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Technical Note

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author: J. M. Ferritto

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CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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A computer program was developed to determine the approximate nonlinear dynamic response of plates subjected to blast pressure loading. Given the explosive parameters and geometry of the plate, the program computes the blast environment and the structural resistance, mass, and stiffness of the plate and solves for the dynamic response. The program contains optimization subroutines that provide for automatic optimum design of least-cost plates. The program will assist engineers in the design and analysis of blast doors that are

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CONTENTS

	Page
INTRODUCTION	1
COMPUTER PROGRAM	2
PROGRAM INPUT	3
STRUCTURAL OPTIMIZATION	6
Fixed Variables	6
Design Parameters, X	6
Constraints, g(X)	6
Objective Function, F	7
APPROXIMATE COMPUTATION OF DOOR REACTION	8
DISCUSSION	9
REFERENCES	10
APPENDIX	26

INTRODUCTION

The Department of Defense (DOD) has numerous facilities engaged in the production of various types of explosives and munitions used by military services. In most cases the production of ammunition utilizes assembly line procedures. Projectiles pass through various stages of preparation: filling with explosive, fuzing, marking, and packing. Hazardous operations, such as the filling of the projectile case with an explosive in a powder form and the compaction of the powder by hydraulic press, are accomplished in protective cells that are intended to confine the effects of an accidental explosion.

Most of the existing production facilities were built in the 1940s. With few exceptions, the manufacturing technology and existing equipment represent the state-of-the-art at that time. The production equipment was operated extensively during World War II, again during the Korean conflict, and recently during the Southeast Asia war. Much of this equipment and the housing structures have been operating beyond their designed capacities (Ref 1).

DOD is conducting an ammunition plant modernization program (Ref 2) intended to greatly enhance safety in the production plants by protective construction, automated processing, and reduction of the number of personnel involved in hazardous operations.

In 1969 a joint-service manual (Ref 3) was published to provide guidance to the structural designers of munition plants. The objectives of the manual were to establish design procedures and construction techniques (1) to prevent propagation of explosions from one building (or part of a building) to another, (2) to prevent mass detonations, and (3) to protect personnel and equipment. The manual establishes blast-load parameters for designing protective structures, provides methods for calculating the dynamic response of concrete walls, and establishes construction details for developing required strength. The design method accounts for close-in effects of a detonation with its associated high pressures and nonuniformity of loading on protective barriers. A detailed method for assessing the degree of protection afforded by a protective facility did not exist prior to this manual's publication; consequently, the manual represents a significant improvement in design methods. The simplifications made in the development of the design procedures have been presented in the manual. The analysis of a structure using the design procedure will generally result in a conservative estimate of the structure's capacity; therefore, structures designed using these procedures will generally be adequate for blast loads exceeding the assumed load conditions (Ref 3).

Even with the simplifications presented in Reference 3, the computational procedures are complex and time-consuming. An automated procedure was required to give structural designers the capability of performing rapid analysis of the structural safety of blast-resistant walls and doors. The design parameters interact in a complex way since the procedure is both nonlinear and dynamic. From a design point of view an optimization procedure was required to minimize cost and maximize safety since blast-resistant construction has been reported to cost three to five times as much as conventional construction. Therefore, the first objective was to automate the analysis procedures for determining the structural response of plates having a bilinear stiffness representation and subjected to blast shock and gas pressures. Plates are the basic elements forming sidewalls, roofs, floors, and doors of cells designed to confine the effects of accidental explosions. The second objective was to provide an optimum design procedure that will automatically produce a least-cost design for a given geometry, material properties, and explosive weight for both feasible and nonfeasible starting points.

COMPUTER PROGRAM

The computer program was written in FORTRAN IV for use with Control Data 6600 series computers. The program is composed of four areas:

1. Blast Load Determination
2. Structural Analysis Parameters
3. Dynamic Response
4. Optimization

The blast-load determination is accomplished by subroutines BLA, PIC, SGRID, HBA, RATIO, GRID, GAS INTERP, EQUIV, HEDATA, ARDC, SHOCK, and TNT. The subroutines read the explosive weight and type and cell geometry, and then compute the equivalent spherical weight of TNT and the equivalent pressure loading using the geometry of the wall and charge location. Both the shock pressure and its duration and the gas pressure and its duration are calculated as in References 3 and 4. Using the duration and pressure data for both shock and gas, the program computes an equivalent triangular pressure loading for each part and adds both together to produce the resultant shown in Figure 1. The total impulse is then determined as in Reference 3.

The structural analysis is accomplished by subroutines SSTIFF, DOOR 1, DOOR 2, DOOR 3, DOOR 4 and DOOR 5. These routines compute the stiffness, resistance, and equivalent mass of the plate using input material properties as in Reference 3. Both flexure and shear are considered. Openings in plates are allowed as indicated in Figure 2c.

The dynamic response calculation is accomplished in subroutine RESP. The program determines the response of the plate modeled as an equivalent dynamic single-degree-of-freedom system with bilinear stiffness and the pressure loading shown in Figure 1. The solution technique is based on a Newmark iteration method.

When a thickness of sand is specified for composite construction (i.e., two plates with sandfill), the program computes the impulse capacity of the first plate using half the mass of the sand as acting with the wall as in Reference 3. Figures 6-38 and 6-39 of Reference 3 give the attenuation of the blast wave on sand for evaluation of the impulse capacity of the second wall.

The optimization of an initial design is accomplished in subroutines OPT, MINIMZ, PMINZ, DMINZ, GETE, SUMRY, TLEFT, and GCOMP. The methodology used is that of a penalty function with individual minimization sequences being accomplished by the Powell method (References 4,5,6).

PROGRAM INPUT

The program input consists of five or six cards per case. Additional cases can be grouped together. Two blank cards are used after the last case. The user's guide, contained in the program with comment cards, is given here to assist in understanding the input. Card format is 8F10.0 except as noted. Figure 2a is an input data sheet to be used in conjunction with Figures 2b and c, which show the slab geometry and orientation that must be followed. The input required for each card is described below.

CARD 1

COL 2	COL 68	HEADING
COL 69	COL 79	OPTIMIZATION 0 = NO OPTIMIZATION CALCULATION, 1 = OPTIMIZATION CALCULATION
COL 71	COL 72	FLAG 1 = 0 FOR PRESSURE CALCULATION, = 1 FOR INPUT PRESSURE (see Card 3)
COL 73	COL 74	FLAG 2 FOR TS OR Z: 0 = TS, 1 = INPUT Z
COL 75	COL 76	FLAG 3 FOR IMPULSE GRID: 0 = OMIT, 1 = GRID
COL 77	COL 78	FLAG 4 0 = NO DOOR, 1 = DOOR
COL 79	COL 80	FLAG 5 PRINT: DOOR EQUILIBRIUM ITERATION 0 = OMIT, 1 = PRINT

CARD 2

COL 1	COL 10	WEIGHT OF ACTUAL EXPLOSIVE, LB
COL 11	COL 20	EXPLOSIVE NUMBER, SEE TABLE 1
COL 21	COL 30	EXPLOSIVE LENGTH/DIAMETER RATIO
COL 31	COL 40	PROJECTILE CASE WEIGHT/EXPLOSIVE WEIGHT RATIO

COL 41	COL 50	AMBIENT PRESSURE PSIA (DEFAULT 14.69 PSI)
COL 51	COL 60	AMBIENT TEMPERATURE, °C (DEFAULT 20°)
COL 61	COL 70	ALTITUDE KFT (WHEN PRESSURE AND TEMPERATURE NOT SPECIFIED)
COL 71	COL 80	EFFECTIVE IMPULSE FRACTION COMPOSITE CONSTRUCTION (see Ref 3)

CARD 3

COL 1	COL 10	RA DISTANCE CHARGE TO WALL FT OR EQUAL IMPULSE PSI-MS IF FLAG 1 = 1.0
COL 11	COL 20	H WALL HEIGHT, FT
COL 21	COL 30	EL WALL LENGTH, FT
COL 31	COL 40	HLIT HEIGHT CHARGE FT OR EQUAL PRESSURE PSI IF FLAG 1 = 1.0
COL 41	COL 50	ELLIT DISTANCE CHARGE TO LEFT SIDE WALL FT
COL 51	COL 60	CELL VOLUME FOR GAS PRESSURE, FT^3
COL 61	COL 70	CELL VENT AREA FOR GAS PRESSURE, FT^2
COL 71		EQ 1 FOR FLOOR REFLECTION
COL 72		EQ 1 FOR ROOF REFLECTION
COL 73		EQ 1 FOR LEFT WALL REFLECTION
COL 74		EQ 1 FOR RIGHT WALL REFLECTION, OTHERWISE, EQ 0 FOR NO REFLECTION

CARD 4

COL 1	COL 10		DYNAMIC YIELD STRESS, PSI
COL 11	COL 20		PLATE THICKNESS, IN.
COL 21	COL 30		NSIDE NUMBER OF SIDES WALL FIXED
		1.0	BOTTOM SIDE FIXED
		2.0	BOTTOM AND SIDE FIXED
		3.0	2 SIDES AND BOTTOM FIXED
		4.0	4 SIDES FIXED
		5.0	SIMPLE SUPPORTED BEAM AT TOP AND BOTTOM
		6.0	FIXED BEAM AT TOP AND BOTTOM
		7.0	BEAM BOTTOM FIXED TOP SIMPLE
		13.0	3 SIDES SIMPLE, 1 SIDE FREE
		14.0	4 SIDES SIMPLE
COL 31	COL 40		PLATE HEIGHT IF NOT EQUAL TO H CARD 3, FT
COL 41	COL 50		PLATE WIDTH IF NOT EQUAL TO EL CARD 3, FT
COL 51	COL 60		ALLOWABLE DUCTILITY LIMIT FOR OPTIMIZATION
COL 61	COL 70		THICKNESS SAND, FT
COL 71	COL 80		E MODULUS OF ELASTICITY, PSI

CARD 5
IF OPTION = 1 ON CARD 1 COLUMN 73-74, OTHERWISE SKIP

COL 1	COL 10	Z HORIZONTAL SECTION MODULUS/IN., $IN.^3/IN.$
COL 11	COL 20	Z VERTICAL SECTION MODULUS/IN., $IN.^3/IN.$
COL 21	COL 30	AVERAGE MOMENT INERTIA/IN., $IN.^4/IN.$
COL 31	COL 40	DOOR WEIGHT TOTAL, LB

CARD 6
BLAST DOOR PARAMETERS
IF OPTION = 1 ON CARD 1 COLUMN 77-78, OTHERWISE SKIP

COL 1	COL 10	DOOR HEIGHT, FT
COL 11	COL 20	DOOR WIDTH, FT
COL 21	COL 30	DISTANCE FROM LEFT SIDE TO DOOR, FT
COL 31	COL 40	DOOR REACTION, LB/IN.
OR		
COL 41	COL 50	DOOR RESISTANCE FOR CALCULATION OF REACTION, PSI
COL 51	COL 60	DISTANCE TO FLOOR, FT

NOTE: All values are fixed point, except for reflection code and options.

The explosive number (Card 2) refers to the list of explosives in Table 1. This is used to compute explosive equivalence. The length/diameter ratio for an explosive sphere is 0.0, which gives a shape factor of 1.0. For an uncased explosive the case explosive weight ratio is 0.0. For sea level calculations, the ambient air pressure P_{amb}, and temperature T_{amb}, and altitude can be left blank and will default to 14.69 psi and 20°C. If the flag in the heading card is set to 1, the impulse, duration, and pressure will be read on Card 3. If the flag is left blank, the charge to wall distance, charge height, and distance from the left side will be read. If NSIDE is left blank, the program will sum the number of reflecting sidewall surfaces specified on Card 3. The separate use of NSIDE is helpful when a frangible wall is present, which creates a shock reflection but does not provide any support.

When optimization and composite construction are specified together, the program will optimize the design to resist the given or computed impulse. For the case when two walls are acting together—each resisting a portion of the impulse—it is necessary to specify the effective impulse to be applied to the wall under design. The total impulse is multiplied by the decimal number specified on Card 2. This procedure is based on similar work for concrete (Ref 4).

The NSIDE (see Figure 2b) conditions 1 through 4 are intended to be used to represent steel cell walls and roofs; NSIDE conditions 5 through 7 are steel plates spanning in one direction. The NSIDE conditions 13 and 14 are specifically intended to represent typical steel plate doors and pass-through windows.

STRUCTURAL OPTIMIZATION

The optimization problem consists of finding the least-cost structure that satisfies all the design constraints; or, stated in optimization terms: Find $\vec{X}$ such that $M(\vec{X})$ is a minimum and

$$g_j(\vec{X}) \leq 0 \qquad i = 1, 2, N$$

where $\vec{X}$ = vector of design variables

N = number of design constraints

g = vector of design constraints

M = objective function

Specifically for this problem, the design variables selected are areas of steel reinforcement and thickness of concrete. The design constraints are the flexural and shear limits. The objective function consists of the costs of formwork and concrete flexural and shear reinforcement.

Fixed Variables

W = explosive weight

H = height

EL = length

h = height of explosive above floor

ℓ = distance of explosive from left side of wall

R_a = distance of explosive from wall

I = reflection code

f = dynamic yield stress

μ = ductility

Design Parameters, X

$X = t$ (thickness of plate)

Constraints, $g(X)$

$\delta(X) = \delta(0)$, maximum deflection

$t \geq 0.05$ minimum thickness

$t \leq 20$ maximum thickness

The methodology (Ref 5 and 6) selected uses the unconstrained minimization approach. The problem is converted to an unconstrained minimization by constructing a function ϕ, of the general form

$$\phi(\vec{X},r) = M(\vec{X}) + P[g_1(\vec{X}), \ldots, g_n(\vec{X}), r]$$

For this problem the interior penalty function technique was selected. This methodology is suitable when gradients are not available, and, because the method uses the feasible region, a usable solution always results. The objective function is augmented with a penalty term that is small at points away from the constraints in the feasible region but increases rapidly as the constraints are approached. The form is as follows:

$$\phi(\vec{X},r) = M(\vec{X}) - r \sum_{j=1}^{N} \frac{1}{g_j(\vec{X})}$$

where M is to be minimized over all $\vec{X}$ satisfying $g(\vec{X}) < 0$, $j = 2 \ldots N$. Note that if r is positive, then, since at any interior point all of the terms in the sum are negative, the effect is to add a positive penalty to $M(\vec{X})$. As the boundary is approached, some $g(\vec{X})$ will approach zero, and the penalty will increase rapidly. The parameter, r, will be made successively smaller in order to obtain the constrained minimum of M.

