Nickerson

tm no 51-91-11

Technical Memorandum

title: BASIS OF DESIGN FOR EXPLOSIVES SAFETY
OF STANDARD MISSILE MAGAZINE
MILCON P-137
NAVAL WEAPONS STATION
SEAL BEACH, CA

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date: MAY 1991

sponsor: SOUTHWEST DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
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CONTENTS

1.0 INTRODUCTION

1.1 PURPOSE

This document presents the basis of design for explosives safety of MILCON Project P-137, STANDARD Missile Magazine, Naval Weapons Station, Seal Beach, California (Ref 1). This document will be used by the Architect and Engineering (A&E) Contractor to develop construction drawings and specifications that comply with explosive safety requirements of NAVSEA OP-5 (Ref 2).

1.2 FACILITY

The STANDARD Missile Magazine is an earth-covered, box structure designed to store 180 containerized STANDARD missiles, as shown in Figures 1-1 through 1-4. The facility is designated as a NAVFAC Type M Box Magazine. The schematic design for the magazine is described in Reference 1.

The box structure will be constructed of reinforced concrete. The box is 70 feet wide, 147 feet long, 18 feet high, and covered with a soil berm, 2.0 feet thick over the roof with a 2:1 downward slope to grade level beyond the perimeter of the roof. An interior reinforced concrete wall divides the length of the box into two bays, as shown in Figure 1-1.

Containerized STANDARD missiles are stored in each bay, as shown in Figure 1-2. The magazine is designed to store up to 100 MK 14 vertical launch containers but the storage capacity can be increased to 180 MK 14 containers by stacking containers 3 high, as shown in Figure 1-2. The magazine will be sited to store 100,000 lbs net explosive weight of hazard Class/Division 1.1.

Access to the magazine is through an opening located at one end of the magazine, as shown in Figure 1-1. The opening (25 x 16 feet) is covered with a sliding steel door. An overhead bridge crane in each bay provides the means to store and retrieve missiles.

Containerized missiles are shipped and received by a railcar or truck parked in the shipping and receiving area. The shipping/receiving area (25' wide x 70'long x 18' high) is located inside the magazine at one end of the box structure, forward of the entrance, as shown in Figure 1-1. The bridge crane in each bay moves the containerized missiles between the storage bay and the parked vehicles.

1.3 SCOPE

This document presents the design blast and fragment loads and allowable deflections for the reinforced concrete box and steel doors to assure compliance with explosives safety objectives. This information will support structural design calculations by the A&E.

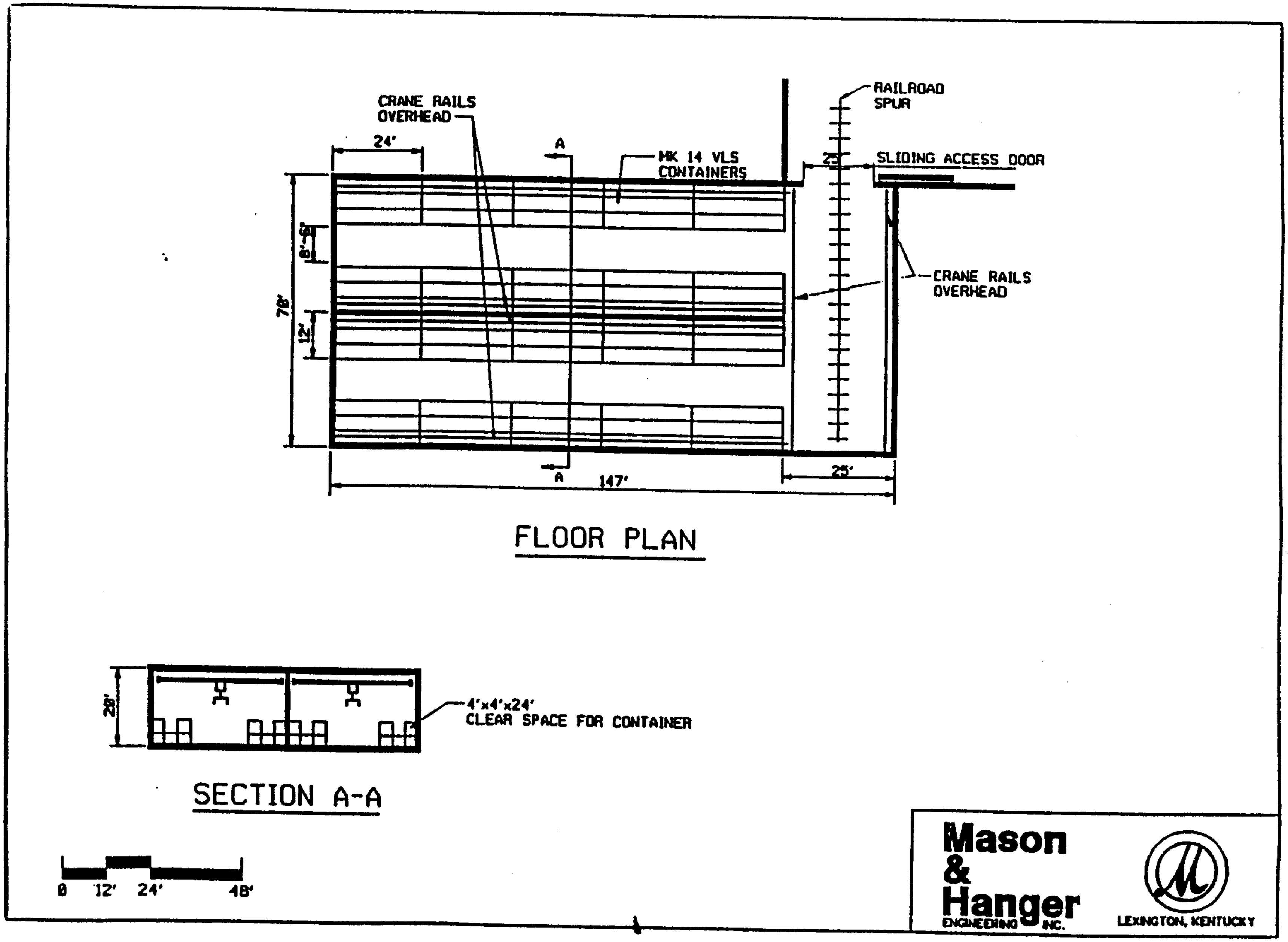


Figure 1-1. Floor plan of STANDARD Missile Magazine, MILCON P-137 (Ref 1).

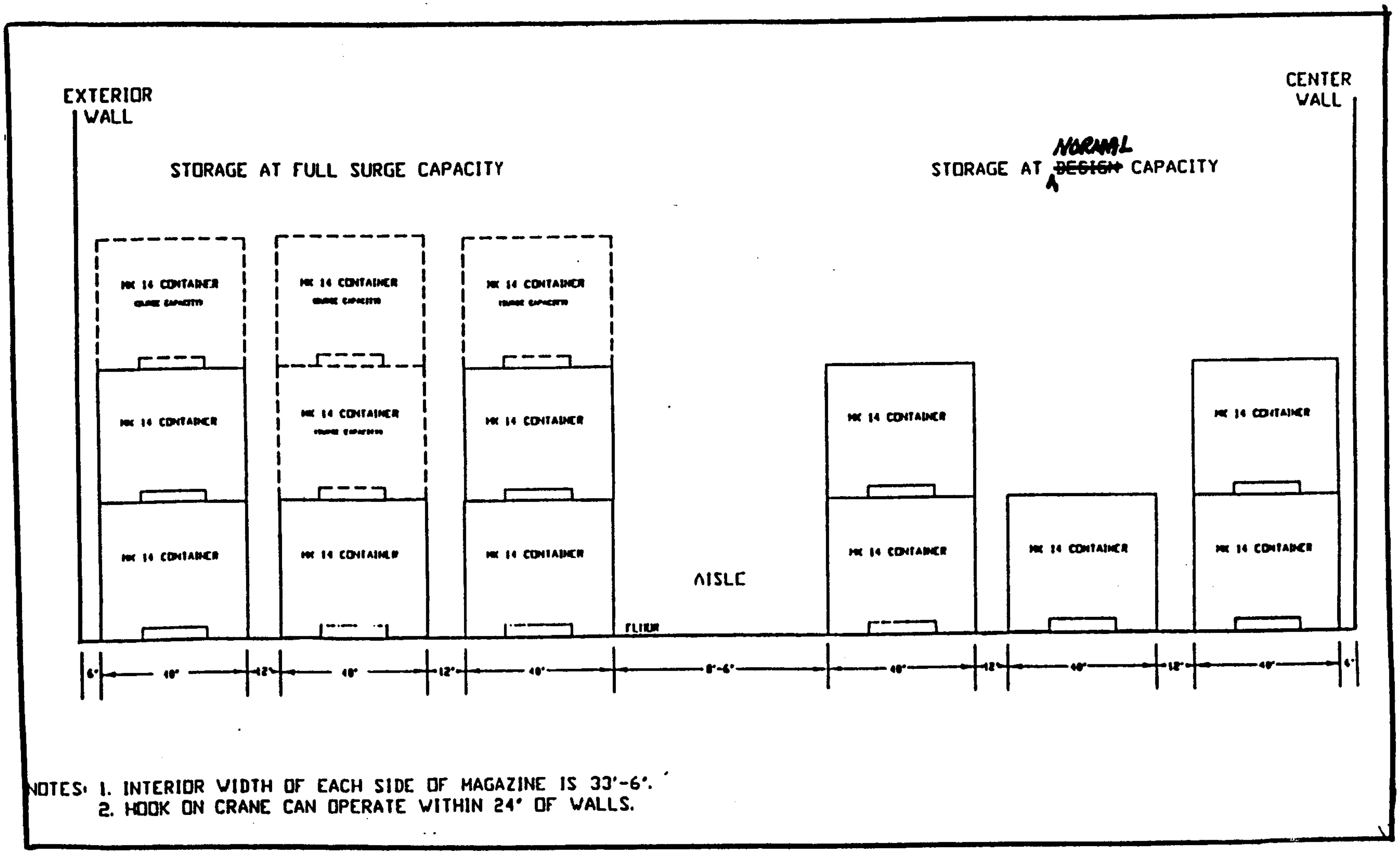


Figure 1-2. Stacking pattern for MK 14 containers in STANDARD Missile Magazine, MILCON P-137 (Ref 1).

