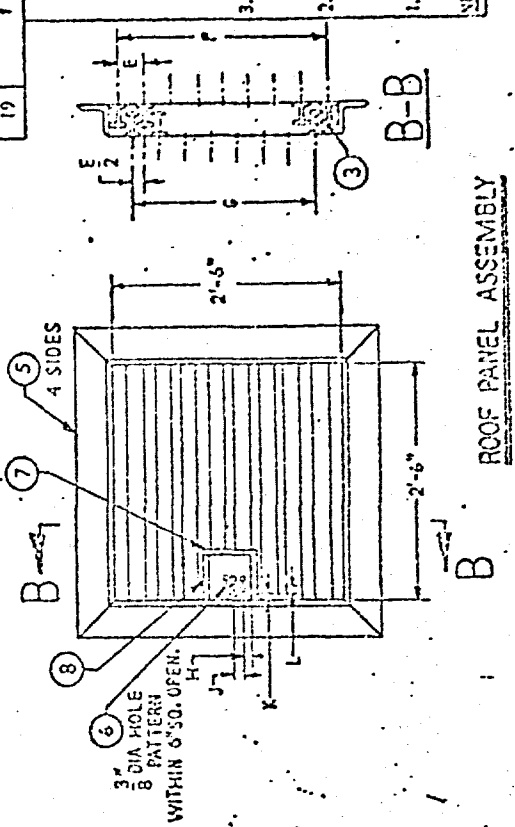
PART	MATERIAL
1	4" X 4" X 1/2" L X 2'-6" LG.
2	1/2" X 4" X 3'-2" LG. WILD STL.
3	3" X 5.71" X 2'-6" LG.
4	1" SCH. 40 STL PIPE X 5'10" L
5	4" X 4" X 1/2" L X 3'-2" LG.
6	1/2" X 7" X 7" WILD STL. PL.
7	1/2" X 4" X 7" STL. FL.
8	1/2" X 4" X 6" STL. PL.
9	3/4" X 3'-7" SO. STEEL FL.
10	1/2" X 5" X 2'-7" LG.
11	10 GA PL X 2'-6" SO. PERF. W/TH 1/8" Ø HOLES ON 1" P.C. 1/2" LG.
12	1" X 1" L X 1/8" X 2'-6" STR. STL.
13	3/16" PL X 2'-6" SO. PERF. W/TH 3/16" Ø HOLES ON 1" P.C. 1/2" LG.
14	1 1/4" X 1 1/4" L X 3/16" X 2'-6" LG.
15	3/16" PL X 2'-6" SO. PERF. W/TH 3/16" Ø HOLES ON 1" P.C. 1/2" LG.
16	3/16" PL X 2'-6" SO. PERF. W/TH 3/16" Ø HOLES ON 1/2" CENT. LG.
17	1" SCH. 40 STL PIPE X 3' 3/4" LG.
18	X 4' 1/4" LG.
19	X 3' LG.



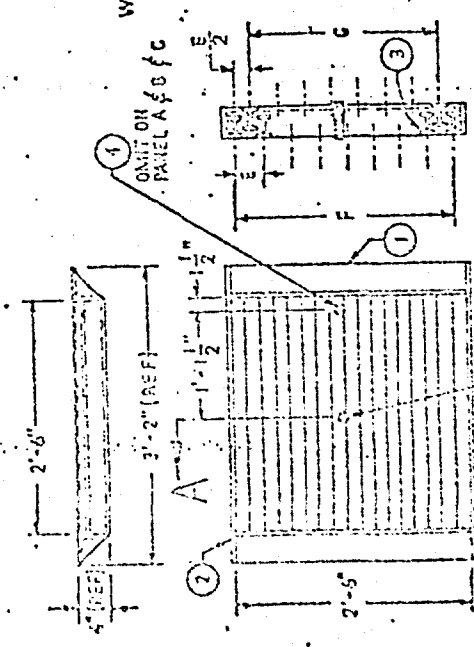
TEST FIXTURE FINAL ASSEMBLY



DETAIL D
TYP. WALL CORNER



ROOF PANEL ASSEMBLY



WALL PANEL ASSEMBLY

- NOTES:
1. PARTS 5, 17, 18, 19 ARE THREADED INSERTS - 1/2" - 20
 2. ALL ASSEMBLED ARE OF CONTINUOUS FINISH WELD CONSTRUCTION
 3. THIS DRAWING NOT TO SCALE WITHOUT SHEET 2.