Objective unction, F

$$\text{Cost} = F = H \cdot EL \cdot t \cdot C$$

where C = volumetric cost of material

$$\phi = F + r \sum_{j=1}^{N} \left[\frac{1}{g_j(\vec{X})}\right]$$

where r = penalty parameter.

The program requires a starting point in the feasible region before optimization can proceed. This is accomplished automatically by the program by incrementing the design variables until a feasible point is reached.

An algorithm which comprises the steps most commonly used is as follows:

1. Given a starting point X_o, satisfying all $g_j(\vec{X}) < 0$, and an initial value for r, minimize ϕ to obtain X_{min}.
2. Check for convergence of X_{min} to the optimum.

3. If the convergence criterion is not satisfied, reduce r by $r \leftarrow rc$, where $c < 1$.

4. Compute a new starting point for the minimization, initialize the minimization algorithm, and repeat from step 1.

The logic diagram for the interior penalty functions technique is shown in Figure 3.

The minimization for $\phi(\vec{X},r)$ shown in Figure 3 is accomplished by a method developed by Powell using conjugate directions (Ref 5 and 6).

Powell's method can be understood as follows: Given that the function has been minimized once in each of the coordinate directions and then in the associated pattern direction, discard one of the coordinate directions in favor of the pattern direction for inclusion in the next m minimizations, since this is likely to be a better direction than the discarded coordinate direction. After the next cycle of minimizations, generate a new pattern direction and again replace one of the coordinate directions. This process is illustrated in Figure 4.

Figure 5 is a logic diagram for the unconstrained minimization algorithm. The pattern move is constructed in block A, then used for a minimization step (blocks B and C), and then stored in S_n (block D) as all of the directions are up-numbered and S_1 is discarded. The direction S_n will then be used for a minimizing step just before the construction of the next pattern direction. Consequently, in the second cycle, both X and Y in block A are points that are minima along S_n, the last pattern direction. This sequence will impart special properties to $S_{n+1} = X - Y$ that are the source of the rapid convergence of the method.

Figure 5 shows a block requiring a one-dimensional minimization of α^* of the function $\phi(\vec{X} + \alpha\ S_q)$. The one-dimensional minimization uses a four-point cubic interpolation. It finds the minimum along the direction S_q, where $\vec{X}$ is the coordinate of the previous minimum. By trial and error it finds three points with the middle one less than the other two. It makes a quadratic interpolation and, then, a cubic interpolation. If the actual function evaluated at the new interpolated point is not sufficiently close to that of the preceding point, or if it is not sufficiently close to the interpolated function, then another cubic interpolation is made. The logic for this algorithm is shown in Figure 6.

APPROXIMATE COMPUTATION OF DOOR REACTION

It should be emphasized that this program is intended to assist in rapid approximate design and not detailed analysis. The basic procedures in References 3 and 4 and used herein have been found to be sufficiently accurate for simple geometries of beams and slabs without openings. Figure 7 compares deflections for a plate fixed on four sides and for a beam; the approximate solutions and the finite element solutions agree within about 10%. However, the static shear procedures suggested in Reference 3 are seen to be substantially below dynamic shears (Figure 8); this is a limitation of the approximate procedures and is under current investigation.

A steel door attached to a concrete wall was examined using a finite element technique. Figure 9 shows the slab and door; Figure 10 shows the deflection of the door by the approximate procedure developed herein and the finite element procedure. There is some disagreement in deflection, especially when one considers the deflecting top support. It should be particularly noted that the deflecting support condition for actual doors on slabs (modeled correctly by finite element and assumed rigid by approximate solution) absorbs significant amounts of energy by rigid-body/door motion. Thus, the resulting center door deflection is reduced. The resulting dynamic shear around the door (transferred to the wall) is reduced from what would be computed for a nondeflecting plate using approximate dynamic plate theory (Figure 11). The alternatives are to use finite element analysis procedures or to modify dynamic plate theory. Finite element analysis is certainly the better approach; however, it is basically an analysis technique and is more difficult and expensive to use than the simpler approximate procedure. It is suggested that the shear calculated from approximate plate theory be adjusted by a constant for use as a door reaction required for input to wall design (Ref 4).

The maximum reaction occurs at the moment the slab first reaches yield. At this point the combination of load and resistance is maximum. Table 2 gives maximum dynamic reaction for a simply supported plate. For the case of one side free and three sides simple-supported, the b-dimension doubled may be used. The values of pressure P and resistance R are taken from the computer output at the time of yielding. The reaction values should be adjusted for support deflection. The value of 1.0 is suggested for nondeflecting supports and 0.5 for full deflecting supports as approximate factors. Once design has been finalized it is suggested that results be analyzed using a finite element analysis.

DISCUSSION

This program was developed to perform rapid design of steel plates used to form the sides and roofs of blast cells and also of steel plates used as doors. Provisions are included for use of plastic section modules for built-up doors; but optimization of such doors may not be performed because the weight-strength function is not defined.

In general, the methods used in the computer program follow Reference 3; consequently, the accuracy of both is the same. These are discussed in detail in References 3 and 4 and will not be presented here. The solution of the dynamic response equation of motion has been found to agree very closely with the response chart of Reference 3. Additionally, the solution covers a wider range and, thus, is more accurate in the areas not defined by the response chart. When the loading is less than one hundredth of the natural period, the response is determined by impulse equilibrium. The basic dynamic model is limited to the primary response mode and does not consider higher modes.

The blast impulse computation is restricted to a geometry in which the slab's height-to-length ratio is greater than 0.2. A modification was made by the Naval Surface Weapons Center to the original Picatinny Arsenal Program to remove several minor problem areas, such as the location of the charge. The blast impulse has all the limitations associated with the original Picatinny programs that are caused by limitations in the test data. It assumes the charge is an equivalent sphere of TNT. Shape effects, explosive equivalence, and explosive casings are considered, but only in an empirical manner as a result of limited available data.

Example problems are presented in the Appendix.

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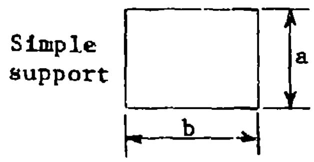
Table 1. List of Explosives

Explosive Number	Explosive Name and Composition
1	TNT
2	TNETB
3	EXPLOSIVE D
4	PENTOLITE (PETN/TNT 50/50)
5	PICRATOL (EXPLOSIVE D/TNT 52/48)
6	CYCLOTOL (RDX/TNT 70/30)
7	COMP B (RDX/TNT/WAX 59.4/39.6/1.0)
8	RDX/WAX (98/2)
9	COMP A-3 (RDX/WAX 91/9)
10	TNETB/AL (90/10)
11	TNETB/AL (78/22)
12	TNETB/AL (72/28)
13	TNETB/AL (65/34)
14	TRITONAL (TNT/AL 80/70)
15	RDX/AL/WAX (88/10/2)
16	RDX/AL/WAX (89/20/2)
17	RDX/AL/WAX (74/21/5)
18	RDX/AL/WAX (74/22/4)
19	RDX/AL/WAX (62/33/5)
20	TORPEX II (RDX/TNT/AL 42/40/18)
21	H6 (RDX/TNT/AL/WAX 45/29/21/5)
22	HBX-1 (RDX/TNT/AL/WAX 40/38/16/5)
23	HBX-3 (RDX/TNT/AL/WAX 31/29/35/5)
24	TNETB/RDX/AL (39/26/35)
25	ALUMINUM
26	WAX
27	RDX
28	PETN
29	TETRYL

Table 2. Four Sides, Uniform Load*



Strain Range	a/b	Dynamic Reactions**	
		V_A/b	V_B/a
Elastic	1.0	0.07P + 0.18R	0.07P + 0.18R
	0.9	0.06P + 0.16R	0.08P + 0.20R
	0.8	0.06P + 0.14R	0.08P + 0.22R
	0.7	0.05P + 0.13R	0.08P + 0.24R
	0.6	0.04P + 0.11R	0.09P + 0.26R
	0.5	0.04P + 0.09R	0.09P + 0.28R
Plastic	1.0	$0.09P + 0.16R_m$	$0.09P + 0.16R_m$
	0.9	$0.08P + 0.15R_m$	$0.09P + 0.18R_m$
	0.8	$0.07P + 0.13R_m$	$0.10P + 0.20R_m$
	0.7	$0.06P + 0.12R_m$	$0.10P + 0.22R_m$
	0.6	$0.05P + 0.10R_m$	$0.10P + 0.25R_m$
	0.5	$0.04P + 0.08R_m$	$0.11P + 0.27R_m$

*Based on information from Ref 7.

**P = pressure at time of yield, psi
R = resistance, psi
R_m = yield resistance, psi

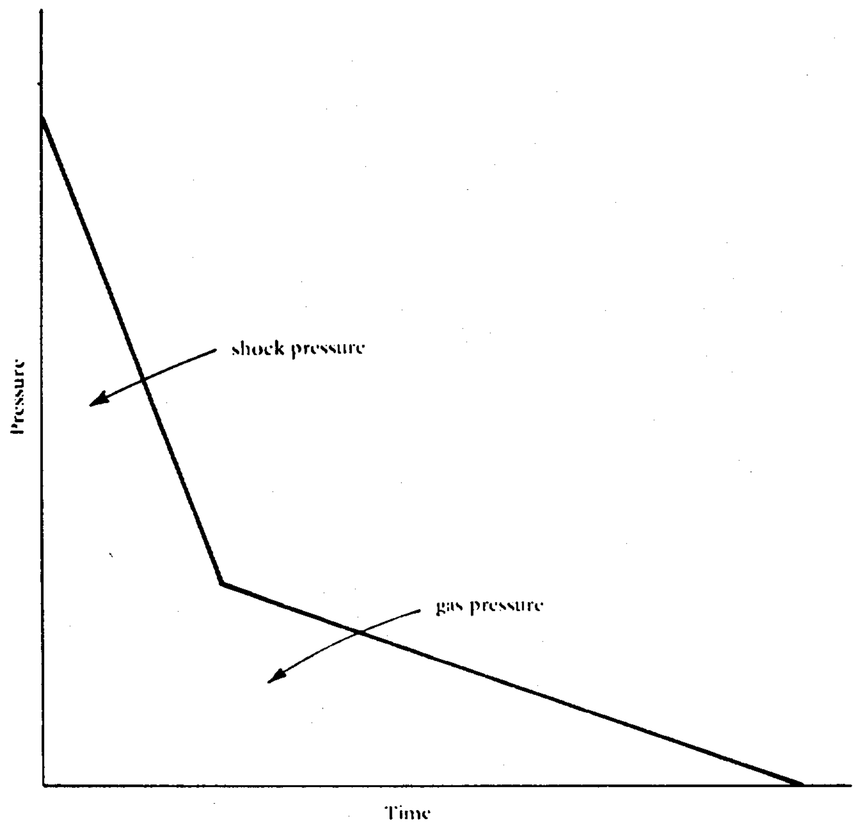


Figure 1. Equivalent pressure loading.

Format For Computer Program SDOOR

OPTIONS 0 or 1: Optimum = 1 | P = 0 or = 1 | T = 0 or Z = 1 | Grid = 1 | Opening = 1 | Door Pr = 1

CARD	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1	Heading							
2	W (lb)	Expl No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (°C)	Altitude (kft)	Fraction I used
3	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft)/P_o (psi)*	I (ft)/t_o (ms)*	Cell Vol (ft^3)	Vent Area (ft^2)	F R L R
4	FS (psi)	TS (in.)	N Side	DH (ft)	DEL (ft)	μ	T Sand (ft)	E
5	Z hor	Z ver	AICAV	WDR				
6	Door Height (ft)	Door Width (ft)	Dist to Left (ft)	Door Reaction (lb/in.)	Door RU (psi)	Dist to Floor (ft)		

FS	Steel stress (psi)
TS	Thickness steel plate (in.)
SN	Code
DH	Plate height if not equal to H (ft)
DEL	Plate width if not equal to L (ft)
μ	Ductility
TSand	Sand thickness (ft)

Option T/Z = 1

Z hor	Plastic Z Section mod horizontal
Z ver	Plastic Z Section Mod vertical
AICAV	Average I moment inertia
WDR	Door weight (lb)

N Side

1	Bottom fixed
2	2 sides fix, 2 free
3	3 sides fix, 1 free
4	4 sides fix
5	Simple beam H
6	Fix Beam H
7	Fix/simple beam
13	3 sides simple, 1 free
14	4 sides simple

Figure 2a. Input data form.