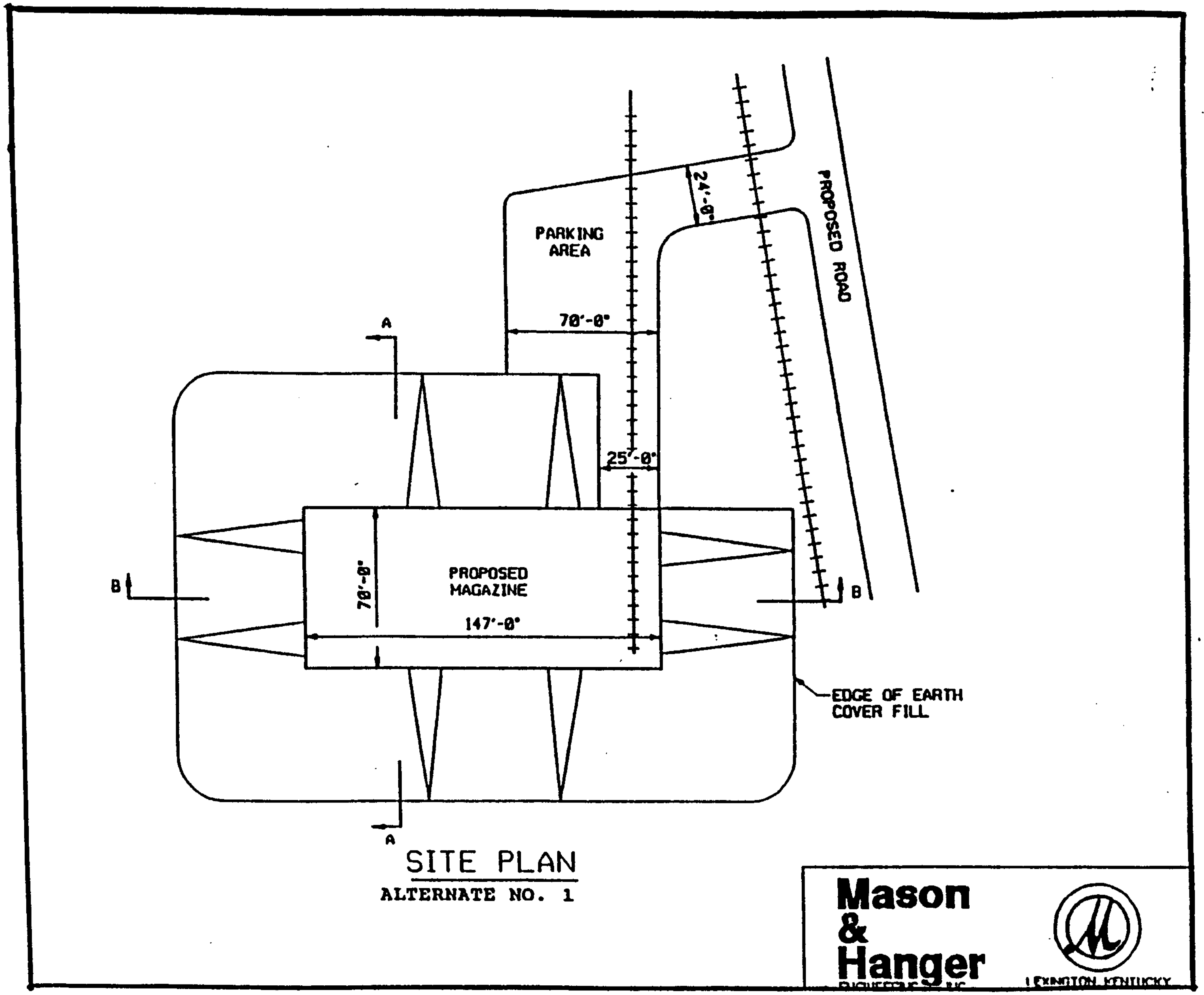


Figure 1-3. General site plan for STANDARD Missile Magazine, MILCON P-137 (Ref 1).

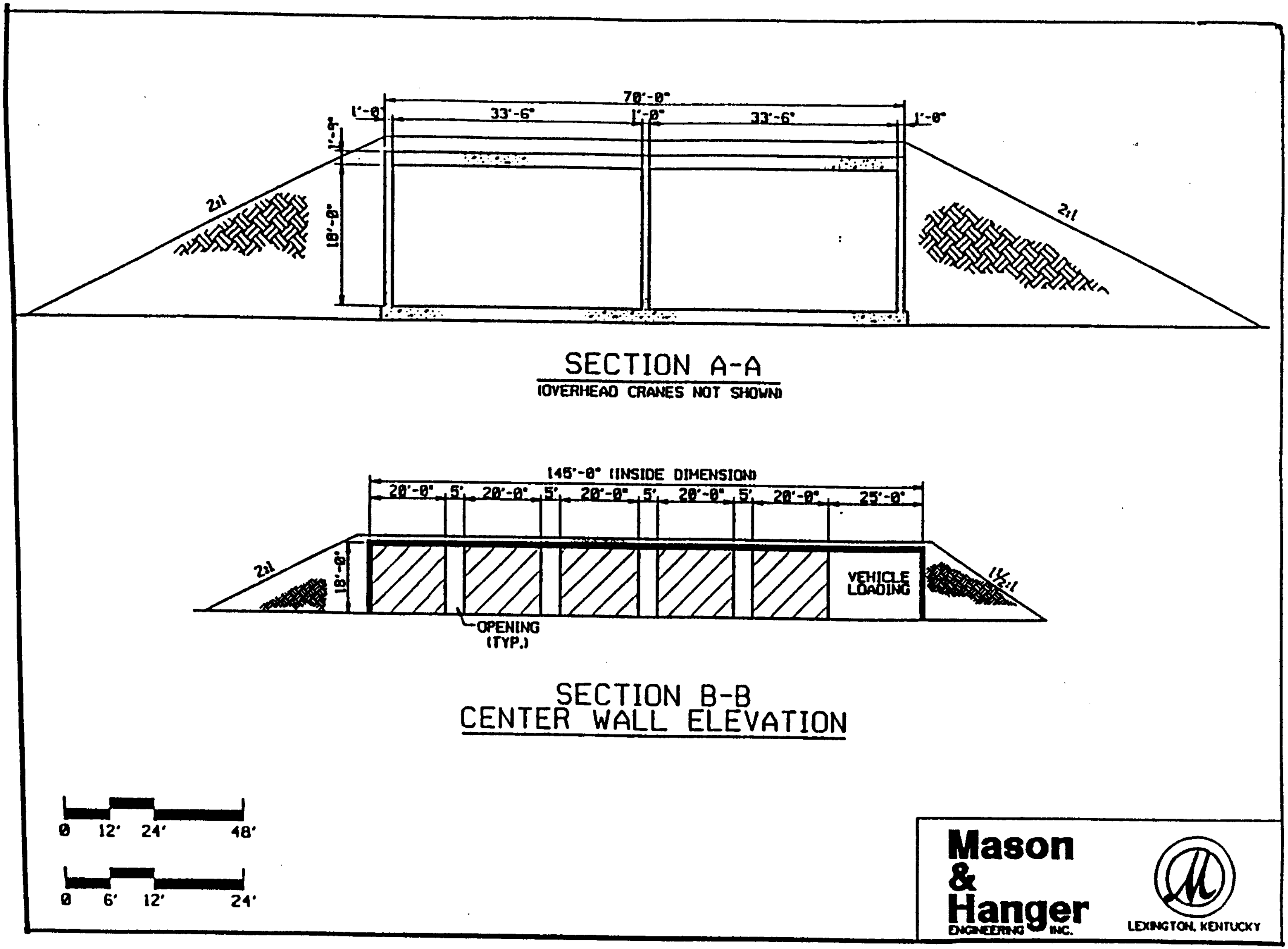


Figure 1-4. Elevation views of STANDARD Missile Magazine, MILCON P-137 (Ref 1).

2.0 EXPLOSIVES SAFETY

2.1 MAXIMUM CREDIBLE EVENT

The maximum credible event (MCE) for the NAVFAC Type M magazine will be inadvertent detonation of 100,000 lb TNT equivalent of hazard Class/Division 1.1 material.

For the purpose of calculating design blast loads for the NAVFAC Type M magazine, the maximum credible event (MCE) will be inadvertent detonation of 350,000 lb TNT equivalent of Class/Division 1.1 material stored in a NAVFAC Type F magazine (100 feet wide, 50 feet deep, and 15 feet high). It shall be assumed that the Type F magazine (donor or source of blast loads on Type M magazine) is sited at the minimum safe separation distance allowed by NAVSEA OP-5 (Ref 2) for standard earth-covered magazines. The Type F donor magazine is oriented, relative to the Type M magazine (acceptor or magazine subjected to blast loads), to produce the maximum possible blast and debris loads on the Type M acceptor magazine. The critical nesting arrangements and minimum safe separation distances resulting in maximum blast loads on the Type M acceptor magazine are shown in Figure 2-1.

2.2 EXPLOSIVES SAFETY OBJECTIVES

- Damage to the NAVFAC Type M acceptor magazine from the MCE in the NAVFAC Type F donor magazine shall not result in blast, fragments or debris that could be a source of sympathetic detonation of missiles stored in the Type M magazine.