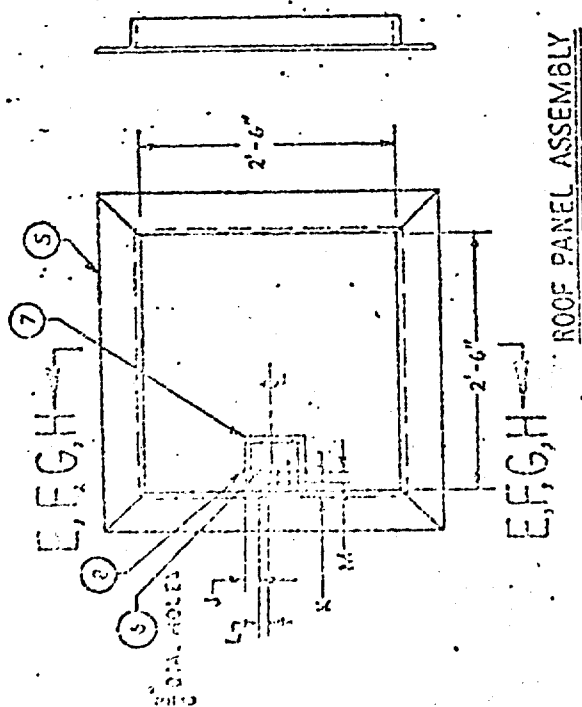
CAL I
TEST FIXTURE ASSEMBLY
I BEAM STRUCTURE
(TYPE 1, 3 & 5)
SHEET 1 OF 2

TYPE	H	J	K	L	HOLES	REQ'D.
1	312	500	543	530	132	1
3	412	559	415	639	81	1
5	608	795	608	795	119	1

TYPE	E	F	G	CO. SPACED, SPIN	REQ'D.
1	7	7	7	7	4
3	10	10	10	10	4
5	13	13	13	13	4

FIGURE 22

FIGURE 23



HOLES IN DOOR DIMENSIONS				
	J	K	L	M
OPTION 1	2"	2"	1 1/2"	1"
OPTION 2	1 1/2"	1 3/4"	1"	1 3/4"
OPTION 3	1 1/2"	1 1/2"	1"	1"
OPTION 4	1 1/4"	1 1/4"	3/4"	3/4"

ROOF PANEL ASSEMBLY

4. **PART II — 1090 HOLE PLATE
PART 13 — 1216
PART 15 — 1595
PART 16 — 3249

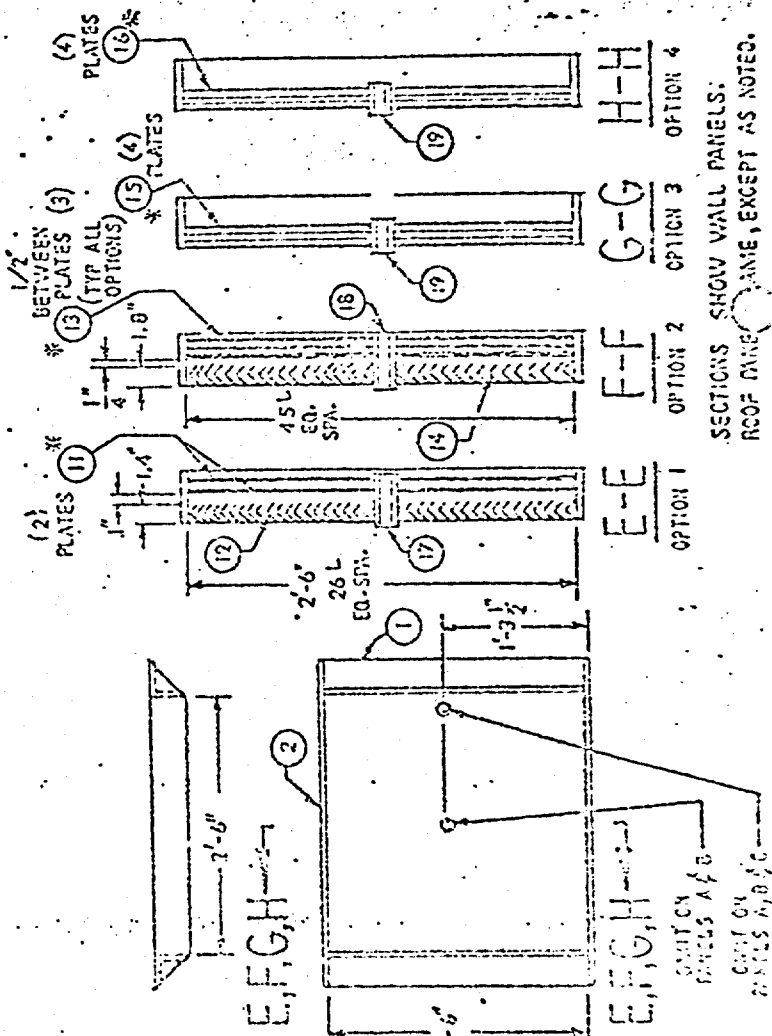
ALL PERF. PLATE MUST BE CUT AND
ALIGNED SO THAT HOLES DO NOT
LINE UP (LINE OF SIGHT)