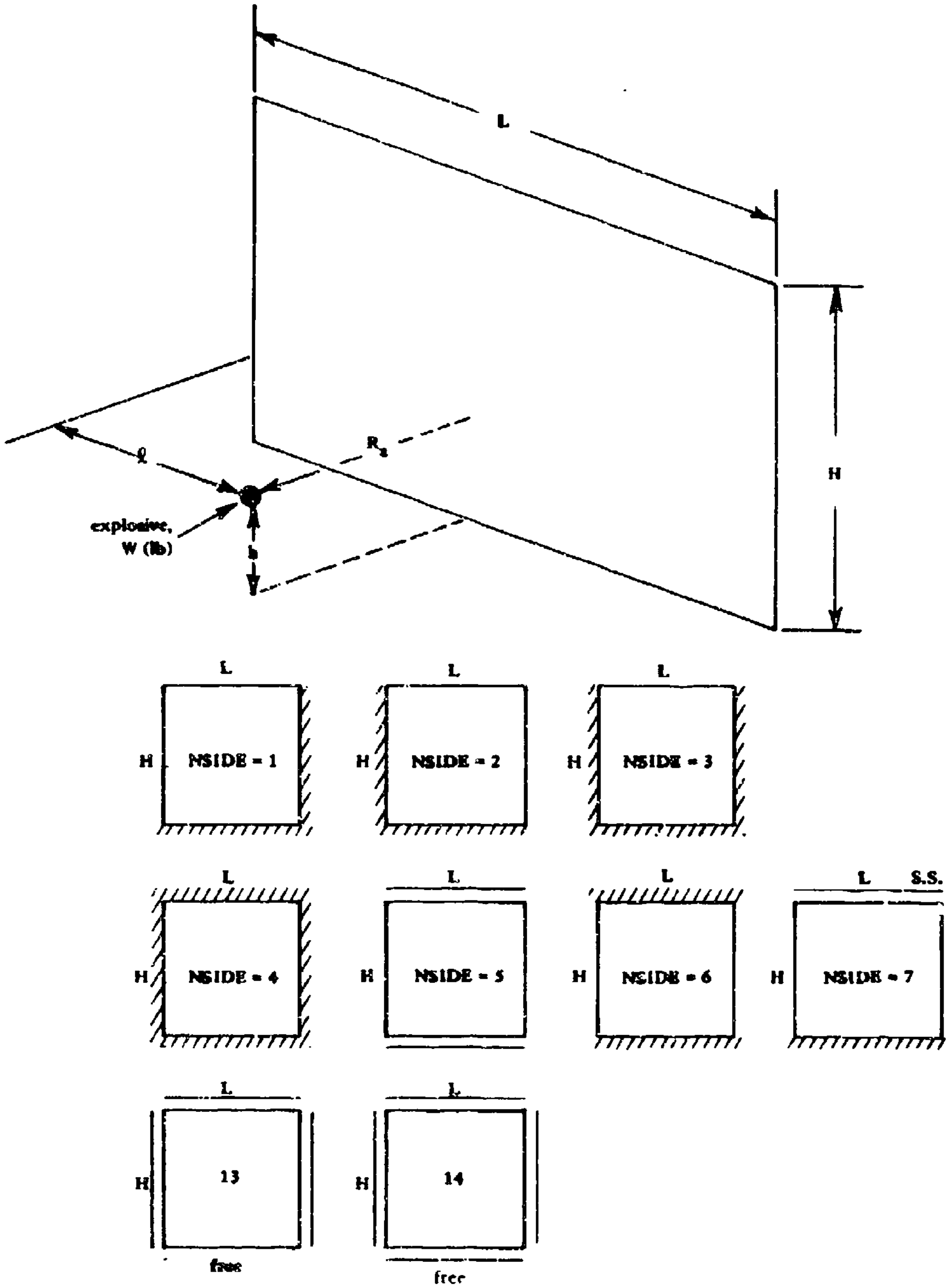
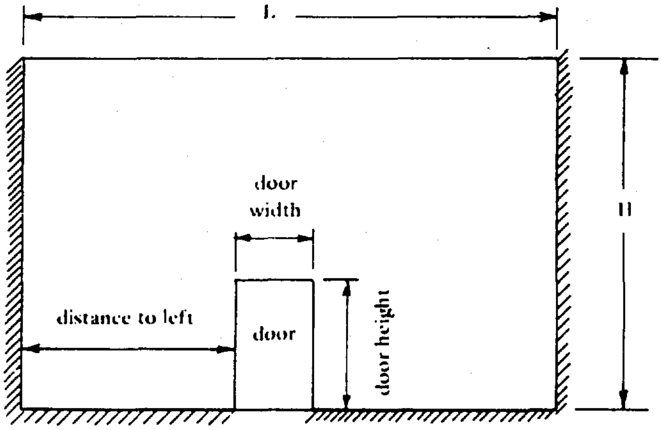
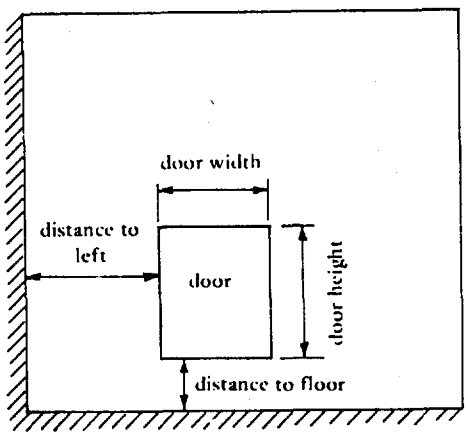


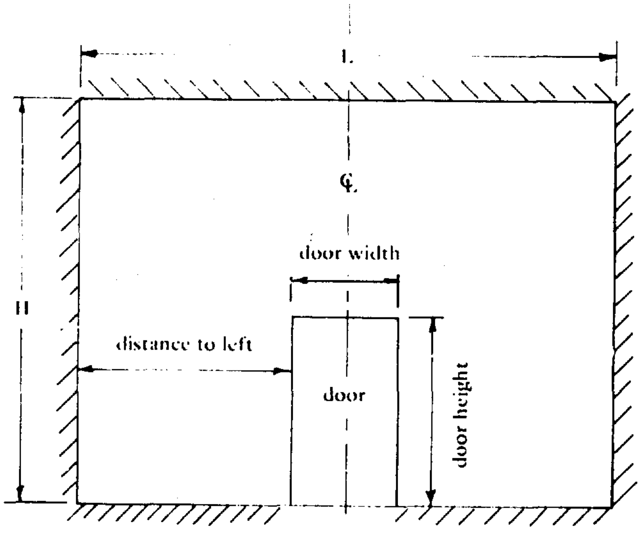
Figure 2b. Wall geometry.



Wall three sides supported with door.



Two sides supported with opening.



*Note opening must be in center of wall.

Wall four sides supported with opening.

Figure 2c. Plate geometry with opening for door.

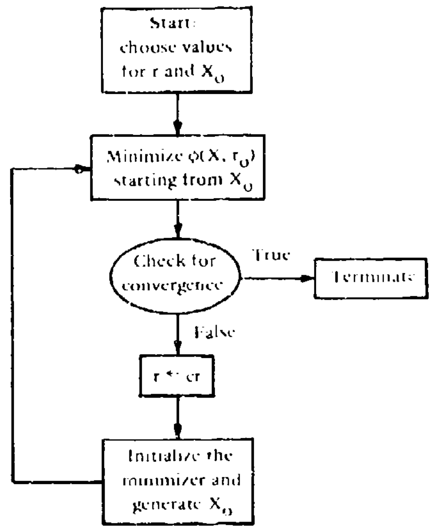


Figure 3. Logic diagram for interior penalty function technique.

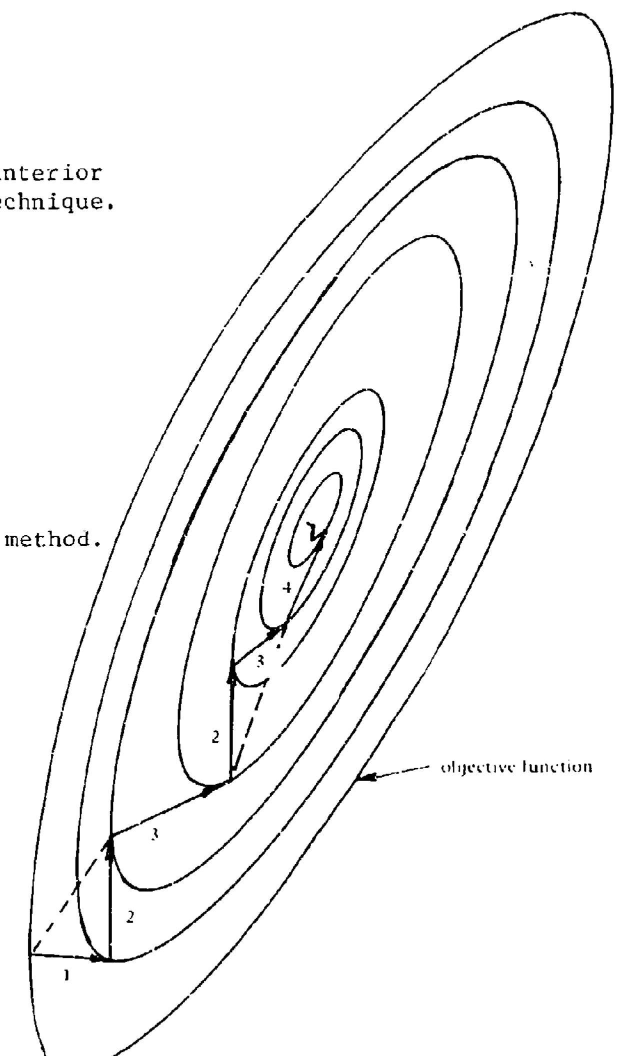


Figure 4. Step process, Powell method.

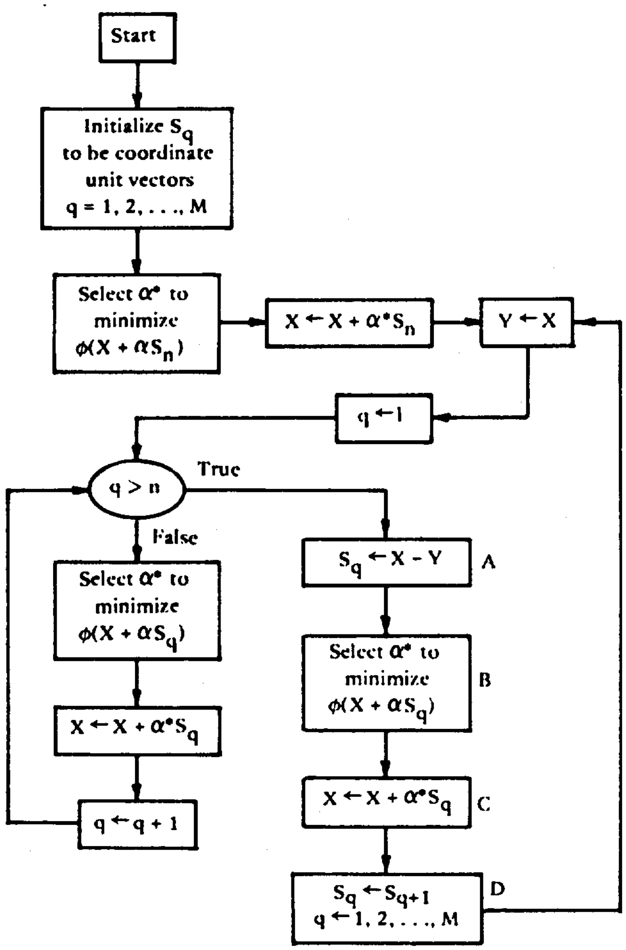
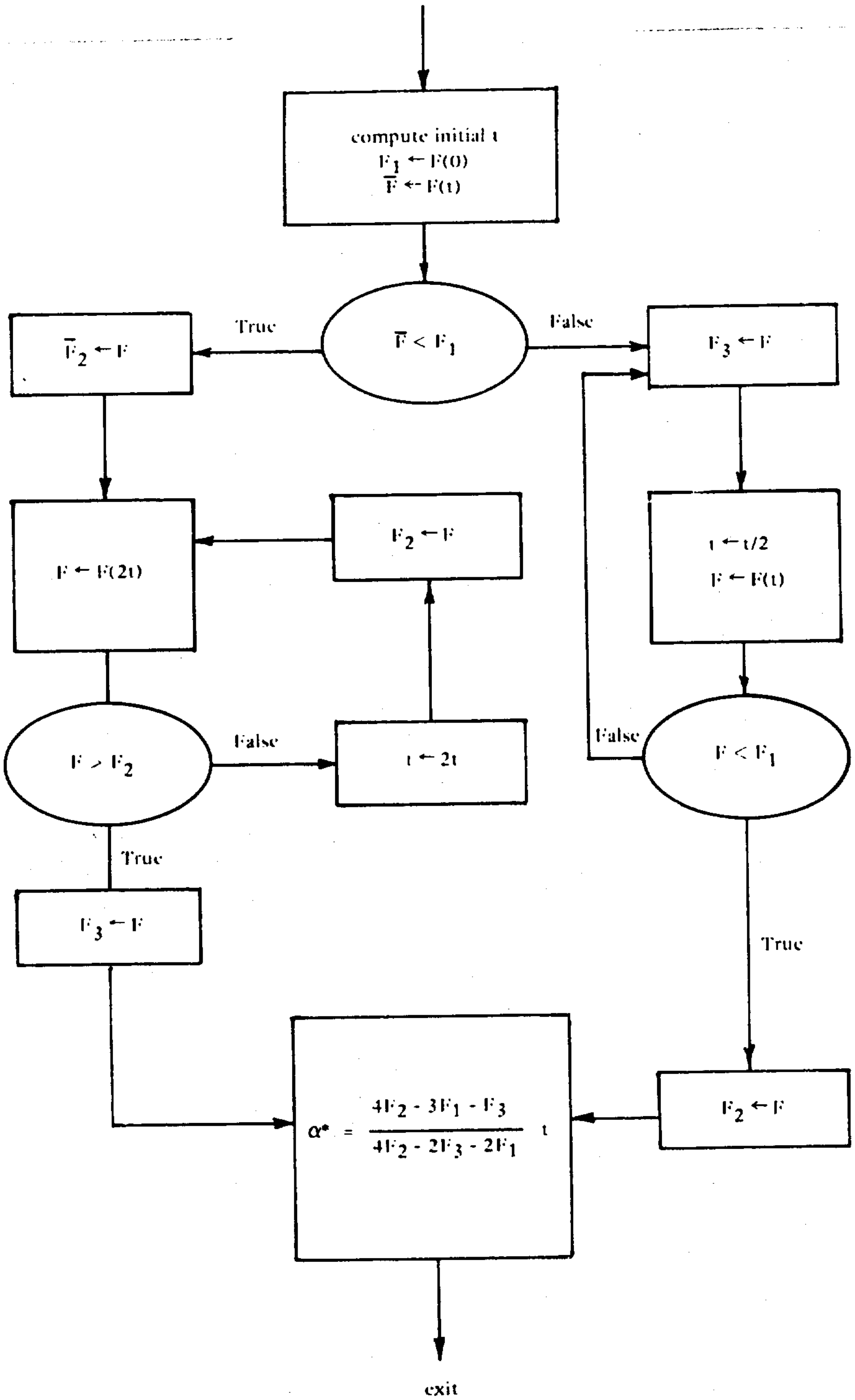


Figure 5. Logic diagram for minimization of $\phi(X)$.



satisfies $F_3 > F_1 > F_2$ or $F_1 > F_3 > F_2$

Figure 6. One-dimensional minimization algorithm.