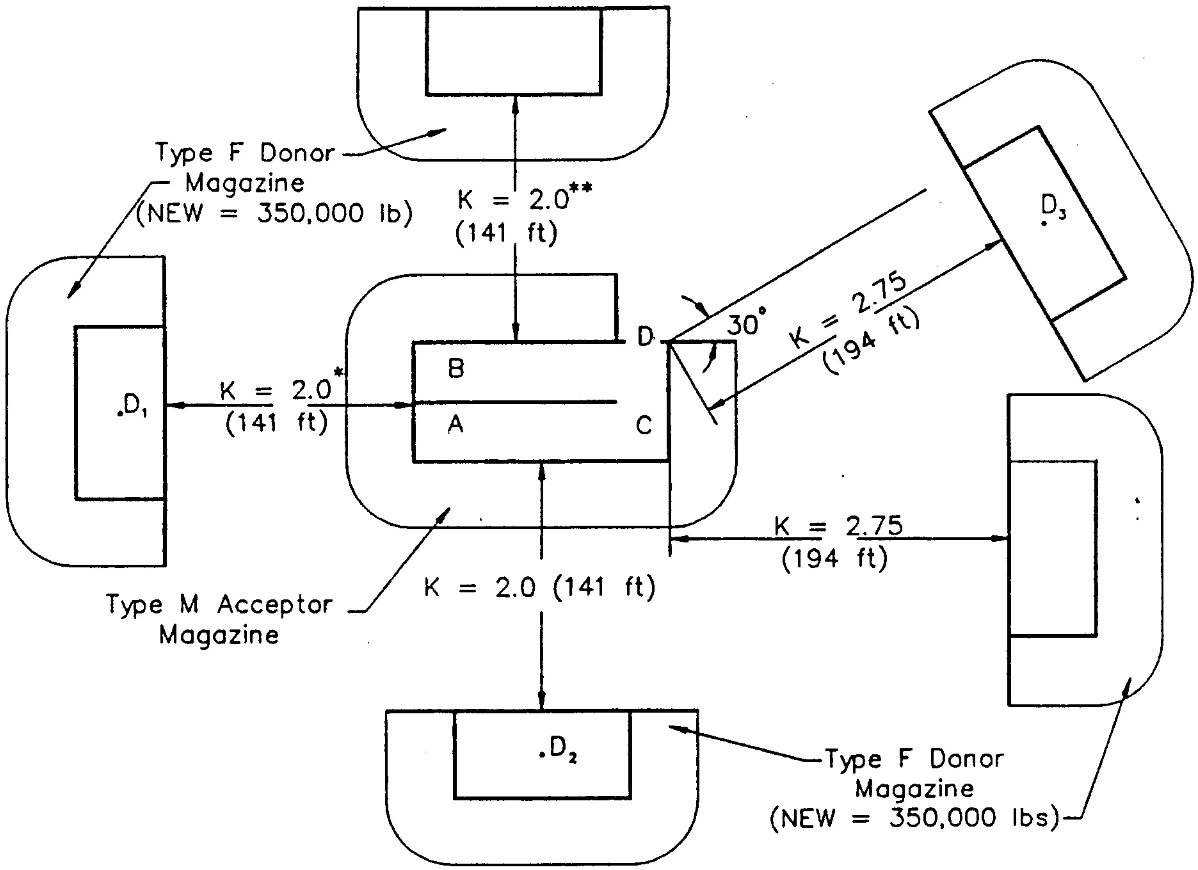
- The value of storage and any economic loss resulting from damage to the Type M magazine will not dictate explosives safety objectives.

2.3 DESIGN NET EXPLOSIVE WEIGHT

The design net explosive weight, W, considered stored in the Type F donor magazine for the purpose of calculating design blast loads for the Type M magazine shall be,

$$W = 1.2 \times 350{,}000 = 420{,}000 \text{ lbs}$$

The factor 1.2 is the value recommended in NAVFAC P-397 (Ref 4) to account for uncertainties in the facility design and construction process.



*K = 2.75 not required because of intervening soil/wing wall adjacent to headwall.

** Design blast load on Type M Magazine from side of donor to front of acceptor at K = 2.75 is less, based on Eskimo VI test data.

Headwall & Doors	Roof Slab	Critical Donor
–	A	D_1, D_2
–	B	D_1
–	C	D_2
D	–	D_3

Figure 2-1. **Critical nesting arrangements and minimum safe separation distances for deriving design blast loads for Type M acceptor magazine from MCE in Type F donor magazine.**

3.0 DESIGN LOADS

3.1 DESIGN BLAST LOADS

3.1.1 Roof Design Blast Load

Step 1: Define critical orientation of Type F donor magazine.

From Eskimo VI[a] test data (Ref 3), the incident shock impulse on the roof of the Type M magazine will be maximum when the front of the Type F donor magazine faces the side of the Type M acceptor magazine, as shown in Figure 3-1.

Step 2: Calculate minimum safe separation distance between donor and acceptor magazines.

The minimum safe separation distance, R_{OP-5}, required by NAVSEA OP-5 is,

$$R_{OP-5} = K_{OP-5} W^{1/3} = 2.0\ (350{,}000)^{1/3} = 140.9 \text{ ft}$$

Step 3: Calculate minimum scaled distance, K, from Type F donor headwall to critical point on roof of Type M acceptor.

The critical point is located at midspan of each bay of the Type M box, or 13.8 feet from the edge of the box, as shown in Figure 3-1. Therefore, the minimum distance, R, and scaled distance, K, from the headwall of the Type F donor magazine to the critical point on the roof of the Type M acceptor magazine are,

$$R = R_{OP-5} + 13.8 = 140.9 + 13.8 = 154.7 \text{ ft}$$

$$K = R/W^{1/3} = 154.7/(1.2 \times 350{,}000)^{1/3} = 2.08 \text{ ft/lb}^{1/3}$$

Step 4: Calculate design blast impulse or peak incident shock impulse, i_s, at critical point on roof of Type M acceptor magazine.

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[a]Eskimo VI was a large-scale explosive test of box magazines to validate explosives safety performance and to evaluate criteria for external blast loads.

From Eskimo VI test data (Figure 3-2), the maximum i_s measured at K = 2.08 (from Step 3) on the roof of the acceptor magazine located to the front of the donor magazine was,

$$i_s/W^{1/3} = 18.3 \text{ psi-msec/lb}^{1/3} \qquad \text{, from Figure 3-2}$$

$$i_s = 18.3\ (1.2 \times 350{,}000)^{1/3} = 1370 \text{ psi-msec}$$

Step 5: Calculate design blast pressure or peak incident shock pressure, P_{so}, at critical point on roof of Type M acceptor magazine.

From Eskimo VI test data (Figure 3-3), the maximum P_{so} measured at K = 2.08 (from Step 3) on the roof of the acceptor magazine located to the front of the donor magazine was,

$$P_{so} = 298 \text{ psi} \qquad \text{, from Figure 3-3.}$$

Step 6: Calculate design blast duration, t_o, at critical point on roof of Type M acceptor magazine.

Assuming a linear decay of pressure with time and i_s = 1370 psi-msec from Step 4, and P_{so} = 298 psi from Step 5,

$$t_o = 2i_s/P_{so} = 2(1370)/298 = 9.2 \text{ msec}$$

Step 7: Summarize the design blast load for the roof of the Type M magazine.

i_s = 1370 psi

P_{so} = 298 psi

t_o = 9.2 msec

3.1.2 Headwall Design Blast Load

Step 1: Define critical orientation of Type F donor magazine.

From Eskimo VI test data (Ref 3), the incident shock impulse on the headwall of the Type M acceptor magazine will be maximum when the front of the Type F donor magazine faces the headwall of the Type M acceptor magazine, as shown in Figure 3-4.

Step 2: Calculate minimum safe separation distance between donor and acceptor magazines.

The minimum safe separation distance, R_{OP-5}, required by NAVSEA OP-5 is when the Type F donor box is just outside the 30 degree arc with respect to the Type M headwall as shown in Figure 3-4. For this location, NAVSEA OP-5 requires $K_{OP-5} = 2.75$ and,

$$R_{OP-5} = K_{OP-5}W^{1/3} = 2.75\ (350{,}000)^{1/3} = 194.0\ \text{ft}$$

Step 3: Calculate minimum scaled distance, K, from center of Type F donor headwall to center of Type M acceptor headwall.

The minimum distance, R, between the centers of the Type F and Type M headwalls, based on a 100 feet wide Type F donor box, a 25.0 feet wide Type M acceptor headwall, and R_{OP-5} = 194.0 feet (from Step 2) is,

$$R = \sqrt{(194.0 + (25.0/2))^2 + (59.0)^2} = 214.9\ \text{ft}$$

Therefore, the minimum scaled distance ,K, from the center of the Type F donor headwall to the center of the Type M acceptor headwall is,

$$K = R/W^{1/3} = 214.9/(1.2 \times 350{,}000)^{1/3} = 2.87\ \text{ft/lb}^{1/3}$$

Step 4: Calculate peak incident shock pressure, P_{so}, at center of Type M acceptor headwall.

From Eskimo VI test data (Figure 3-5), the peak incident shock pressure at the center of the Type M acceptor headwall at K = 2.87 (from Step 3) is,

P_{so} = 138 psi , from Figure 3-5.

Step 5: Calculate design blast pressure or peak reflected shock pressure, $P_{r\alpha}$, at center of Type M acceptor headwall.

The angle of incidence, α, of the shock wave front with respect to the Type M acceptor headwall is,

$$\alpha = 90.0 - [30.0 - \sin^{-1}(59.0/214.9)] = 90.0 - 14.1 = 75.9°$$

The reflected pressure coefficient, $C_{r\alpha}$, for α = 75.9 degrees and P_{so} = 138 psi (from Step 4), based on Figure 3-6 (Figure 2-193 of NAVFAC P-397) is,

$C_{r\alpha}$ = 1.42 , from Figure 3-6.