3. THIS DRAWING NOT COMPLETE
WITHOUT SHEET 1.

2. SEE SHEET 1 FOR MATERIAL &
NEXT ASSEMBLY.

1. DIMEN. NOT SHOWN ARE SAME AS PREV.
DIMEN. ON SHEET 1.

NOTES



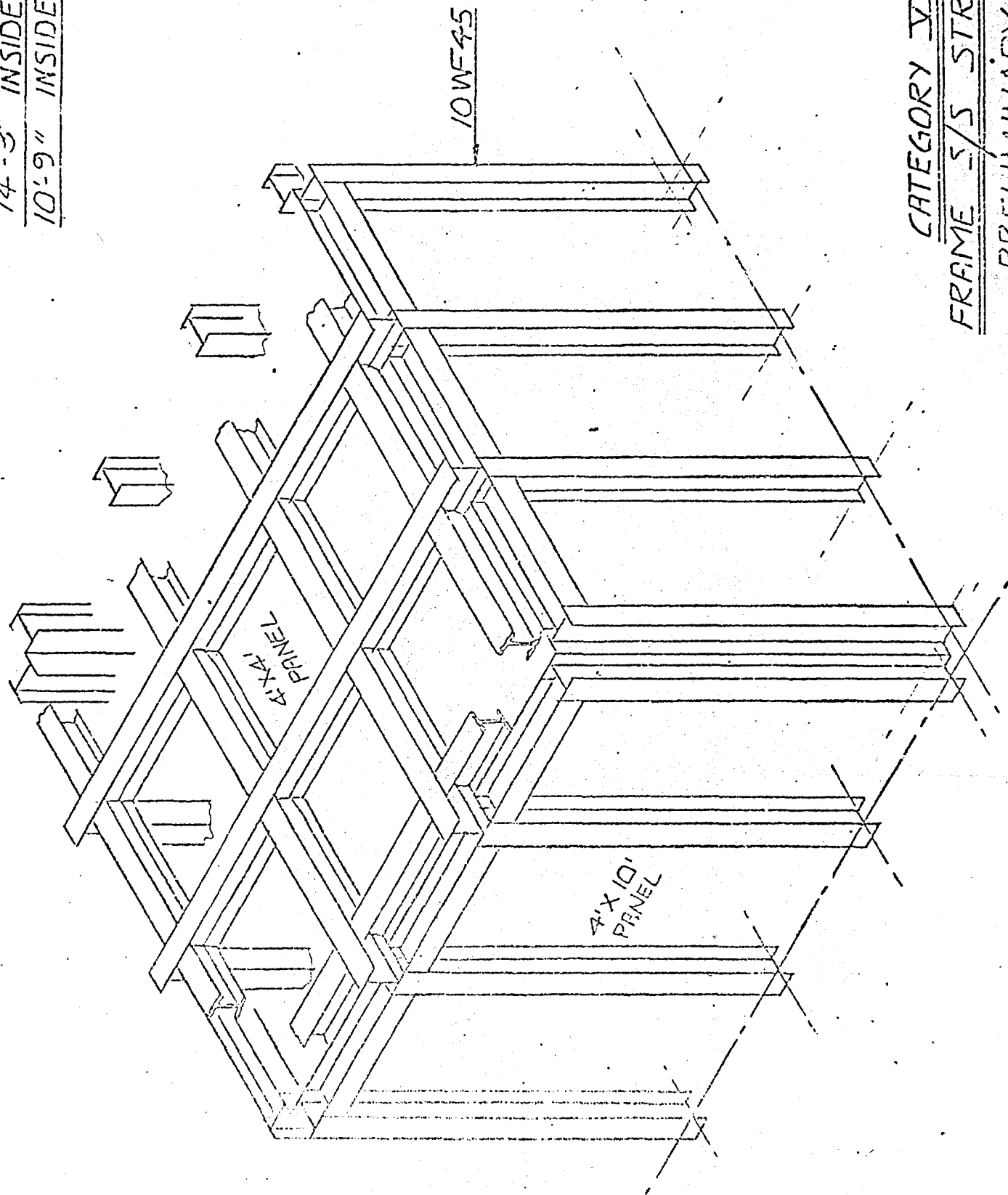
CAT. I
TEST FIXTURE ASSEMBLY
ANGLE & PLATE STRUCTURE
(OPTIONS 1, 2, 3 & 4)

SECTIONS SHOW WALL PANELS:
ROOF DRING SAME EXCEPT AS NOTED.

14'-3" INSIDE DIM. SQ.
10'-9" INSIDE HEIGHT

FIGURE 24

CATEGORY V
FRAME S/S STRUCTURE
PRELIMINARY



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