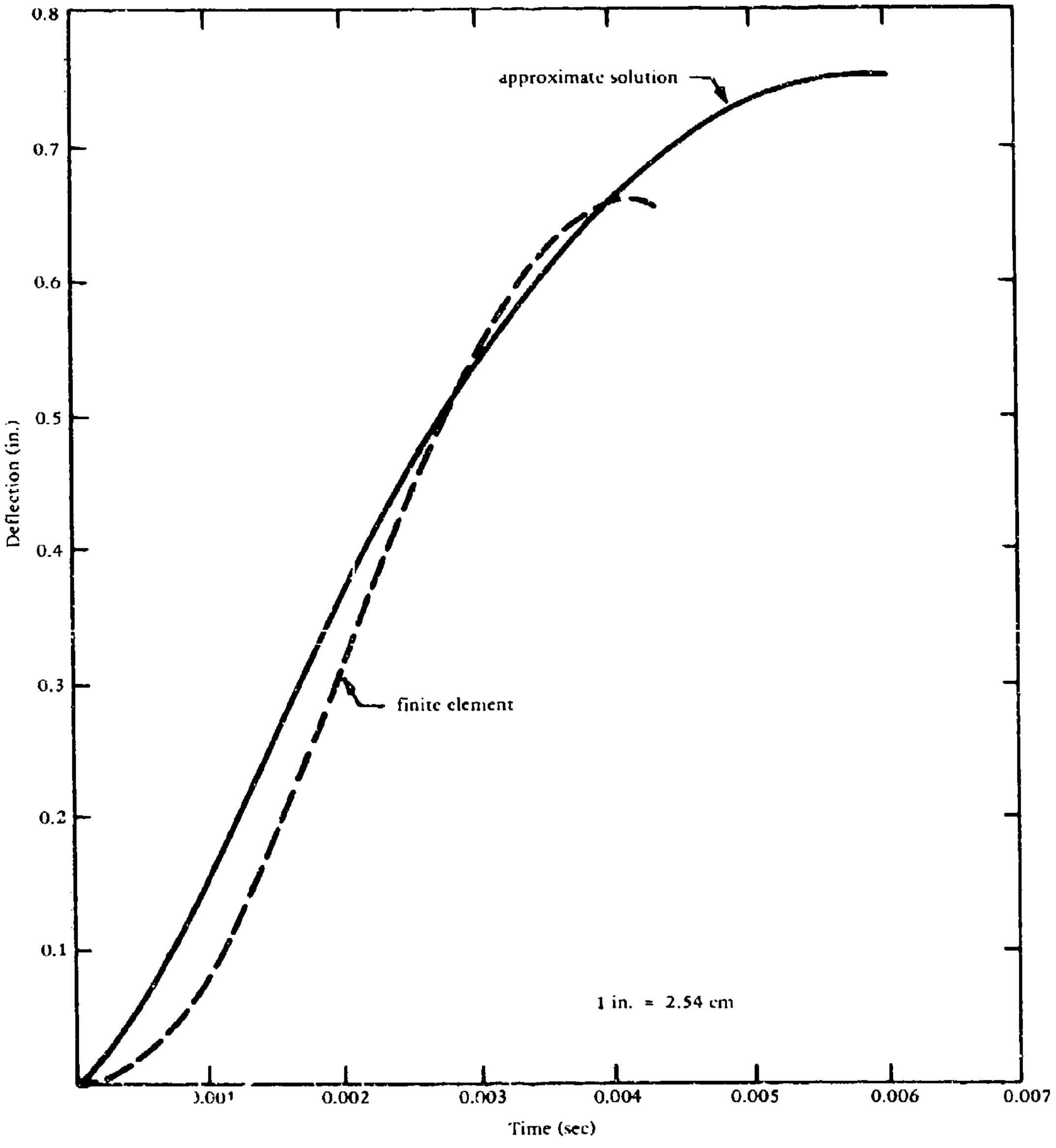


Figure 7a. Displacement history of 4 x 4-ft (1.2 x 1.2-m) plate.

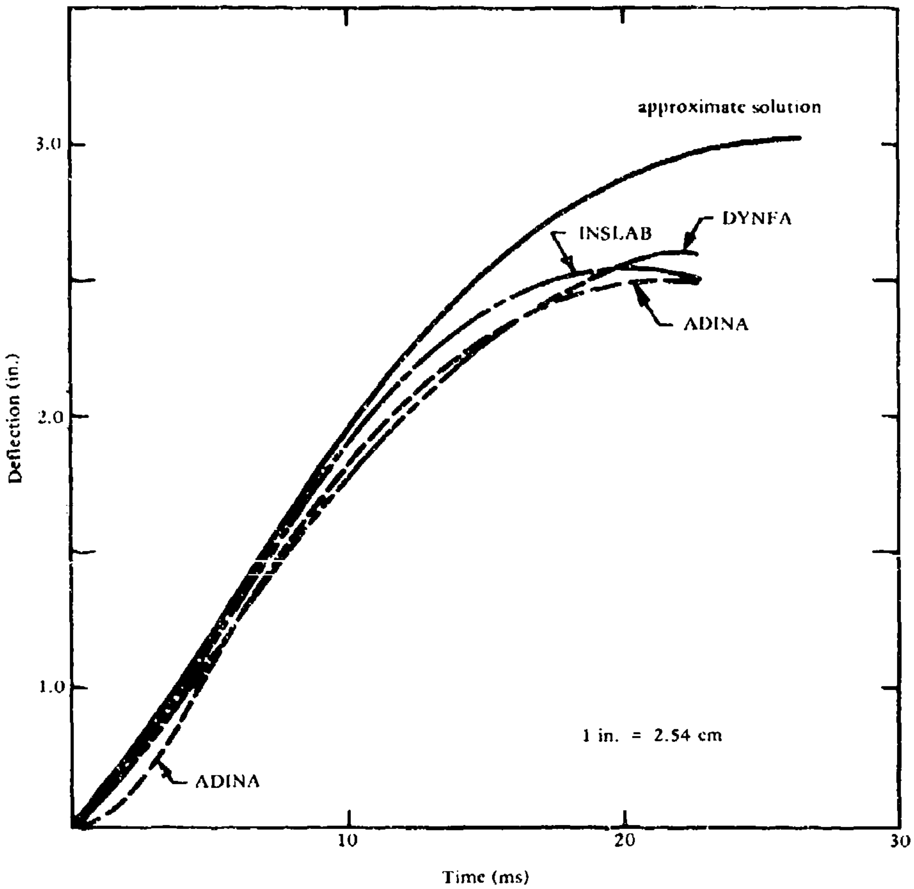


Figure 7b. Deflection of center, 10-ft (3-m) beam.

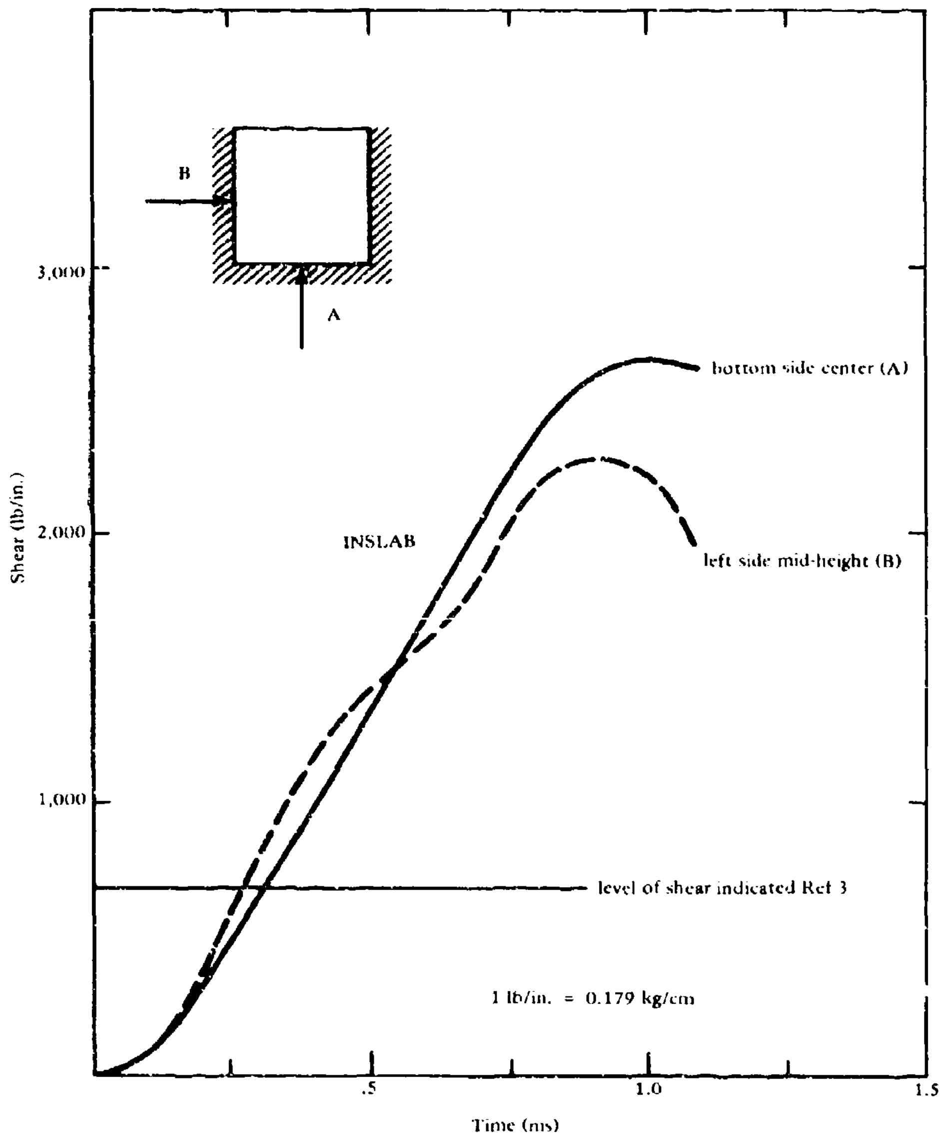


Figure 8. Shear in plate.

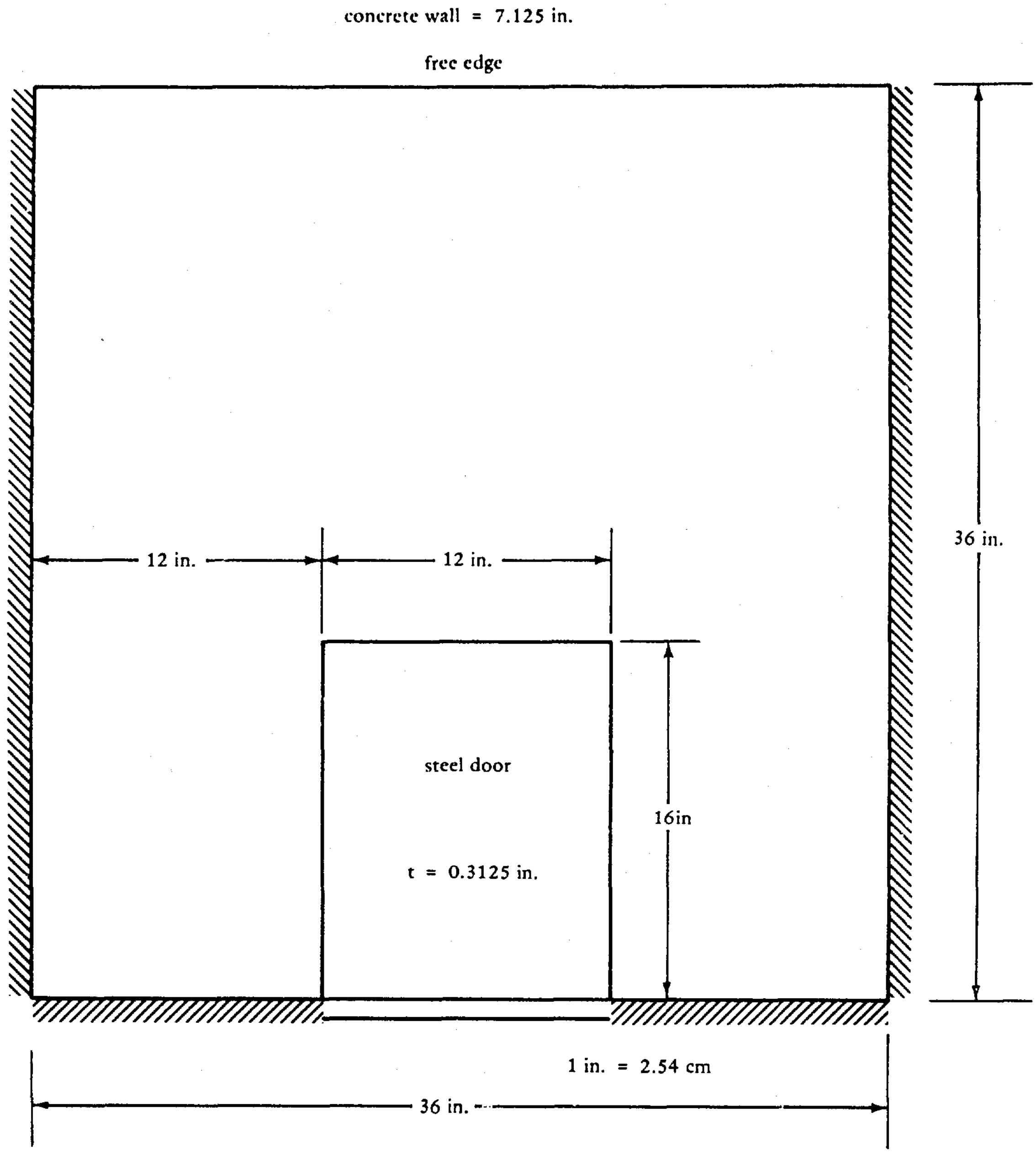


Figure 9. Geometry slab with door.