Therefore, the peak reflected shock pressure, $P_{r\alpha}$, at the center of the Type M acceptor headwall, accounting for the attack angle of the incident shock wave and P_{so} = 138 psi is,

$$P_{r\alpha} = C_{r\alpha}\ P_{so} = 1.42 \times 138 = 196\ \text{psi}$$

Step 6: Calculate scaled incident shock impulse, $i_s/W^{1/3}$, at center of Type M acceptor headwall.

From Eskimo VI test data (Figure 3-7), the scaled incident shock impulse, $i_s/W^{1/3}$, at the center of the Type M acceptor headwall located at K = 2.87 (from Step 3) is,

$$i_s/W^{1/3} = 19.4 \text{ psi-msec/lb}^{1/3} \quad \text{, from Figure 3-7.}$$

Step 7: Calculate reflected shock impulse, $i_{r\alpha}$, neglecting shock wave reflections off adjoining wingwall.

Entering Figure 3-8 (Figure 2-194 of Reference 4) with α = 75.9 degrees (from Step 5) and either $i_s/W^{1/3}$ = 19.4 at α = 90 degrees (from Step 6) or P_{so} = 138 psi (from Step 4), the scaled reflected shock impulse, $i_{r\alpha}/W^{1/3}$, is,

$$i_{r\alpha}/W^{1/3} = 27.0 \text{ psi-msec/lb}^{1/3} \quad \text{, from Figure 3-8.}$$

$$i_{r\alpha} = 27.0\ (1.2 \times 350{,}000)^{1/3} = 2022 \text{ psi-msec}$$

Step 8: Calculate wingwall reflection factor, C_{rw}, for headwall that accounts for increase in reflected shock impulse on headwall from shock wave reflections off adjoining wingwall.

Using computer program SHOCK (Ref 5) and accounting for α = 75.9 degree incidence angle but neglecting shock wave reflections off adjoining surfaces (i.e., N = 1 reflecting surface) as shown in Figure 3-9, SHOCK output (Appendix A) predicts the reflected shock impulse, $i_{r\alpha}$, on the Type M headwall is,

$$i_{r\alpha}\ (N = 1) = 3212 \text{ psi-msec} \quad \text{, from SHOCK (see Appendix A)}$$

Using computer program SHOCK (Ref 5) and accounting for α = 75.9 degree incidence angle and shock wave reflections off adjoining wingwall (i.e., N = 2 reflecting surfaces) as shown in Figure 3-9, SHOCK output (Appendix A) predicts the reflected shock impulse, $i_{r\alpha}$, on the Type M headwall is,

$$i_{r\alpha}\ (N = 2) = 4611 \text{ psi=msec} \quad \text{, from SHOCK (see Appendix A)}$$

Based on the above calculated values of $i_{r\alpha}$, the wingwall reflection factor, C_{rw}, that accounts for the angle of incidence of the shock wave striking the headwall and shock wave reflections off the adjoining wingwall, is,

$$C_{rw} = i_{r\alpha}\ (N = 2)/i_{r\alpha}\ (N = 1) = 4611/3212 = 1.44$$

Step 9: Calculate design blast impulse or total reflected impulse, $i_{r\alpha}$, on headwall, accounting for angle of incidence of shock wave, shock wave reflections off ground and adjoining wingwall, and direct incident shock wave striking headwall.

From Step 7, $i_{r\alpha}$ = 2022 psi-msec and from Step 8, C_{rw} = 1.44. Therefore, the total reflected impulse, $i_{r\alpha}$, on headwall is,

$$i_{r\alpha} = i_{r\alpha}(N = 1) \times C_{rw} = 2022 \times 1.44 = 2912 \text{ psi-msec.}$$

This value $i_{r\alpha}$ = 2912 psi msec reflects ESKIMO VI test data (Ref 3) and is considered to be more accurate than instead using $i_{r\alpha}$ = 4611 psi-msec calculated in Step 8.

Step 10: Calculate design blast duration, t_0, for headwall of Type M magazine.

Assuming a linear decay of pressure with time, and $i_{r\alpha}$ = 2912 psi-msec from Step 9, and $P_{r\alpha}$ = 196 psi from Step 5,

$$t_o = 2i_{r\alpha}/P_{r\alpha} = 2(2912)/196$$

$$t_o = 29.7 \text{ msec}$$

Step 11: Summarize design blast load for headwall of Type M magazine.

$i_{r\alpha}$ = 2912 psi-msec

$P_{r\alpha}$ = 196 psi

t_o = 29.7 msec

3.1.3 Earth Bermed Wall Design Blast Load

The walls of the Type M box, except the headwall, are covered with an earth berm, sloping 2:1 from 2 feet above the roofline to natural grade. This soil berm will reduce the blast loading on the box walls. Based on wall deflections measured in Eskimo VI (Ref 3), the blast loading on earth bermed walls at K = 1.25 from the donor is very small. Therefore, it is recommended that the blast loading on earth bermed walls of the Type M box be neglected. However, a hydracode analysis should be conducted to validate this recommendation. Design the earth bermed walls for design dead plus live plus seismic loads.

3.1.4 Equipment Door Design Blast Load

The equipment door (25 x 16 ft) covers most of the headwall (25 x 18 ft). Therefore, the design blast loads for the headwall and equipment door are the same. From Step 11, Section 3.1.2, the design blast load for the equipment door is,

$i_{r\alpha}$ = 2912 psi-msec

$P_{r\alpha}$ = 196 psi

t_o = 29.7 msec

3.1.5 Personnel Door Design Blast Load

Step 1: Define critical orientation of Type F donor magazine.

The critical orientation of the Type F donor magazine for the maximum blast load on the Type M personnel door is described in Section 3.1.2, Step 1, and shown in Figure 3-4.

Step 2: Calculate minimum safe separation distance between Type F donor headwall and Type M personnel door.

The minimum safe separation distance, R_{OP-5}, is developed in Section 3.1.2, Step 2, and

R_{OP-5} = 194.0 ft

Step 3: Calculate minimum separation distance, K, from center of Type F donor headwall to center of Type M personnel door.

The minimum distance, R, between the centers of the Type F headwall and Type M personnel door, based on a 100-foot wide Type F donor box, a 3.2-foot wide personnel door located 5.0 feet to the left of the Type M equipment door, and R_{OP-5} = 194.0 feet (from Step 2), is

$$R = \sqrt{(194 - 5.0 - 3.2/2)^2 + (48.0)^2} = 193.4 \text{ ft}$$

Therefore, the minimum scaled distance, K, from the center of the Type F donor headwall to the center of the Type M personnel door is,

$$K = R/W^{1/3} = 193.4/(1.2 \times 350{,}000)^{1/3} = 2.58 \text{ ft/lb}^{1/3}$$

Step 4: Calculate peak incident shock pressure, P_{so}, at center of Type M personnel door.

From Eskimo VI test data (Figure 3-5), the peak incident shock pressure at the center of the Type M personnel door at K = 2.58 (from Step 3) is,

P_{so} = 152 psi , from Figure 3-5

Step 5: Calculate design blast pressure or peak reflected shock pressure, $P_{r\alpha}$, at center of Type M personnel door.

The angle of incidence, α, of the shock wave front with respect to the Type M personnel door is,

$$\alpha = 90.0 - [30.0 - \sin^{-1}(48.0/194)] = 90.0 - 15.7 = 74.3^\circ$$

The reflected pressure coefficient, $C_{r\alpha}$, for α = 74.3 degrees and P_{so} = 152 psi (from Step 4), based on Figure 3-6 (Figure 2-193 of NAVFAC P-393) is,

$$C_{r\alpha} = 1.60 \qquad \text{, from Figure 3-6.}$$

Therefore, the peak reflected shock pressure, $P_{r\alpha}$, at the center of the Type M personnel door, accounting for the attack angle of the incident shock wave and P_{so} = 152 psi is,

$$P_{r\alpha} = C_{r\alpha} P_{so} = 1.60 \times 152 = 243 \text{ psi}$$

Step 6: Calculate scaled incident shock impulse, $i_s/W^{1/3}$, at center of Type M personnel door.

From Eskimo VI test data (Figure 3-7), the scaled incident shock impulse, $i_s/W^{1/3}$, at the center of the Type M personnel door located at K = 2.58 (from Step 3) is,

$$i_s/W^{1/3} = 19.9 \text{ psi-msec/lb}^{1/3} \qquad \text{,from Figure 3-7.}$$

Step 7: Calculate reflected shock impulse, $i_{r\alpha}$, neglecting shock wave reflections off adjoining wingwall.

Entering Figure 3-8 (Figure 2-194 of Reference 4) with α = 74.3 degrees (from Step 5) and either $i_s/W^{1/3}$ = 19.9 at $\alpha = 90^\circ$ (from Step 6) or P_{so} = 152 psi (from Step 4), the scaled reflected shock impulse, $i_{r\alpha}/W^{1/3}$, is,

$$i_{r\alpha}/W^{1/3} = 28.5 \text{ psi-msec/lb}^{1/3} \qquad \text{, from Figure 3-8}$$

$$i_{r\alpha} = 28.5 \times (1.2 \times 350{,}000)^{1/3} = 2133 \text{ psi-msec}$$

Step 8: Calculate wingwall reflection factor, C_{rw}, for Type M personnel door that accounts for increase in reflected shock impulse on personnel door from shock wave reflections off adjoining wingwall.

Using computer program SHOCK (Ref 5) and accounting for α = 74.3 degree incidence angle but neglecting shock wave reflections off adjoining surfaces (i.e., N = 1 reflecting surface) as shown in Figure 3-9, SHOCK output (Appendix A) predicts the reflected shock impulse, $i_{r\alpha}$, on the Type M personnel door is,

$i_{r\alpha}$ = 3527 psi-msec , from SHOCK (see Appendix A)

Using computer program SHOCK (Ref 5) and accounting for $\alpha = 74.3$ degree incidence angle and shock wave reflections off the adjoining wingwall (i.e., N = 2 reflecting surfaces) as shown in Figure 3-9, SHOCK output (Appendix A) predicts the reflected shock impulse, $i_{r\alpha}$, on the Type M personnel door is,

$i_{r\alpha}$ = 4793 psi-msec , from SHOCK (see Appendix A)

Based on the above calculated values of $i_{r\alpha}$, the wingwall reflection factor, C_{rw}, for the personnel door, that accounts for the angle of incidence of the shock wave striking the personnel door and shock wave reflections off the adjoining wingwall, is

$$C_{rw} = i_{r\alpha} (N = 2)/i_{r\alpha} (N = 1) = 4793/3527 = 1.36$$

Step 9: Calculate design blast impulse or total reflected impulse, $i_{r\alpha}$, on personnel door, accounting for angle of incidence of shock wave, shock wave reflections off ground and adjoining wingwall, and direct incident shock wave striking personnel door.

From Step 7, $i_{r\alpha}$ = 2133 psi-msec and from Step 8, $C_{r\alpha} = 1.36$. Therefore, the total reflected impulse, $i_{r\alpha}$, on the personnel door is,

$$i_{r\alpha} = i_{r\alpha} (N = 1) \times C_{rw} = 2133 \times 1.36 = 2900 \text{ psi-msec}$$

Step 10: Calculate design blast duration, t_o, for personnel door of Type M magazine.

Assuming a linear decay of pressure with time, and $i_{r\alpha}$ = 2900 psi-msec from Step 9 and $P_{r\alpha}$ = 243 psi from Step 5,

$$t_o = 2i_{i\alpha}/P_{r\alpha} = 2(2900)/243.$$

$$t_o = 23.9 \text{ msec}$$

Step 11: Summarize design blast load for personnel door of Type M magazine.

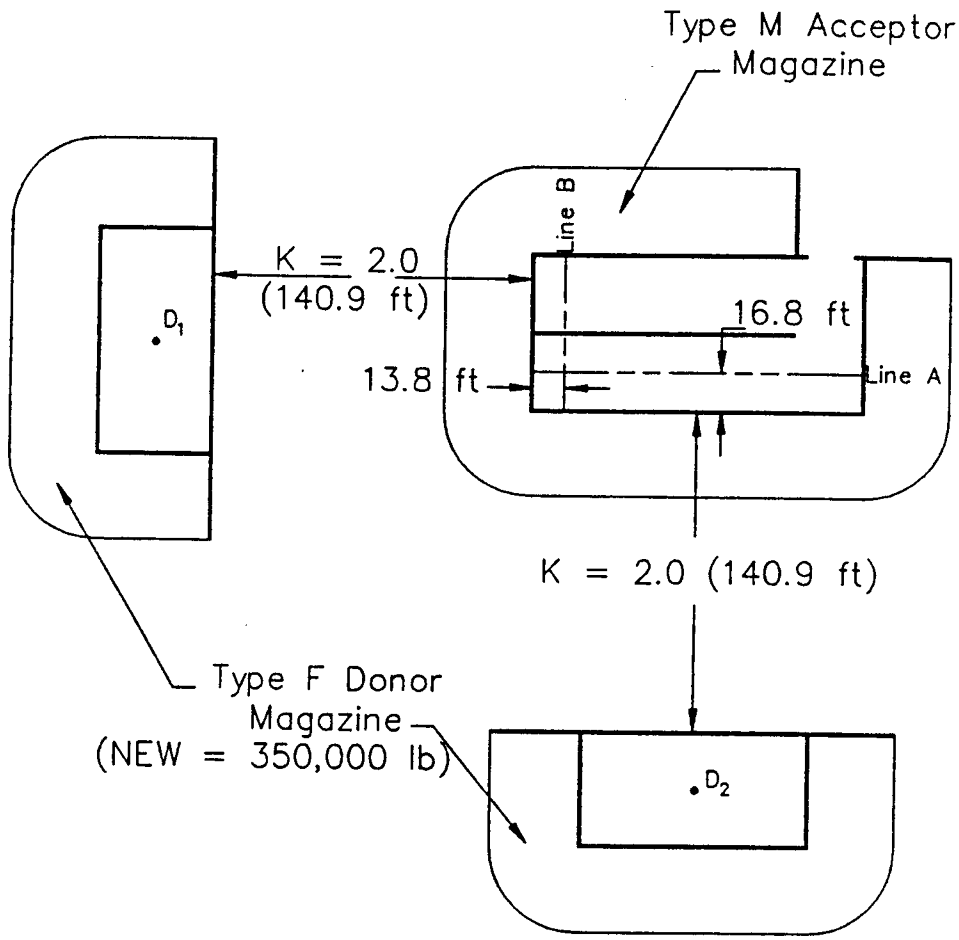
$i_{r\alpha}$ = 2900 psi-nsec

$P_{r\alpha}$ = 243 psi

t_o = 23.9 msec

3.2 DESIGN FRAGMENT LOAD

It is assumed that the minimum safe separation distances required by NAVSEA OP-5 will prevent primary fragments from the Type F donor magazine from causing sympathetic detonation of ordnance stored in the Type M magazine.



Note: Critical locations for design blast load on roof over storage area and shipping/receiving area are lines A and B.

Figure 3-1. Orientation of Type F donor magazine for maximum blast loading on roof of Type M acceptor magazine.

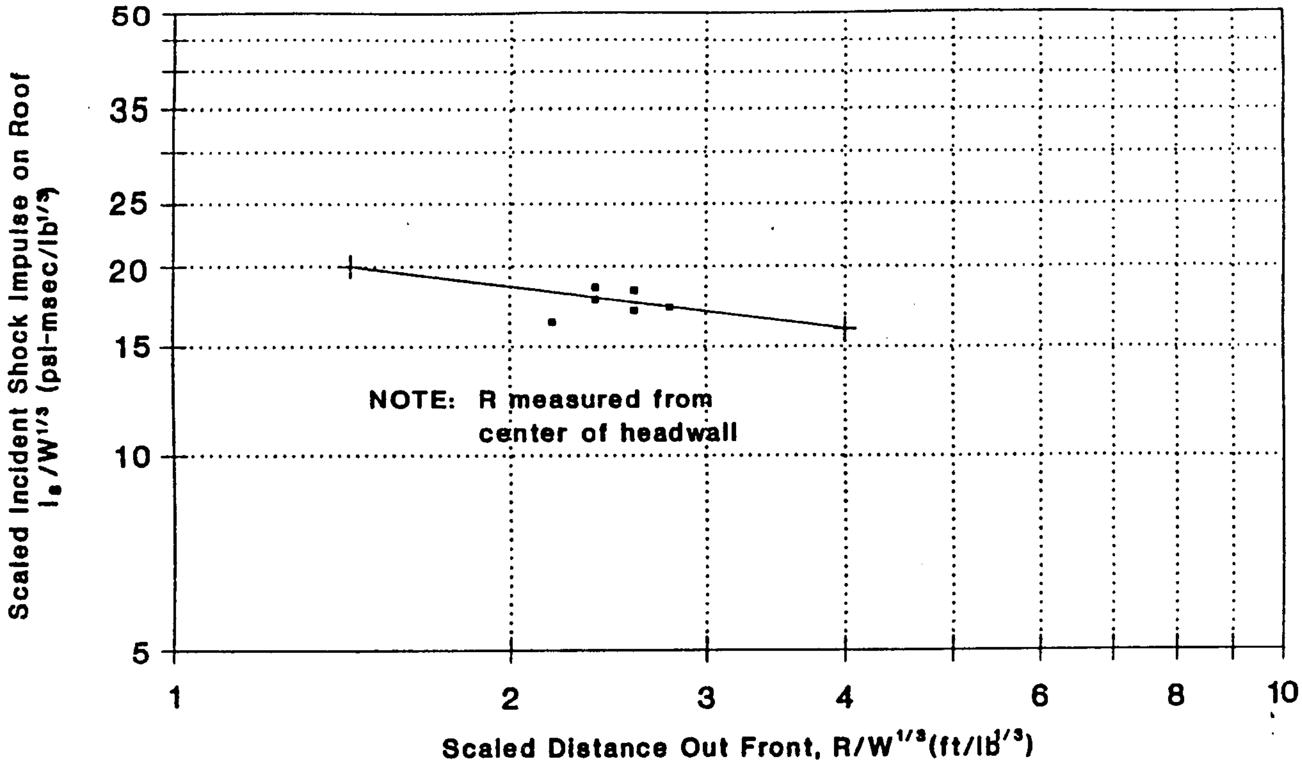


Figure 3-2. Peak incident shock impulse measured on roof of acceptor box magazine located to front of donor box magazine (Ref 3).