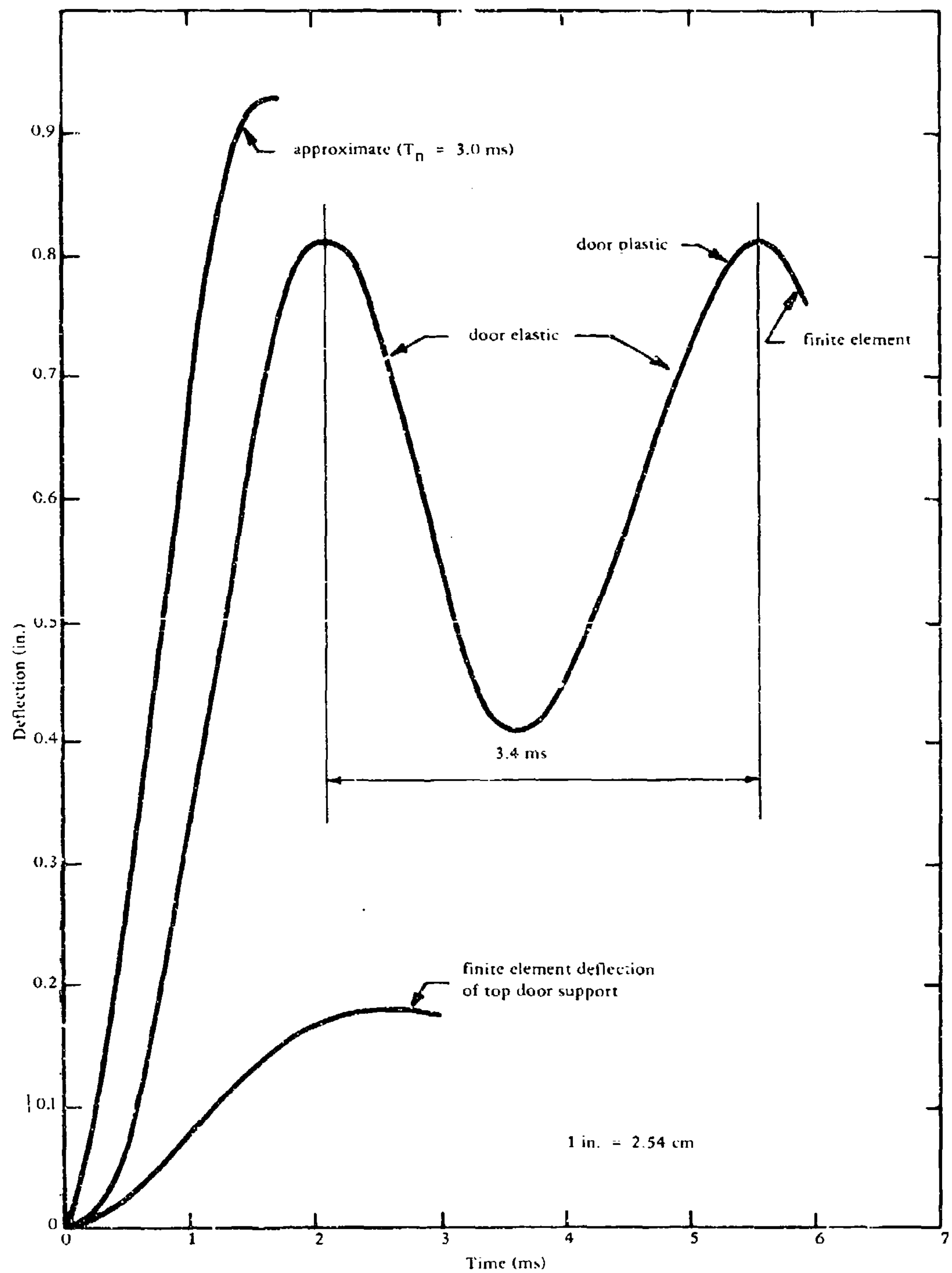


Figure 10. Deflection of door center.

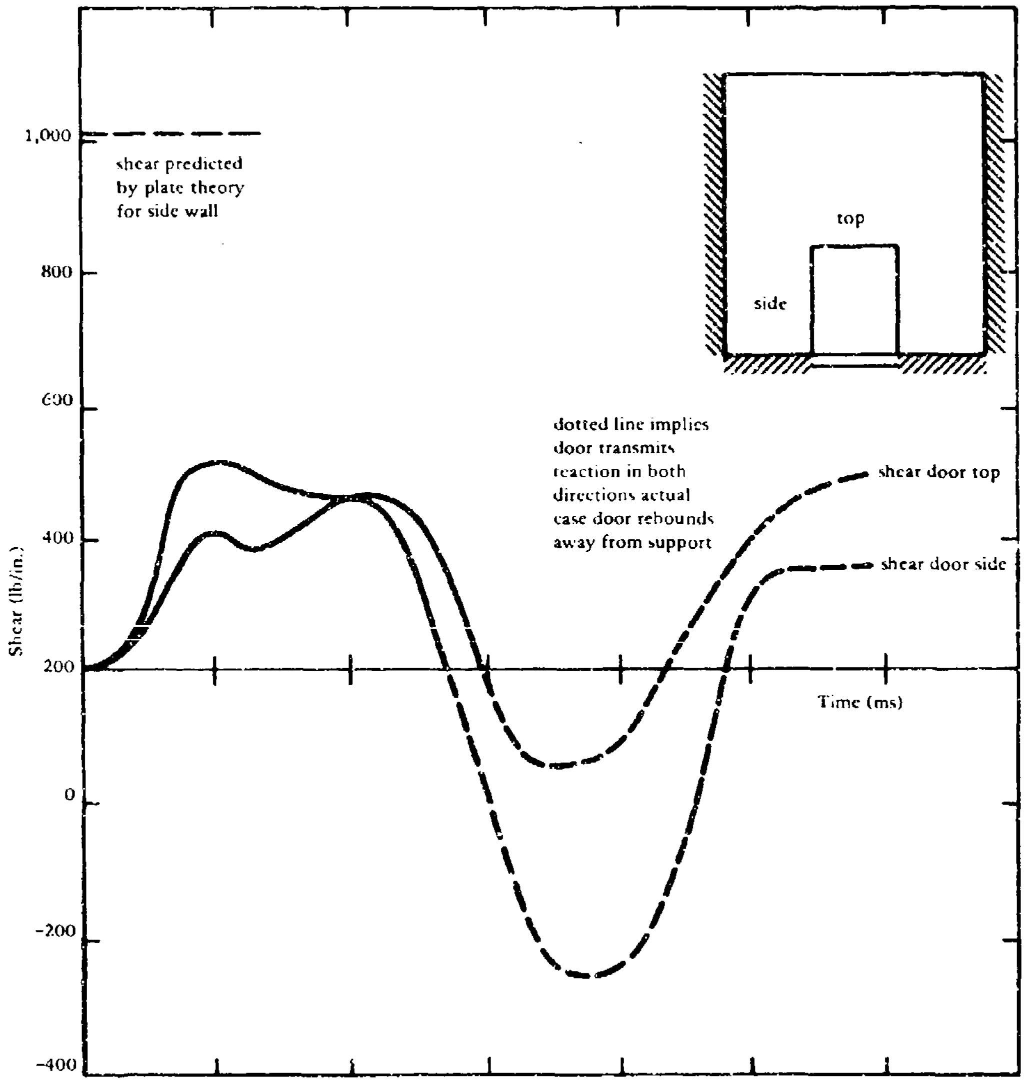


Figure 11. Door reaction.

APPENDIX

EXAMPLE PROBLEM 1

Design a door made of steel plate for the following:

1. Door Height = 6 ft
2. Door Width = 4 ft
3. Dynamic Yield Stress = 48,000 psi
4. Simple Support, Bottom Free
5. Allowable Ductility = 10

The door is contained in a wall 12 ft wide by 10 ft high. Side walls and roof are present to provide reflecting surfaces. The explosive is 10 lb Composition B uncased located 3 ft from the wall, 5 ft from the left side, and 3 ft above the floor. Figure A-1 shows the example problem input form, and Figure A-2 shows the output.

EXAMPLE PROBLEM 2

Design a steel plate window:

1. Height = 3 ft
2. Width = 3 ft
3. Dynamic Yield Stress = 48,000 psi
4. Simple Support, Four Sides
5. Allowable Ductility = 10

The window is located on the wall of a cell 12 ft long by 10 ft high. A 12-lb TNT explosive with length-to-diameter of 2.5 and case-to-explosive of 1.2 is located 3 ft away from the wall, 5 ft from the left side, and 3 ft above ground. The cell has two sidewalls and a floor. No roof reflecting surface is present. Figure A-3 shows the example problem input and Figure A-4 gives the output.

CARD								OPTIONS 0 or 1: Optimum = 1	P = 0 or = 1	T = 0 or Z = 1	I Grid = 1	Opening = 1	Door Pr = 1
1	Heading							1			1		
	1 — 10	11 — 20	21 — 30	31 — 40	41 — 50	51 — 60	61 — 70	71 72	73 74		75 76	77 78	79 80
	W (lb)	Expl No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (°C)	Altitude (kft)	Fraction I used					
2	10.	7.											
	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft/P_o (psi)*	I (ft)/t_o (ms)*	Cell Vol (ft^3)	Vent Area (ft^2)	F R	L R				
3	3.	10.	12.	3.	5.			1 1	1 1				
	FS (psi)	TS (in.)	N Side	DH (ft)	DFL (ft)	μ	T Sand (ft)	E					
4	48,000.	2.0	13.	6.	4.	10.							
	Z hor	Z ver	AICAV	WDR									
5													
	Door Height (ft)	Door Width (ft)	Dist to Left (ft)	Door Reaction (lb/in.)	Door RU (psi)	Dist to Floor (ft)							
6													

FS	Steel stress (psi)
TS	Thickness steel plate (in.)
SN	Code
DH	Plate height if not equal to H (ft)
DFL	Plate width if not equal to L (ft)
μ	Ductility
TSand	Sand thickness (ft)

Option T/Z = 1

Z hor	Plastic Z Section mod horizontal
Z ver	Plastic Z Section Mod vertical
AICAV	Average I moment inertia
WDR	Door weight (lb)

N Side

1 Bottom fixed
2 2 sides fix, 2 free
3 3 sides fix, 1 free
4 4 sides fix
5 Simple beam H
6 Fix Beam H
7 Fix/simple beam
[illegible] ides simple, 1 free
[illegible] es simple

Figure A-1. Computer data format for example problem 1.

```
    EXAMPLE 1
COMP B (RDX/TNT/WAX,59.4/39.6/1.0)

EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  10.00
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G     C     H     N     O    AL
   7  1.100  .004330   .252  .026  .298  .424 0.000

PAMB(PSIA)=  14.69        TAMB(C)=  20.00


SHOCK WAVE CALCULATION

INPUT PARAMETERS                               CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)        =    10.00            ADJUSTED WT(LB TNT)  =   11.00
EXPLOSIVE NUMBER         =     7               HE ENERGY FACTOR     =   1.100
L/D RATIO                = -0.                 CHARGE SHAPE FACTOR  =   1.000
CASE/CHARGE WT RATIO     = -0.                 CASE WEIGHT FACTOR   =   1.000
CHAMBER PRESSURE(PSIA)=      14.69             PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)          =   20.00             DISTANCE SCALE FACTOR=   .4496
ALTITUDE (KFT)           = -0.                 TIME SCALE FACTOR    =   .4535
                                               NORMAL REFL FACTOR   =   7.526

DESIRED DISTANCE(FT)   =    3.000
                (CM)   =    91.44

 TIME AFTER   TIME AFTER   INCIDENT    NORM REFL
 EXPLOSION    SHOCK ARR    OVERPRESS   OVERPRESS
  (MSEC)       (MSEC)        (PSI)       (PSI)
  .2615       0.            497.2        3742
  .3698        .1083        156.8        1180
  .4240        .1625        98.81       743.6
  .4782        .2167        64.16       482.9
  .5324        .2708        41.97       315.9
  .5865        .3250        27.05       203.6
  .6407        .3792        16.66       125.4
  .6949        .4334        9.259       69.68
  .7490        .4375        3.905       29.39
  .8032        .5417       0.          0.

IMPULSE (PSI.MSEC)--
    INCIDENT =    53.86
    REFLECTED=    405.3

.....CAUTION--CONTACT SURFACE HAS ARRIVED.
       DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 75.6173E-03
```

Figure A-2. Output for example problem 1.