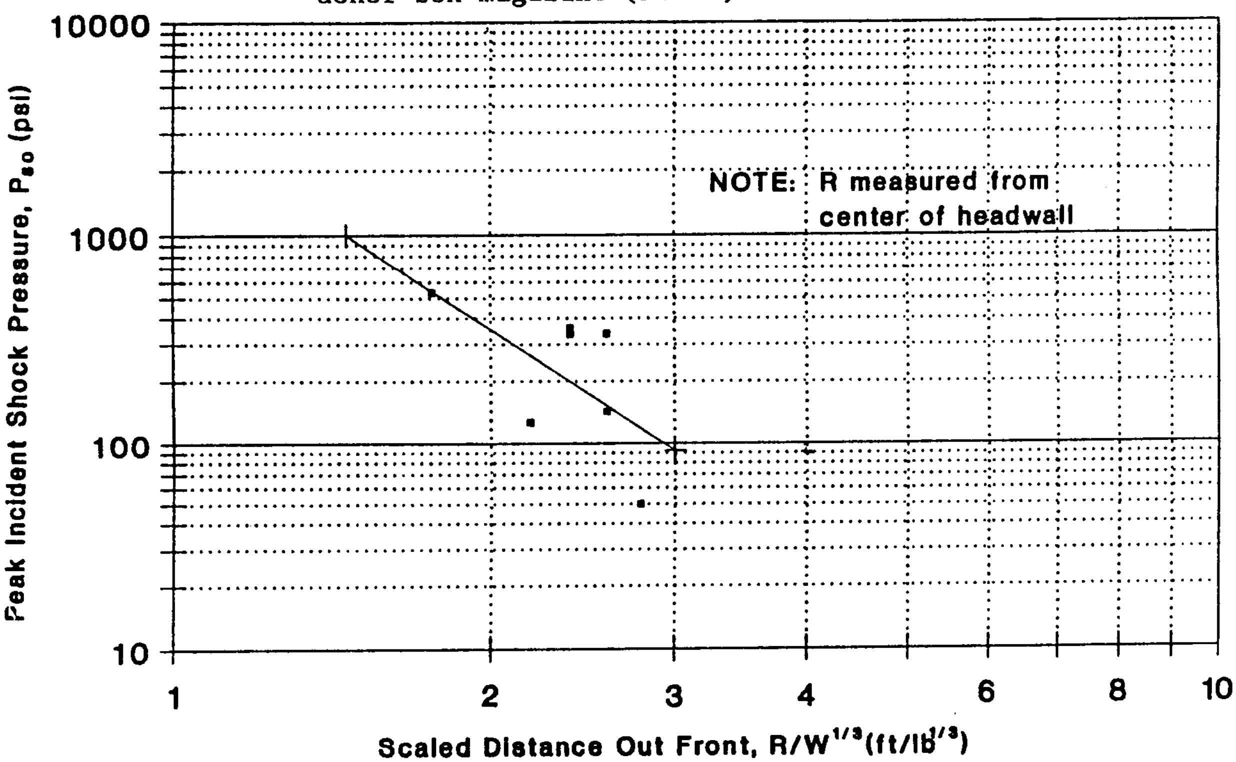


Figure 3-3. Peak incident shock pressure measured on roof of acceptor box magazine located to front of donor box magazine (Ref 3).

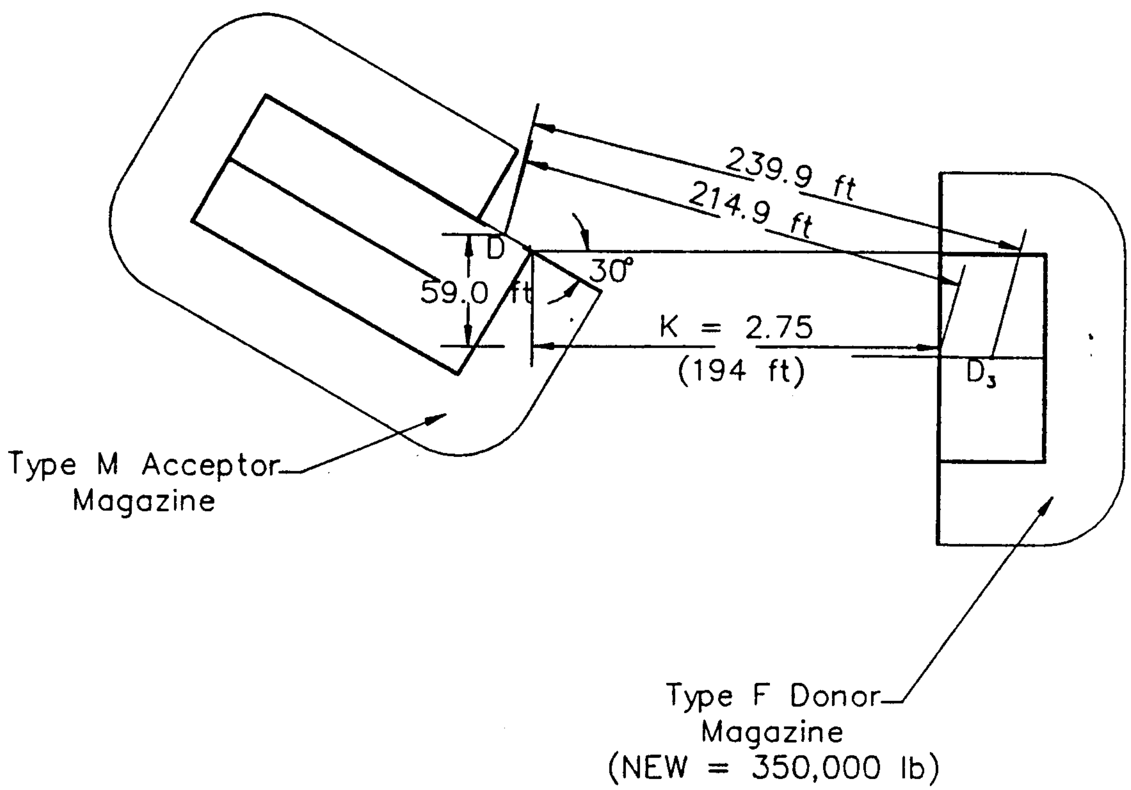


Figure 3-4. Orientation of Type F donor magazine for maximum blast loading on headwall and doors of Type M acceptor magazine.

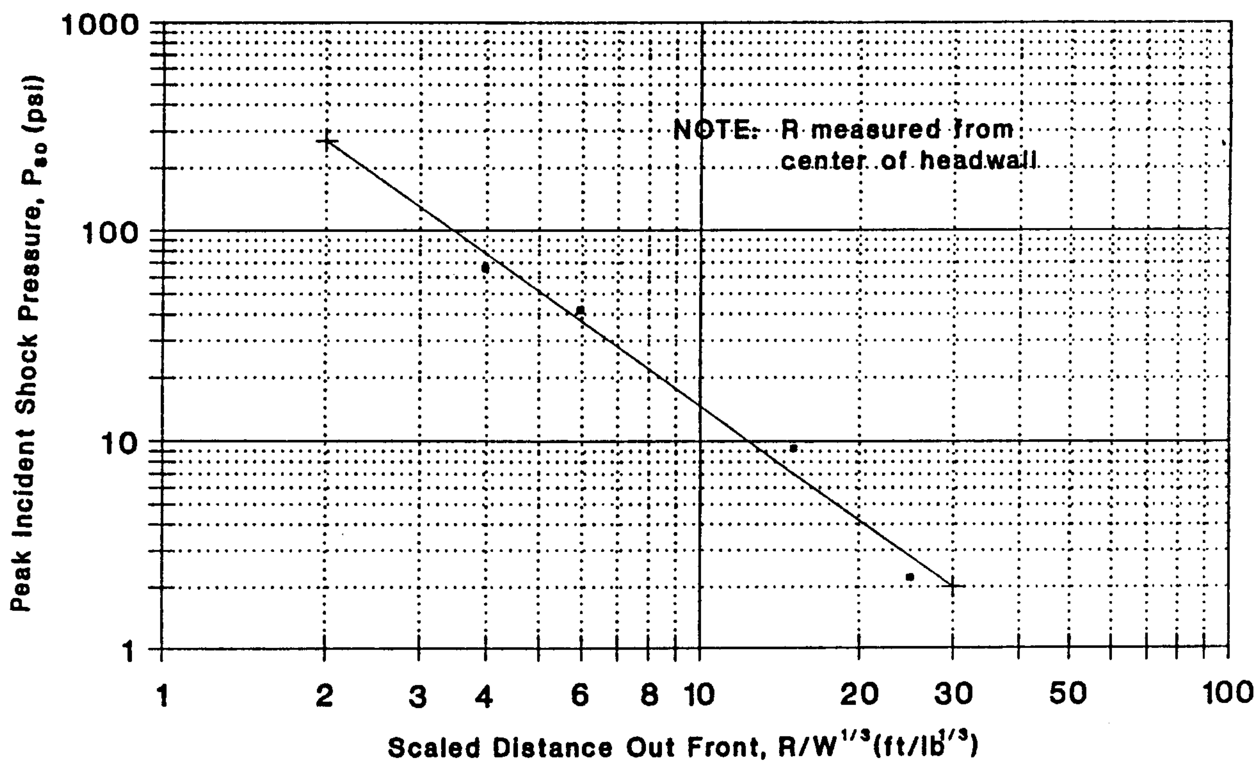


Figure 3-5. Peak incident shock pressure measured to the front (off-structure) of donor box magazine (Ref 3).