PRECEDING PAGE BLANK-NOT FILMED

DISTANCE OF CHARGE FROM BLAST WALL	FT.	3.00
CHARGE WEIGHT	LBS.	11.00
BLAST WALL HEIGHT	FT.	10.00
BLAST WALL LENGTH	FT.	12.00
HEIGHT OF CHARGE ABOVE GROUND	FT.	3.00
MIN. DIST. BETWEEN CHARGE + ADJ. WALL	FT.	5.00
REFLECTION CODE		1 1 1 1

THE REFLECTED IMPULSE (PSI-MSEC) AT EACH GRID POINT ON THE BLAST WALL IS...
(MACH REFLECTIONS NOT INCLUDED)

J= 11	440.7 396.2	431.1 390.8	409.8 392.6	403.5	399.5	397.0	395.6	393.8	392.2	394.3
J= 10	448.8 380.1	413.3 384.9	404.5 392.4	391.2	381.1	376.3	375.9	378.1	381.2	378.7
J= 9	433.5 373.0	411.8 381.6	394.1 399.4	379.3	368.6	362.6	361.5	362.6	364.7	367.8
J= 8	448.8 369.4	415.5 381.7	392.4 398.9	374.7	362.1	354.9	353.2	354.4	357.0	361.3
J= 7	472.2 369.5	423.8 386.6	395.9 398.2	375.4	361.3	353.2	351.0	352.2	355.1	360.4
J= 6	523.1 372.0	433.8 387.4	402.8 402.4	380.8	366.0	357.5	354.8	355.7	357.9	363.0
J= 5	543.9 378.1	446.2 390.9	414.6 408.2	392.8	378.2	369.7	366.5	366.6	367.4	370.9
J= 4	560.0 388.8	461.5 398.2	432.4 421.5	412.9	399.8	391.8	387.9	386.4	384.5	384.8
J= 3	571.3 405.5	482.2 422.5	459.4 426.4	445.7	438.8	432.9	427.1	419.6	412.2	406.9
J= 2	615.6 464.5	578.8 441.1	511.8 434.1	513.8	512.6	508.9	501.4	488.6	466.9	508.0
J= 1	609.4 506.7	650.4 463.9	730.2 441.7	838.8	632.7	639.7	622.4	815.6	689.3	586.9
I=	1 11	2 12	3 13	4	5	6	7	8	9	10

Figure A-2. Continued

```
TOTAL IMPULSE     413.35

        TOTAL  IMPULSE            440.28 PSI-MS

        DURATION OF LOAD          5.72156  MSEC

        FICTITIOUS PEAK PRESSURE        153.90200  PSI
        EFFECTIVE IMPULSE                  440.28PSI MS
       FS DYNAMIC  48000.00
       PL THICK        2.00
       SPT CODE       13.00
       D H             6.00
       D L             4.00
       U DUC          10.00
       T SAND         -0.00


      HEIGHT       72.00     LENGTH        48.00

    POSITIVE VERTICAL MOMENT     48000.00
    NEGATIVE VERTICAL  OMENT     48000.00
    POSITIVE HORIZONTAL MOMENT     48000.00
    NEGATIVE HORIZONTAL MOMENT     48000.00
      X           24.0000
      Y           34.7913
      RU         243.2252
      W1         245.6  6
      W2         237.9305

        XE          .8885
        K          273.75
        MASS       996.24

    ALLOWABLE MAX DEFLECTION        8.8850

 MASS         996.236
LOAD         153.902
DURATION        5.722
RESISTANCE    243.225
STIFFNESS   273.749
 GAS PRESSURE         0.00
 DURATION         0.00
```

Figure A-2. Continued

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.026623	.1537	.0041	.0001	153.1859	.0300
.079868	.1521	.0123	.0007	151.7537	.1793
.133113	.1504	.0204	.0016	150.3214	.4466
.186359	.1486	.0283	.0030	148.8892	.8307
.239604	.1467	.0362	.0049	147.4570	1.3302
.292849	.1446	.0440	.0071	146.0248	1.9434
.346095	.1425	.0517	.0097	144.5925	2.6690
.399340	.1402	.0592	.0128	143.1603	3.5050
.452586	.1378	.0667	.0163	141.7281	4.4499
.505831	.1353	.0740	.0201	140.2959	5.5017
.559076	.1327	.0811	.0243	138.8636	6.6585
.612322	.1300	.0881	.0289	137.4314	7.9180
.665567	.1272	.0950	.0339	135.9992	9.2779
.718812	.1243	.1017	.0392	134.5670	10.7359
.772058	.1213	.1082	.0449	133.1347	12.2899
.825303	.1182	.1146	.0509	131.7025	13.9374
.878548	.1150	.1208	.0573	130.2703	15.6760
.931794	.1118	.1268	.0639	128.8381	17.5032
.985039	.1084	.1327	.0709	127.4058	19.4166
1.038285	.1050	.1384	.0782	125.9736	21.4134
1.091530	.1014	.1439	.0858	124.5414	23.4910
1.144775	.0978	.1492	.0937	123.1092	25.6466
1.198021	.0942	.1543	.1018	121.6769	27.8774
1.251266	.0904	.1592	.1102	120.2447	30.1806
1.304511	.0866	.1639	.1189	118.8125	32.5532
1.357757	.0827	.1684	.1278	117.3803	34.9922
1.411002	.0787	.1727	.1370	115.9480	37.4947
1.464247	.0747	.1768	.1463	114.5158	40.0575
1.517493	.0707	.1807	.1559	113.0836	42.6775
1.570738	.0666	.1843	.1657	111.6514	45.3516
1.623984	.0624	.1878	.1756	110.2191	48.0765
1.677229	.0582	.1910	.1858	108.7869	50.8490
1.730474	.0539	.1940	.1960	107.3547	53.6658
1.783720	.0496	.1967	.2065	105.9225	56.5237
1.836965	.0452	.1992	.2171	104.4902	59.4191
1.890210	.0409	.2015	.2278	103.0580	62.3488
1.943456	.0365	.2036	.2386	101.6258	65.3094
1.996701	.0320	.2054	.2495	100.1936	68.2974
2.049946	.0276	.2070	.2605	98.7613	71.3094
2.103192	.0231	.2084	.2716	97.3291	74.3419
2.156437	.0186	.2095	.2827	95.8969	77.3915
2.209683	.0141	.2103	.2939	94.4647	80.4546
2.262928	.0095	.2110	.3051	93.0324	83.5277
2.316173	.0050	.2114	.3164	91.6002	86.6074
2.369419	.0005	.2115	.3276	90.1680	89.6900
2.422664	-.0041	.2114	.3389	88.7358	92.7722
2.475909	-.0086	.2111	.3501	87.3035	95.8503

Figure A-2. Continued

2.529155	-.0131	.2105	.3614	85.8713	98.9209
2.582400	-.0176	.2097	.3725	84.4391	101.9805
2.635645	-.0221	.2086	.3837	83.0069	105.0255
2.688891	-.0266	.2073	.3947	81.5746	108.0525
2.742136	-.0310	.2058	.4057	80.1424	111.0580
2.795381	-.0355	.2040	.4166	78.7102	114.0385
2.848627	-.0399	.2020	.4274	77.2780	116.9907
2.901872	-.0442	.1998	.4380	75.8457	119.9111
2.955118	-.0486	.1973	.4486	74.4135	122.7963
3.008363	-.0529	.1946	.4590	72.9813	125.6430
3.061608	-.0571	.1917	.4692	71.5491	128.4479
3.114854	-.0613	.1885	.4793	70.1168	131.2076
3.168099	-.0655	.1851	.4892	68.6846	133.9189
3.221344	-.0696	.1815	.4989	67.2524	136.5786
3.274590	-.0736	.1777	.5084	65.8202	139.1834
3.327835	-.0776	.1737	.5177	64.3879	141.7304
3.381080	-.0816	.1695	.5268	62.9557	144.2163
3.434326	-.0854	.1650	.5357	61.5235	146.6382
3.487571	-.0892	.1604	.5443	60.0913	148.9930
3.540817	-.0930	.1555	.5526	58.6590	151.2779
3.594062	-.0966	.1505	.5607	57.2268	153.4899
3.647307	-.1002	.1452	.5685	55.7946	155.6261
3.700553	-.1037	.1398	.5760	54.3624	157.6840
3.753798	-.1071	.1342	.5832	52.9301	159.6607
3.807043	-.1105	.1284	.5902	51.4979	161.5535
3.860289	-.1137	.1224	.5968	50.0657	163.3600
3.913534	-.1169	.1163	.6030	48.6335	165.0777
3.966779	-.1200	.1100	.6090	47.2012	166.7040
4.020025	-.1229	.1035	.6146	45.7690	168.2366
4.073270	-.1258	.0969	.6198	44.3368	169.6733
4.126516	-.1286	.0901	.6247	42.9046	171.0118
4.179761	-.1313	.0832	.6292	41.4723	172.2499
4.233006	-.1338	.0762	.6334	40.0401	173.3859
4.286252	-.1363	.0690	.6371	38.6079	174.4181
4.339497	-.1387	.0617	.6405	37.1757	175.3444
4.392742	-.1410	.0543	.6435	35.7434	176.1631
4.445988	-.1431	.0468	.6461	34.3112	176.8725
4.499233	-.1451	.0391	.6483	32.8790	177.4708
4.552478	-.1471	.0314	.6501	31.4468	177.9564
4.605724	-.1489	.0235	.6514	30.0145	178.3279
4.658969	-.1506	.0156	.6524	28.5823	178.5839
4.712214	-.1521	.0075	.6529	27.1501	178.7230
4.765460	-.1536	-.0006	.6529	25.7179	178.7441

Figure A-2. Continued

```
NATURAL PERIOD                     11.986273

MAXIMUM DEFLECTION                  .652964

TIME TO MAXIMUM DEFLECTION         4.738837

DURATION/NATURAL PERIOD             .477343

LOAD/RESISTANCE                     .632755

ELASTIC DEFLECTION LIMIT            .888496
  XLIMIT              9.58
     TOTAL COST     1185.60
   COUNT          0.00

X)S ARE
2.000000E+00

G)S ARE
8.231998E+00 1.950000E+00 1.800000E+01 8.923036E+00


R = 1.47844666E+03
ITER =     0      P = 2.37120000E+03      OBJ = 1.18560000E+03
ITER =     3      P = 2.30497843E+03      OBJ = 9.31358665E+02
X)S ARE
 1.571118E+00

 G)S ARE
 1.014689E+01 1.521116E+00 1.842888E+01 8.412525E+00

FUNCTION CALLS =    45


R = 1.47844666E+02
ITER =     0      P = 1.06872064E+03      OBJ = 9.31358665E+02
ITER =     4      P = 7.41826574E+02      OBJ = 4.83514076E+02
X)S ARE
 8.156445E-01

 G)S ARE
 1.530044E+01 7.656445E-01 1.918436E+01 3.090083E+00

FUNCTION CALLS =    60

XNEXT(I) =
 7.385036E-01
```

Figure A-2. Continued

```
R = 1.47844666E+01
ITER =     0      P = 4.75907474E+02      OBJ = 4.37784917E+02
ITER =     2      P = 4.75857728E+02      OBJ = 4.36843725E+02
X)S ARE
 7.369159E-01

 G)S ARE
 1.547552E+01 6.869159E-01 1.926308E+01 9.376134E-01

FUNCTION CALLS =   52

XNEXT(I) =
 7.120197E-01



R = 1.47844666E+00
ITER =     0      P = 4.53479894E+02      OBJ = 4.22085264E+02
ITER =     3      P = 4.33341040E+02      OBJ = 4.26103978E+02
X)S ARE
 7.187989E-01

 G)S ARE
 1.545027E+01 6.687989E-01 1.928120E+01 3.045773E-01

FUNCTION CALLS =   77

XNEXT(I) =
 7.130698E-01



R = 1.47844666E-01
ITER =     0      P = 4.24577319E+02      OBJ = 4.22707772E+02
ITER =     2      P = 4.24570356E+02      OBJ = 4.22807189E+02
X)S ARE
 7.132375E-01

 G)S ARE
 1.543553E+01 6.632375E-01 1.928676E+01 9.707400E-02

FUNCTION CALLS =   39

XNEXT(I) =
 7.114788E-01

TOTAL FUNCTION CALLS =   273
```

Figure A-2. Continued

```
ITER =    0      PF =  4.2457036E+02      OBJ =  4.2176465E+02      X+S ARE
 7.114788E-01

 G)S ARE
 1.543046E+01 6.614788E-01 1.928852E+01 3.042509E-02



       HEIGHT        72.00    LENGTH        48.00
        FS DYNAMIC  48000.00
        PL THICK         .71
        SPT CODE       13.00
        D H             6.00
        D L             4.00
        U DUC          10.00
        T SAND         -0.00

    POSITIVE VERTICAL MOMENT      6074.43
    NEGATIVE VERTICAL MOMENT      6074.43
    POSITIVE HORIZONTAL MOMENT      6074.43
    NEGATIVE HORIZONTAL MOMENT      6074.43
      X           24.0000
      Y           34.7913
      RU          30.7803
      W1          31.1153
      W2          30.1102

        XE         2.4976
        K           12.32
        MASS       354.40

    ALLOWABLE MAX DEFLECTION       24.9760

 MASS         354.400
LOAD         153.902
DURATION       5.722
RESISTANCE    30.780
STIFFNESS    12.324
 GAS PRESSURE       0.00
 DURATION        0.00
```

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.093547	.4270	.0403	.0038	151.3857	.0466
.280641	.4122	.1188	.0224	146.3532	.2761
.467735	.3968	.1945	.0553	141.3206	.6817