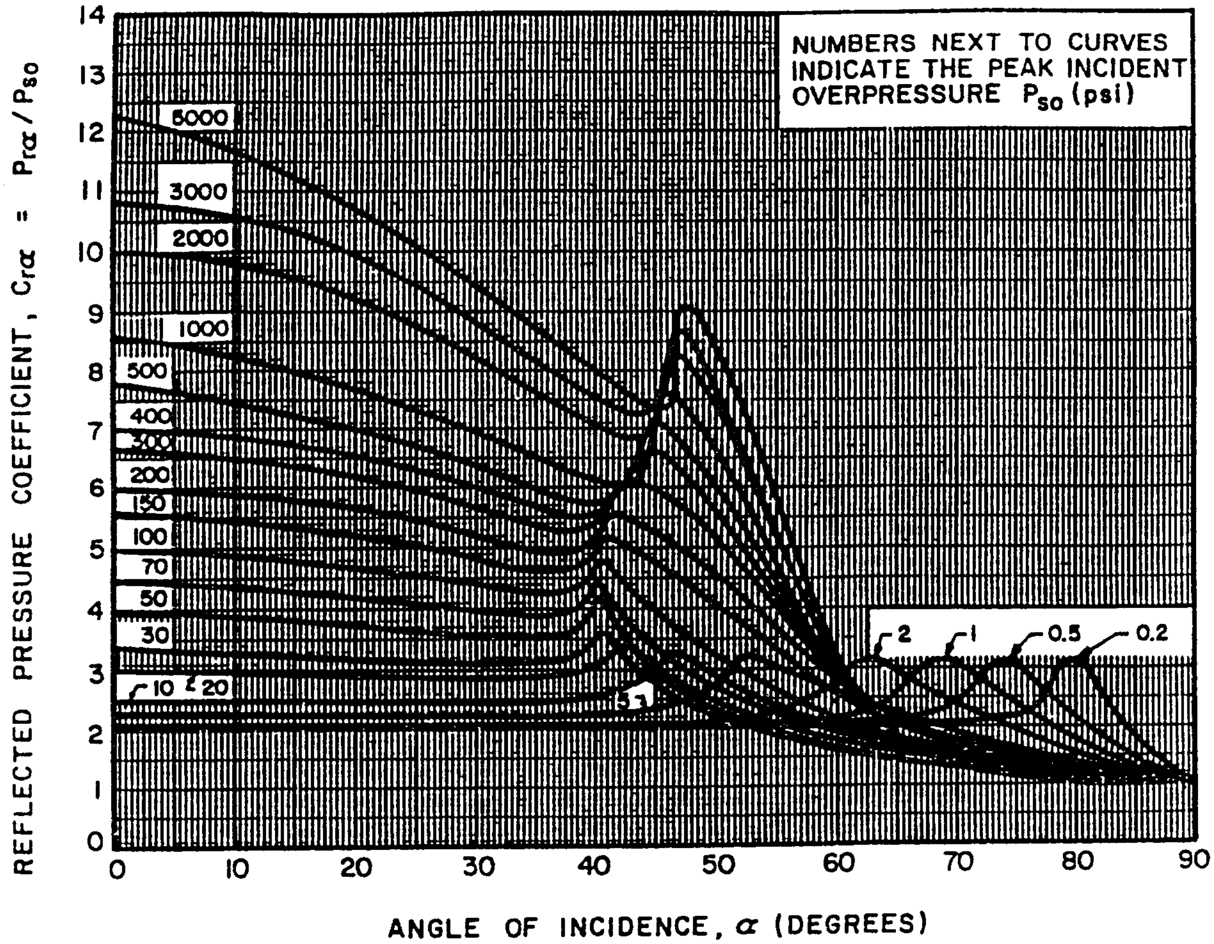


Figure 3-6. Reflected pressure coefficient, $C_{r\alpha}$, from Figure 2-193, NAVFAC P-397 (Ref 4).

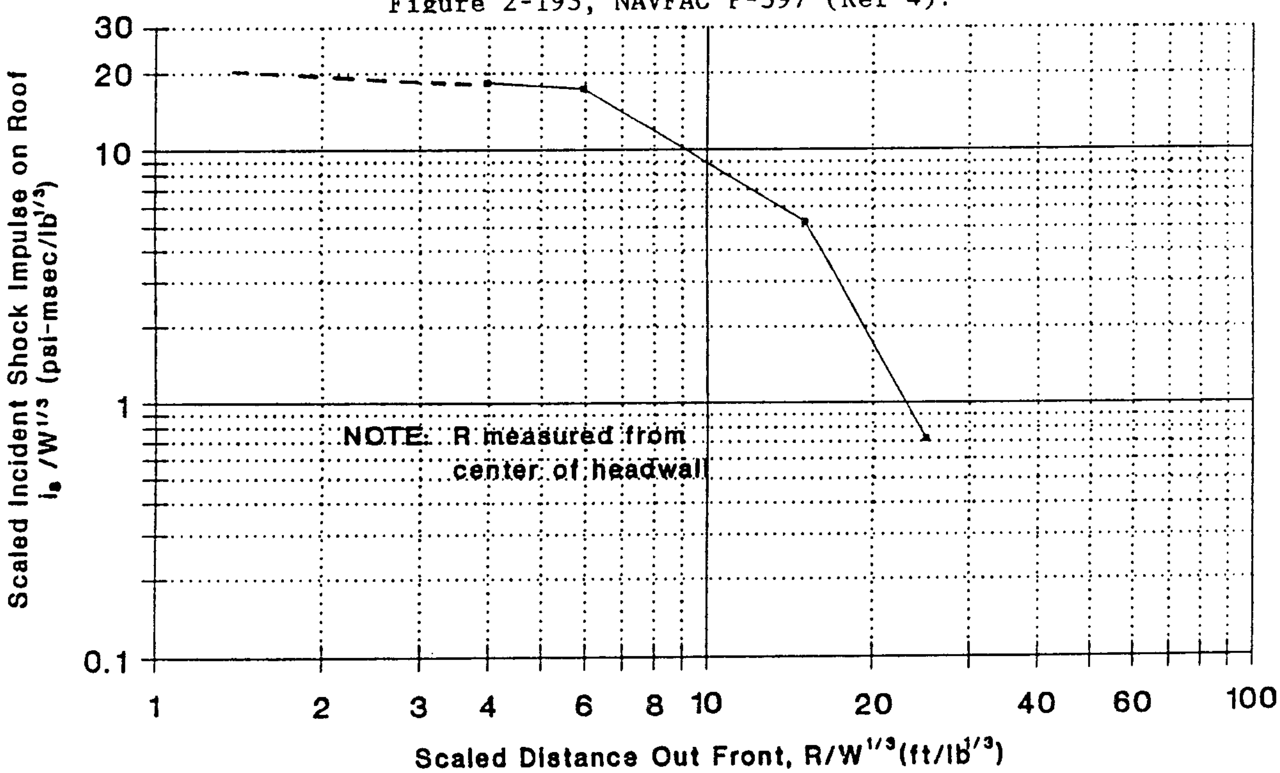


Figure 3-7. Scaled incident shock impulse measured to the front (off-structure) of donor box magazine (Ref 3).