Figure A-2. Continued

.654829	.3610	.2673	.1020	136.2880	1.2503
.841923	.3647	.3370	.1614	131.2555	1.9946
1.029017	.3480	.4037	.2343	126.2229	2.8879
1.216111	.3309	.4672	.3188	121.1903	3.9295
1.403205	.3133	.5275	.4144	116.1578	5.1119
1.590299	.2954	.5844	.5216	111.1252	6.4276
1.777393	.2772	.6380	.6385	106.0926	7.8687
1.964487	.2586	.6881	.7650	101.0601	9.4275
2.151581	.2396	.7347	.9003	96.0275	11.0957
2.338675	.2205	.7778	1.0438	90.9950	12.8653
2.525769	.2010	.8172	1.1951	85.9624	14.7270
2.712863	.1813	.8530	1.3531	80.9298	16.6759
2.899957	.1614	.8850	1.5172	75.8973	18.6982
3.087051	.1413	.9133	1.6868	70.8647	20.7889
3.274145	.1210	.9378	1.8613	65.8321	22.9384
3.461239	.1006	.9586	2.0398	60.7996	25.1378
3.648333	.0801	.9755	2.2216	55.7670	27.3785
3.835427	.0595	.9886	2.4060	50.7345	29.6515
4.022520	.0421	.9978	2.5924	45.7019	30.7803
4.209614	.0279	1.0045	2.7801	40.6693	30.7803
4.396708	.0137	1.0084	2.9686	35.6368	30.7803
4.583802	-.0005	1.0096	3.1575	30.6042	30.7803
4.770896	-.0147	1.0082	3.3463	25.5716	30.7803
4.957990	-.0289	1.0041	3.5344	20.5391	30.7803
5.145084	-.0431	.9974	3.7214	15.5065	30.7803
5.332178	-.0573	.9880	3.9067	10.4739	30.7803
5.519272	-.0715	.9759	4.0899	5.4414	30.7803
5.706366	-.0857	.9612	4.2705	.4088	30.7803
5.893460	-.0869	.9450	4.4481	0.0000	30.7803
6.080554	-.0869	.9288	4.6226	0.0000	30.7803
6.267648	-.0869	.9125	4.7941	0.0000	30.7803
6.454742	-.0869	.8963	4.9626	0.0000	30.7803
6.641836	-.0869	.8800	5.1280	0.0000	30.7803
6.828930	-.0869	.8638	5.2904	0.0000	30.7803
7.016024	-.0869	.8476	5.4497	0.0000	30.7803
7.203118	-.0869	.8313	5.6060	0.0000	30.7803
7.390212	-.0869	.8151	5.7592	0.0000	30.7803
7.577306	-.0869	.7988	5.9094	0.0000	30.7803
7.764400	-.0869	.7826	6.0566	0.0000	30.7803
7.951494	-.0869	.7663	6.2007	0.0000	30.7803
8.138588	-.0869	.7501	6.3418	0.0000	30.7803
8.325682	-.0869	.7338	6.4799	0.0000	30.7803
8.512776	-.0869	.7176	6.6149	0.0000	30.7803
8.699870	-.0869	.7013	6.7469	0.0000	30.7803
8.886964	-.0869	.6851	6.8758	0.0000	30.7803
9.074058	-.0869	.6688	7.0017	0.0000	30.7803
9.261152	-.0869	.6526	7.1245	0.0000	30.7803
9.448246	-.0869	.6363	7.2443	0.0000	30.7803

Figure A-2. Continued

9.635340	-.0869	.6201	7.3611	0.0000	30.7803
9.822434	-.0869	.6038	7.4748	0.0000	30.7803
10.009528	-.0869	.5876	7.5855	0.0000	30.7803
10.196622	-.0869	.5713	7.6932	0.0000	30.7803
10.383716	-.0869	.5551	7.7978	0.0000	30.7803
10.570810	-.0869	.5388	7.8994	0.0000	30.7803
10.757904	-.0869	.5226	7.9979	0.0000	30.7803
10.944998	-.0869	.5063	8.0934	0.0000	30.7803
11.132092	-.0869	.4901	8.1858	0.0000	30.7803
11.319186	-.0869	.4738	8.2752	0.0000	30.7803
11.506280	-.0869	.4576	8.3616	0.0000	30.7803
11.693373	-.0869	.4413	8.4449	0.0000	30.7803
11.880467	-.0869	.4251	8.5252	0.0000	30.7803
12.067561	-.0869	.4088	8.6025	0.0000	30.7803
12.254655	-.0869	.3926	8.6767	0.0000	30.7803
12.441749	-.0869	.3763	8.7478	0.0000	30.7803
12.628843	-.0869	.3601	8.8160	0.0000	30.7803
12.815937	-.0869	.3438	8.8810	0.0000	30.7803
13.003031	-.0869	.3276	8.9431	0.0000	30.7803
13.190125	-.0869	.3113	9.0021	0.0000	30.7803
13.377219	-.0869	.2951	9.0581	0.0000	30.7803
13.564313	-.0869	.2788	9.1110	0.0000	30.7803
13.751407	-.0869	.2626	9.1609	0.0000	30.7803
13.938501	-.0869	.2463	9.2077	0.0000	30.[illegible]03
14.125595	-.0869	.2301	9.2515	0.0000	30.[illegible]03
14.312689	-.0869	.2138	9.2923	0.0000	30.7803
14.499783	-.0869	.1976	9.3300	0.0000	30.7803
14.686877	-.0869	.1813	9.3647	0.0000	30.7803
14.873971	-.0869	.1651	9.3963	0.0000	30.7803
15.061065	-.0869	.1488	9.4249	0.0000	30.7803
15.248159	-.0869	.1326	9.4505	0.0000	30.7803
15.435253	-.0869	.1163	9.4730	0.0000	30.7803
15.622347	-.0869	.1001	9.4925	0.0000	30.7803
15.809441	-.0869	.0838	9.5090	0.0000	30.7803
15.996535	-.0869	.0676	9.5224	0.0000	30.7803
16.183629	-.0869	.0513	9.5327	0.0000	30.7803
16.370723	-.0869	.0351	9.5400	0.0000	30.7803
16.557817	-.0869	.0188	9.5443	0.0000	30.7803
16.744911	-.0869	.0026	9.5456	0.0000	30.7803

Figure A-2. Continued

```
NATURAL PERIOD                   33.693969

MAXIMUM DEFLECTION                9.545575

TIME TO MAXIMUM DEFLECTION       16.744911

DURATION/NATURAL PERIOD            .169810

LOAD/RESISTANCE                   5.000020

ELASTIC DEFLECTION LIMIT          2.497604
 DIF          1.4343
 TIME TO YIELD     3.92897349
  XLIMIT            9.58
     TOTAL COST      421.76
   COUNT      278.00
```

Figure A-2. Continued

Format For Computer Program SDOOR

OPTIONS 0 or 1

Optimum = 1	P = 0 or I = 1	T = 0 or Z = 1	I Grid = 1	Opening = 1	Door Fr = 1
1			1		

CARD	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
1	Heading							
	W (lb)	Expl No.	l/d Ratio	Case/Explo	P_{amb} (psia)	T_{amb} (°C)	Altitude (kft)	Fraction I used
2	12.	1.	2.5	1.2				
	R_a (ft)/I (psi-ms)*	H (ft)	L (ft)	h (ft/P_o (psi)*	I (ft)/t_o (ms)*	Cell Vol (ft^3)	Vent Area (ft^2)	F R L R
3	3.	10.	12.	3.	5.			1 0 1 1
	FS (psi)	TS (in.)	N Side	DH (ft)	DEL (ft)	μ	T Sand (ft)	E
4	48,000.	2.	14.	3.	3.	10.		
	Z hor	Z ver	AICAV	WDR				
5								
	Door Height (ft)	Door Width (ft)	Dist to Left (ft)	Door Reaction (lb/in.)	Door RU (psi)	Dist to Floor (ft)		
6								

FS Steel stress (psi)
TS Thickness steel plate (in.)
SN Code
DH Plate height if not equal to H (ft)
DEL Plate width if not equal to L (ft)
μ Ductility
TSand Sand thickness (ft)

Option T/Z = 1
Z hor Plastic Z Section mod horizontal
Z ver Plastic Z Section Mod vertical
AICAV Average I moment inertia
WDR Door weight (lb)

N Side
1 Bottom fixed
2 2 sides fix, 2 free
3 3 sides fix, 1 free
4 4 sides fix
5 Simple beam H
6 Fix Beam H
7 Fix/simple beam
13 3 sides simple, 1 free
14 4 sides simple

Figure A-3. Input for example problem 2.

```
   EXAMPLE 2
TNT

EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  12.00
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
          KCAL/G      C     H      N      O    AL
  1  1.000 -.079400  .370  .022  .185  .423 0.000

PAMB(PSIA)=  14.69        TAMB(C)=  20.00
.....CHARGE SHAPE CORRECTION IS CRUDE.  PSI EXCEEDS  RANGE OF EXPERIMENTAL DATA.
.....CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS  RANGE OF EXPERIMENTAL DATA.


SHOCK WAVE CALCULATION

INPUT PARAMETERS                            CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)       =   12.00           ADJUSTED WT(LB TNT)  =   31.59
EXPLOSIVE NUMBER        =    1              HE ENERGY FACTOR     =   1.000
L/D RATIO               =   2.500           CHARGE SHAPE FACTOR  =   3.703
CASE/CHARGE WT RATIO    =   1.200           CASE WEIGHT FACTOR   =   .7109
CHAMBER PRESSURE(PSIA)=     14.69           PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)         =   20.00           DISTANCE SCALE FACTOR=   .3163
ALTITUDE (KFT)          = -0.               TIME SCALE FACTOR    =   .3190
                                            NORMAL REFL FACTOR   =   8.650

DESIRED DISTANCE(FT)   =    3.000
                (CM)   =    91.44

 TIME AFTER   TIME AFTER    INCIDENT    NORM REFL
 EXPLOSION    SHOCK ARR    OVERPRESS    OVERPRESS
  (MSEC)       (MSEC)        (PSI)        (PSI)
   .2004       0.            954.3         8254
   .3135        .1131        301.0         2603
   .3700        .1696        189.6         1640
   .4265        .2261        123.1         1065
   .4831        .2826        80.56        696.8
   .5396        .3392        51.91        449.0
   .5961        .3957        31.98        276.6
   .6526        .4522        17.77        153.7
   .7092        .5088        7.494        64.82
   .7657        .5653       0.            0.

 IMPULSE (PSI.MSEC)--
     INCIDENT =    107.9
     REFLECTED=    933.1
```

Figure A-4. Output for example problem 2.

```
.....CAUTION--CONTACT SURFACE HAS ARRIVED,
     DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 37.1725E-03


DISTANCE OF CHARGE FROM BLAST WALL          FT.                  3.00
CHARGE WEIGHT                              LBS.                 31.59
BLAST WALL HEIGHT                           FT.                 10.00

BLAST WALL LENGTH                           FT.                 12.00
HEIGHT OF CHARGE ABOVE GROUND               FT.                  3.00
MIN. DIST. BETWEEN CHARGE + ADJ. WALL       FT.                  5.00
REFLECTION CODE                                            1  0  1  1

         TOTAL  IMPULSE          749.25 PSI-MS

         DURATION OF LOAD        4.42317  MSEC

         FICTITIOUS PEAK PRESSURE      338.78456  PSI
         EFFECTIVE IMPULSE                749.25PSI MS
        FS DYNAMIC  48000.00
        PL THICK        2.00
        SPT CODE       14.00
        D H             3.00
        D L             3.00
        U DUC          10.00
        T SAND         -0.00



       HEIGHT       36.00    LENGTH       36.00

     POSITIVE VERTICAL MOMENT    48000.00
     NEGATIVE VERTICAL MOMENT    48000.00
     POSITIVE HORIZONTAL MOMENT    48000.00
     NEGATIVE HORIZONTAL MOMENT    48000.00
       X            18.00
       Y            18.00
       RU          888.89

        XE          .2783
        K         3194.19
        MASS       822.04
```

Figure A-4. Continued

ALLOWABLE MAX DEFLECTION 2.7828

MASS 822.045
LOAD 338.785
DURATION 4.423
RESISTANCE 888.889
STIFFNESS 3194.186
GAS PRESSURE 0.00
DURATION 0.00

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.008319	.4112	.0034	.0000	338.1474	.0911
.024956	.4091	.0103	.0002	336.8731	.5458
.041593	.4066	.0171	.0004	335.5988	1.3621
.058231	.4036	.0238	.0008	334.3245	2.5380
.074868	.4002	.0305	.0013	333.0502	4.0707
.091505	.3964	.0372	.0019	331.7759	5.9571
.108142	.3921	.0437	.0026	330.5016	8.1940
.124780	.3874	.0502	.0034	329.2273	10.7775
.141417	.3823	.0567	.0043	327.9530	13.7036
.158054	.3768	.0630	.0053	326.6787	16.9675
.174692	.3708	.0692	.0064	325.4044	20.5646
.191329	.3645	.0754	.0077	324.1301	24.4895
.207966	.3578	.0814	.0090	322.8558	28.7367
.224603	.3507	.0873	.0104	321.5815	33.3000
.241241	.3432	.0931	.0120	320.3072	38.1719
.257878	.3354	.0987	.0136	319.0329	43.3455
.274515	.3272	.1043	.0153	317.7586	48.8139
.291153	.3186	.1096	.0171	316.4843	54.5697
.307790	.3097	.1149	.0190	315.2100	60.6052
.324427	.3005	.1199	.0209	313.9357	[illegible]6.9125
.341064	.2910	.1249	.0230	312.6614	[illegible]3.4834
.357702	.2811	.1296	.0251	311.3871	80.3094
.374339	.2709	.1342	.0274	310.1128	87.3818
.390976	.2605	.1386	.0296	308.8385	94.6913
.407614	.2498	.1429	.0320	307.5642	102.2289
.424251	.2388	.1469	.0344	306.2899	109.9849
.440888	.2276	.1508	.0369	305.0156	[illegible]7.9496
.457526	.2161	.1545	.0395	303.7413	126.1129
.474163	.2044	.1580	.0421	302.4670	134.4647
.490800	.1924	.1613	.0448	301.1927	142.9946
.507437	.1803	.1644	.0475	299.9184	151.6919
.524075	.1680	.1673	.0503	298.6441	160.5460
.540712	.1555	.1700	.0531	297.3698	169.5458
.557349	.1428	.1725	.0559	296.0954	178.6804
.573987	.1300	.1748	.0588	294.8211	187.9383
.590624	.1171	.1768	.0618	293.5468	197.3084

Figure A-4. Continued

.607261	.1040	.1786	.0647	292.2725	206.7792
.623898	.0908	.1803	.0677	290.9982	216.3389
.640536	.0775	.1817	.0707	289.7239	225.9761
.657173	.0642	.1828	.0738	288.4496	235.6788
.673810	.0508	.1838	.0768	287.1753	245.4354
.690448	.0373	.1845	.0799	285.9010	255.2338
.707085	.0238	.1850	.0830	284.6267	265.0623
.723722	.0103	.1853	.0861	283.3524	274.9088
.740360	-.0033	.1854	.0891	282.0781	284.7614
.756997	-.0168	.1852	.0922	280.8038	294.6082
.773634	-.0303	.1848	.0953	279.5295	304.4371
.790271	-.0438	.1842	.0984	278.2552	314.2362
.806909	-.0572	.1834	.1014	276.9809	323.9937
.823546	-.0705	.1823	.1045	275.7066	333.6976
.840183	-.0838	.1810	.1075	274.4323	343.3362
.856821	-.0970	.1795	.1105	273.1580	352.8978
.873458	-.1101	.1778	.1134	271.8837	362.3708
.890095	-.1230	.1759	.1164	270.6094	371.7435
.906732	-.1358	.1737	.1193	269.3351	381.0047
.923370	-.1485	.1713	.1221	268.0608	390.1429
.940007	-.1610	.1688	.1250	266.7865	399.1470
.956644	-.1733	.1660	.1277	265.5122	408.0061
.973282	-.1855	.1630	.1305	264.2379	416.7091
.989919	-.1974	.1598	.1331	262.9636	425.2456
1.006556	-.2091	.1564	.1357	261.6893	433.6049
1.023193	-.2206	.1529	.1383	260.4150	441.7768
1.039831	-.2319	.1491	.1408	259.1407	449.7510
1.056468	-.2429	.1451	.1432	257.8664	457.5179
1.073105	-.2536	.1410	.1456	256.5921	465.0676
1.089743	-.2641	.1367	.1479	255.3178	472.3907
1.106380	-.2742	.1322	.1501	254.0435	479.0782
1.123017	-.2841	.1276	.1523	252.7692	486.3209
1.139655	-.2937	.1228	.1543	251.4949	492.9103
1.156292	-.3029	.1178	.1563	250.2206	499.2380
1.172929	-.3118	.1127	.1582	248.9463	505.2959
1.189566	-.3204	.1074	.1600	247.6720	511.0762
1.206204	-.3287	.1020	.1617	246.3977	516.5713
1.222841	-.3365	.0965	.1634	245.1234	521.7741
1.239478	-.3441	.0908	.1649	243.8491	526.6776
1.256116	-.3512	.0851	.1663	242.5748	531.2753
1.272753	-.3580	.0792	.1677	241.3005	535.5618
1.289390	-.3643	.0732	.1689	240.0262	539.5318
1.306027	-.3703	.0671	.1701	238.7519	543.1797
1.322665	-.3759	.0609	.1711	237.4776	546.5002
1.339302	-.3811	.0547	.1720	236.2033	549.4883
1.355939	-.3859	.0483	.1729	234.9290	552.1395
1.372577	-.3902	.0419	.1736	233.6547	554.4495
1.389214	-.3942	.0353	.1742	232.3804	556.4146

Figure A-4. Continued

```
 1.405851          -.3977          .0288          .1747          231.1061          558.0311
 1.422488          -.4008          .0221          .1751          229.8318          559.2961
 1.439126          -.4034          .0155          .1754          228.5575          560.2067
 1.455763          -.4057          .0087          .1756          227.2832          560.7606
 1.472400          -.4075          .0020          .1756          226.0089          560.9559

   NATURAL PERIOD                 3.187478

   MAXIMUM DEFLECTION              .175618

   TIME TO MAXIMUM DEFLECTION     1.472400

   DURATION/NATURAL PERIOD        1.387672

   LOAD/RESISTANCE                 .381133

   ELASTIC DEFLECTION LIMIT        .278283
     XLIMIT          4.79
       TOTAL COST     444.60
      COUNT        0.00

 X)S ARE
 2.000000E+00

 G)S ARE
 2.607216E+00 1.950000E+00 1.800000E+01 4.612382E+00


R = 3.80411425E+02
ITER =     0      P = 8.89200000E+02      OBJ = 4.44600000E+02
ITER =     3      P = 8.09138937E+02      OBJ = 2.94159923E+02
X)S ARE
 1.323257E+00

 G)S ARE
 3.615606E+00 1.273257E+00 1.867674E+01 4.197567E+00

FUNCTION CALLS =    60


R = 3.80411425E+01
ITER =     0      P = 3.45657824E+02      OBJ = 2.94159923E+02
ITER =     4      P = 2.77968776E+02      OBJ = 1.98321056E+02
X)S ARE
 8.921325E-01
```

Figure A-4. Continued

```
 G)S ARE
 3.273839E+00 8.421325E-01 1.910787E+01 1.823227E+00

FUNCTION CALLS =    69

XNEXT(I) =
 8.161653E-01


R = 3.80411425E+00
ITER =     0      P = 1.93991835E+02      OBJ = 1.81433536E+02
ITER =     2      P = 1.93944567E+02      OBJ = 1.80849350E+02
X)S ARE
 8.135373E-01

 G)S ARE
 2.640894E+00 7.635373E-01 1.918646E+01 5.875754E-01

FUNCTION CALLS =    45

XNEXT(I) =
 7.886834E-01


R = 3.80411425E-01
ITER =     0      P = 1.80636195E+02      OBJ = 1.75324312E+02
ITER =     2      P = 1.79129860E+02      OBJ = 1.76452025E+02
X)S ARE
 7.937563E-01

 G)S ARE
 2.415064E+00 7.437563E-01 1.920624E+01 1.912539E-01

FUNCTION CALLS =    49

XNEXT(I) =
 7.875010E-01


R = 3.80411425E-02
ITER =     0      P = 1.75803414E+02      OBJ = 1.75061469E+02
ITER =     2      P = 1.75799602E+02      OBJ = 1.75108190E+02
X)S ARE
 7.877112E-01
```

Figure A-4. Continued

```
G)S ARE
2.338819E+00 7.377112E-01 1.921229E+01 6.119876E-02

FUNCTION CALLS =    48

XNEXT(I) =
7.857995E-01

TOTAL FUNCTION CALLS =   271

ITER =    0      PF =  1.7579960E+02      OBJ =  1.7468323E+02      X+S ARE
7.857995E-01

G)S ARE
2.314746E+00 7.357995E-01 1.921420E+01 1.993667E-02



      HEIGHT         36.00     LENGTH          36.00
       FS DYNAMIC  48000.00
       PL THICK          .79
       SPT CODE        14.00
       D H              3.00
       D L              3.00
       U DUC           10.00
       T SAND          -0.00

    POSITIVE VERTICAL MOMENT       7409.77
    NEGATIVE VERTICAL MOMENT       7409.77
    POSITIVE HORIZONTAL MOMENT       7409.77
    NEGATIVE HORIZONTAL MOMENT       7409.77
      X              19.00
      Y              18.00
      RU            137.22

       XE             .7083
       K            193.73
       MASS         322.98

    ALLOWABLE MAX DEFLECTION         7.0828

 MASS         322.981
LOAD         338.785
DURATION       4.423
RESISTANCE   137.218
STIFFNESS    193.734
 GAS PRESSURE        0.00
 DURATION        0.00
```

Figure A-4. Continued

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.035137	1.0398	.0369	.0013	336.0933	.2509
.105412	1.0193	.1094	.0077	330.7107	1.4958
.175686	.9958	.1802	.0192	325.3282	3.7111
.245961	.9693	.2493	.0355	319.9457	6.8730
.316235	.9400	.3164	.0565	314.5631	10.9554
.386510	.9080	.3813	.0822	309.1806	15.9296
.456784	.8732	.4439	.1123	303.7980	21.7644
.527059	.8359	.5040	.1467	298.4155	28.4259
.597333	.7962	.5613	.1852	293.0330	35.8778
.667608	.7541	.6158	.2275	287.6504	44.0816
.737882	.7099	.6673	.2736	282.2679	52.9964
.808157	.6635	.7155	.3230	276.8853	62.5794
.878431	.6153	.7605	.3757	271.5028	72.7858
.948705	.5652	.8020	.4314	266.1203	83.5689
1.018980	.5135	.8399	.4897	260.7377	94.8806
1.089254	.4603	.8741	.5506	255.3552	106.6710
1.159529	.4059	.9045	.6137	249.9726	118.8888
1.229803	.3502	.9311	.6787	244.5901	131.4817
1.300078	.3158	.9542	.7453	239.2076	137.2180
1.370352	.2991	.9758	.8135	233.8250	137.2180
1.440627	.2824	.9962	.8832	228.4425	137.2180
1.510901	.2658	1.0155	.9542	223.0599	137.2180
1.581176	.2491	1.0336	1.0266	217.6774	137.2180
1.651450	.2324	1.0505	1.1001	212.2949	137.2180
1.721725	.2158	1.0663	1.1748	206.9123	137.2180
1.791999	.1991	1.0808	1.2505	201.5298	137.2180
1.862274	.1825	1.0943	1.3272	196.1472	137.2180
1.932548	.1658	1.1065	1.4047	190.7647	137.2180
2.002823	.1491	1.1176	1.4831	185.3822	137.2180
2.073097	.1325	1.1274	1.5621	179.9996	137.2180
2.143372	.1158	1.1362	1.6418	174.6171	137.2180
2.213646	.0991	1.1437	1.7221	169.2345	137.2180
2.283921	.0825	1.1501	1.8028	163.8520	137.2180
2.354195	.0658	1.1553	1.8839	158.4695	137.2180
2.424470	.0491	1.1594	1.9653	153.0869	137.2180
2.494744	.0325	1.1622	2.0470	147.7044	137.2180
2.565018	.0158	1.1639	2.1287	142.3218	137.2180
2.635293	-.0009	1.1644	2.2106	136.9393	137.2180
2.705567	-.0175	1.1638	2.2924	131.5568	137.2180
2.775842	-.0342	1.1620	2.3741	126.1742	137.2180
2.846116	-.0509	1.1590	2.4556	120.7917	137.2180
2.916391	-.0675	1.1548	2.5368	115.4091	137.2180
2.986665	-.0842	1.1495	2.6177	110.0266	137.2180
3.056940	-.1009	1.1430	2.6982	104.6441	137.2180
3.127214	-.1175	1.1353	2.7781	99.2615	137.2180
3.197489	-.1342	1.1265	2.8574	93.8790	137.2180
3.267763	-.1508	1.1165	2.9361	88.4964	137.2180

Figure A-4. Continued

3.339038	-.1675	1.1053	3.0139	83.1139	137.2180
3.408312	-.1842	1.0929	3.0910	77.7314	137.2180
3.478587	-.2008	1.0794	3.1671	72.3488	137.2180
3.548861	-.2175	1.0647	3.2422	66.9663	137.2180
3.619136	-.2342	1.0488	3.3161	61.5837	137.2180
3.689410	-.2508	1.0318	3.3890	56.2012	137.2180
3.759685	-.2675	1.0136	3.4605	50.8187	137.2180
3.829959	-.2842	.9942	3.5307	45.4361	137.2180
3.900234	-.3008	.9736	3.5995	40.0536	137.2180
3.970508	-.3175	.9519	3.6668	34.6710	137.2180
4.040783	-.3342	.9290	3.7325	29.2885	137.2180
4.111057	-.3508	.9049	3.7965	23.9060	137.2180
4.181331	-.3675	.8797	3.8588	18.5234	137.2180
4.251606	-.3842	.8533	3.9193	13.1409	137.2180
4.321880	-.4008	.8257	3.9778	7.7583	137.2180
4.392155	-.4175	.7969	4.0343	2.3758	137.2180
4.462427	-.4248	.7672	4.0887	0.0000	137.2180
4.532704	-.4248	.7374	4.1411	0.0000	137.2180
4.602978	-.4248	.7075	4.1913	0.0000	137.2180
4.673253	-.4248	.6776	4.2395	0.0000	137.2180
4.743527	-.4248	.6478	4.2855	0.0000	137.2180
4.813802	-.4248	.6179	4.3295	0.0000	137.2180
4.884076	-.4248	.5881	4.3713	0.0000	137.2180
4.954351	-.4248	.5582	4.4111	0.0000	137.2180
5.024625	-.4248	.5284	4.4487	0.0000	137.2180
5.094900	-.4248	.4985	4.4843	0.0000	137.2180
5.165174	-.4248	.4687	4.5177	0.0000	137.2180
5.235449	-.4248	.4388	4.5491	0.0000	137.2180
5.305723	-.4248	.4089	4.5784	0.0000	137.2180
5.375998	-.4248	.3791	4.6055	0.0000	137.2180
5.446272	-.4248	.3492	4.6306	0.0000	137.2180
5.516547	-.4248	.3194	4.6536	0.0000	137.2180
5.586821	-.4248	.2895	4.6744	0.0000	137.2180
5.657096	-.4248	.2597	4.6932	0.0000	137.2180
5.727370	-.4248	.2298	4.7099	0.0000	137.2180
5.797644	-.4248	.2000	4.7245	0.0000	137.2180
5.867919	-.4248	.1701	4.7369	0.0000	137.2180
5.938193	-.4248	.1402	4.7473	0.0000	137.2180
6.008468	-.4248	.1104	4.7556	0.0000	137.2180
6.078742	-.4248	.0805	4.7618	0.0000	137.2180
6.149017	-.4248	.0507	4.7659	0.0000	137.2180
6.219291	-.4248	.0208	4.7679	0.0000	137.2180
6.289566	-.4248	-.0090	4.7677	0.0000	137.2180

Figure A-4. Continued

```
NATURAL PERIOD                    8.112700

MAXIMUM DEFLECTION                4.768063

TIME TO MAXIMUM DEFLECTION        6.254429

DURATION/NATURAL PERIOD            .545216

LOAD/RESISTANCE                   2.468952

ELASTIC DEFLECTION LIMIT           .708281
 DIF          1.5000
 TIME TO YIELD     1.26494062
  XLIMIT            4.79
     TOTAL COST      174.68
   COUNT      276.00
```

Figure A-4. Continued

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