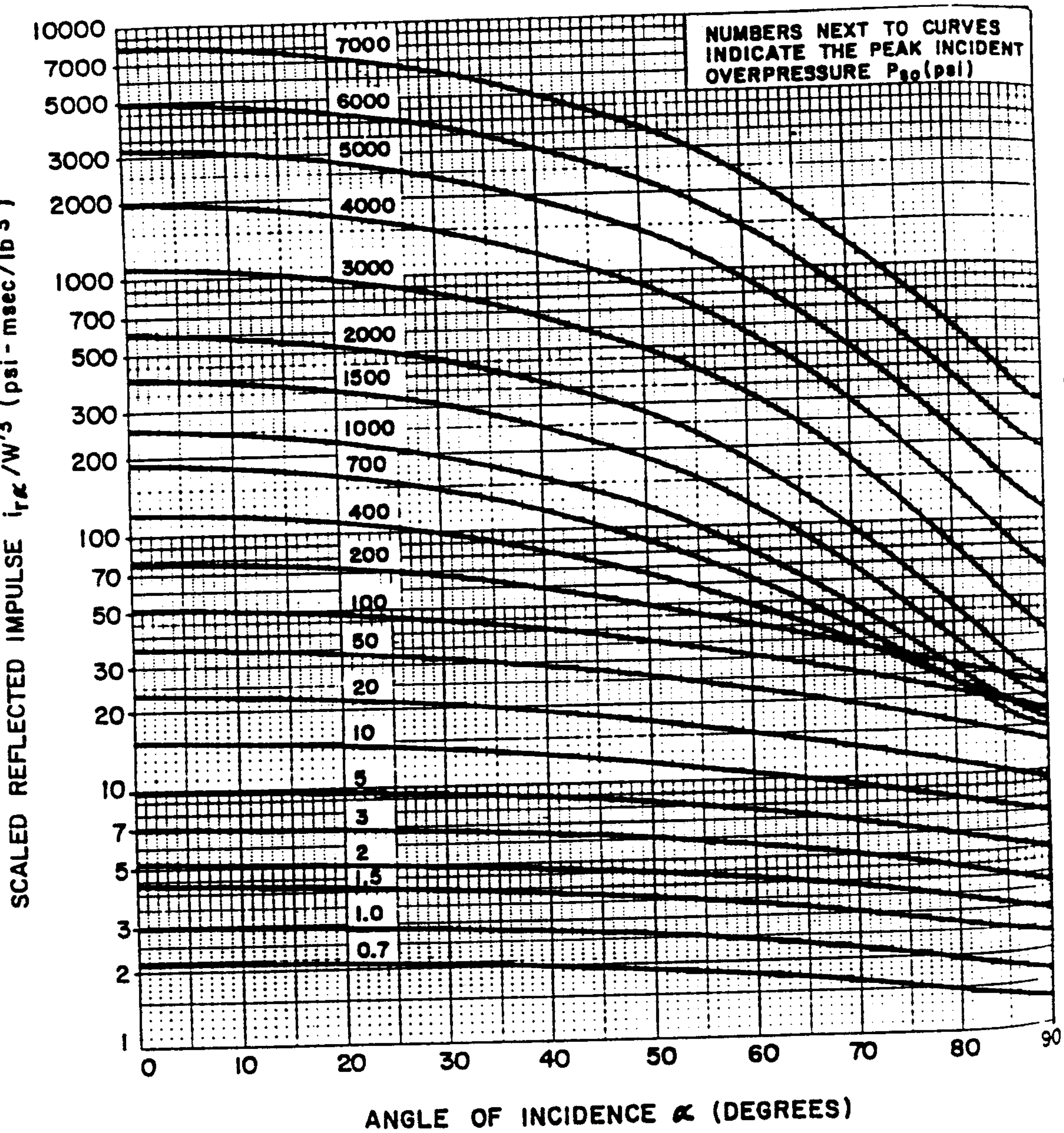
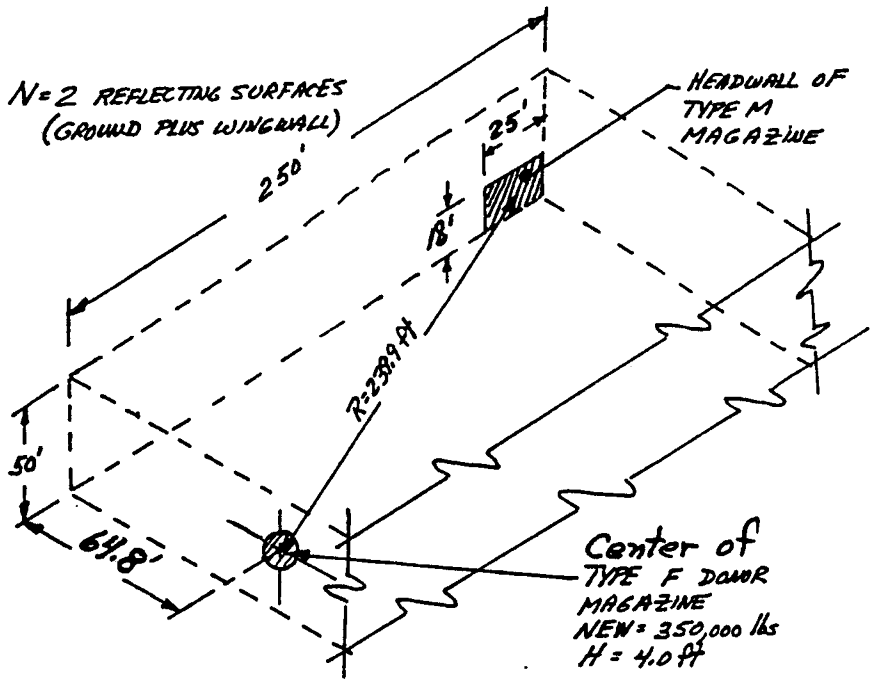
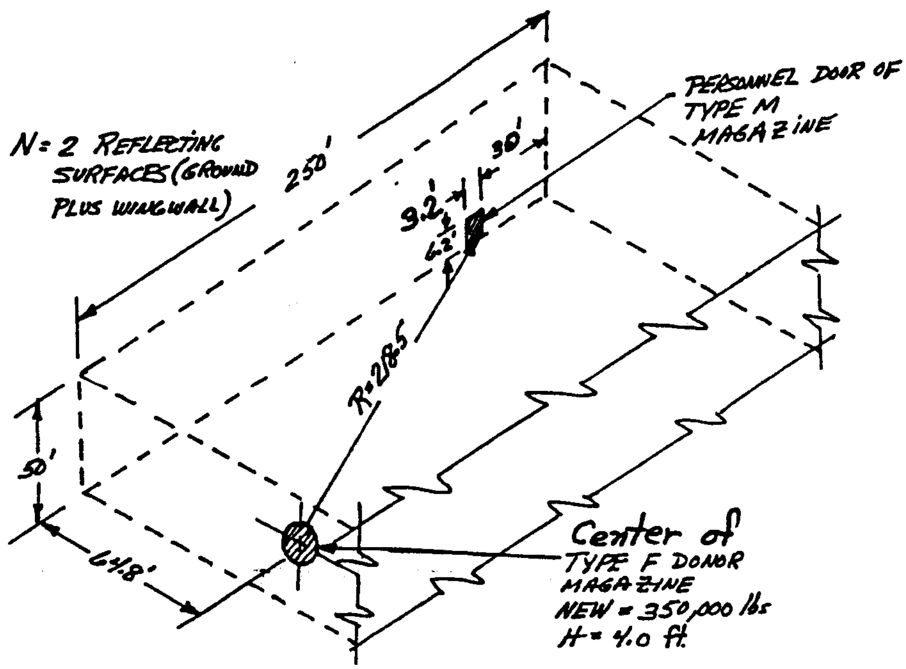


Figure 3-8. Scaled reflected shock impulse versus angle of incidence from Figure 2-194, NAVFAC P-397 (Ref 4).



(b) SHOCK parameters for headwall and equipment door



(a) SHOCK parameters for personnel door

Figure 3-9. Input parameters to computer program SHOCK for deriving wingwall reflection factors, C_{rw}, for Type M headwall, equipment door, and personnel door.

4.0 ALLOWABLE DEFLECTIONS

4.1 INTRODUCTION

In accordance with explosives safety objectives described in Section 2.2, one design objective is to prevent debris, resulting from blast damage to the Type M magazine, from causing sympathetic detonation of stored ordnance. One approach to achieve this design objective is to predict the post-failure weight and velocity distributions of debris and compare these predictions with the threshold distributions for debris causing sympathetic detonation. There are large uncertainties associated with this approach. Therefore, the recommended approach is to limit the maximum deflection of structural elements under the design blast loads to the deflection corresponding to incipient failure, as defined by NAVFAC P-397 (Ref 4).

4.2 REINFORCED CONCRETE

The maximum support rotation, θ_m, of reinforced concrete elements under the design blast load shall not exceed the allowable support rotation, θ_u, listed below.

Structural Element	Allowable Support Rotation, θ_u (degrees)
• Roof	
- Slabs	4.0
- Beams	2.0
• Headwall	
-Slabs	4.0
-Pillasters	2.0

"aspect ratio" [illegible] will not allow for Tensile membrane action (center [illegible] [illegible] slab into [illegible] slender [illegible] one way action) could add transverse beams to break up slab into squares & get membrane action but then have extra cost & these [illegible] [illegible] thinner roof

The predicted maximum support rotation, θ_m, shall be based on design procedures outlined in NAVFAC P-397 (Ref 4).

4.3 STEEL DOORS

The maximum support rotation, θ_m, and maximum deflection, X_m, of steel doors (equipment door and personnel door) under the design blast load shall not exceed the allowable support rotation, θ_u, and allowable deflection, X_u, listed below.

Structural Element	Allowable Support Rotation, θ_u (degree)	Allowable Ductility Factor, X_u/X_E [a]
Equipment Door	12	20[b]
Personnel Door	12	20[b]

[a] X_E = equivalent elastic yield deflection

[b] Based on ASTM A36 steel

Underlying the allowable deflections listed above is the assumption that failure of either door could result in sympathetic detonation of stored ordnance. However, if ordnance is never stored in the shipping/receiving area, except when the equipment door is open and the flatbed truck or railcar is being loaded, then it can be assumed that failure of the equipment and personnel doors would not result in sympathetic detonation of stored ordnance. Therefore, if ordnance operations will prevent ordnance from ever being stored in the shipping/receiving area, then the equipment and personnel doors need not be blast hardened for explosives safety (However, the doors should meet minimum physical security requirements). If ordnance operations will allow ordnance to be stored in the shipping/receiving area, then the maximum deflection of the doors under the design blast load should comply with the allowable deflections listed above.

5.0 REFERENCES

1. Southwest Division, Naval Facilities Engineering Command. Technical Report: Final Schematic Submittal for Standard Missile Magazine, P-137, Naval Weapons Station, Seal Beach, CA. (Report prepared under contract N68711-90-C-0173 by Mason and Hanger Engineering, Inc., Lexington, KY 40504). San Diego, CA. March 1991.

2. Naval Sea Systems Command. NAVSEA OP-5, Volume 1: Ammunition and Explosives Ashore - Safety Regulations for Handling, Storing, Production, Renovation, and Shipping. Fifth Edition. 1 August 1990.

3. Naval Civil Engineering Laboratory. Technical Report, TR-899: ESKIMO VI Test Results, by P.E. Tafoya. Port Hueneme, CA 93043. Nov 1981.

4. Naval Facilities Engineering Command. NAVFAC Publication P-397, "Structures to Resist the Effects of Accidental Explosions," vol. I through VI. Latest Edition. April 1987.

5. Naval Civil Engineering Laboratory. Technical Memorandum, TM-51-88 (Draft): SHOCK Users Manual, by P.C. Wager. Port Hueneme, CA 93043. Jan 1988.

Appendix A

Outputs From Computer Program SHOCK (Ref 5)

PROGRAM SHOCK
VERSION 1.0

****

PROGRAM FOR CALCULATION OF AVERAGE BARRIER REFLECTED SHOCK PRESSURES AND IMPULSES DUE TO AN INCIDENT WAVE AND REFLECTED WAVES FROM ONE TO FOUR REFLECTION SURFACES.
ORIGINAL PROGRAM "PAIMPRES" DEVELOPED BY AMMANN AND WHITNEY
MODIFIED INPUT AND OUTPUT BY NAVAL CIVIL ENGINEERING LAB

INPUT DATA

DATA SET TITLE:
Type M Magazine, Headwall Load, W-420000, Refl - floor

A. CHARGE WEIGHT, LBS........................	420000.00	
B. DISTANCE TO BLAST SURFACE, FT...........	64.80	
C. WIDTH OF BLAST SURFACE, FT..............	250.00	
D. HEIGHT OF BLAST SURFACE, FT.............	50.00	
E. HORIZONTAL (X) DISTANCE TO CHARGE FROM REFLECTING SURFACE NO. 2, FT.......	5.12	
F. VERTICAL (Y) DISTANCE TO CHARGE FROM REFLECTING SURFACE NO. 1, FT.......	4.00	
G. REFLECTING SURFACES "1" FOR FULL REFLECTION, "0" FOR NONE		
SURFACE 1 (FLOOR).....................	1	
SURFACE 2 (LEFT SIDEWALL)............	0	
SURFACE 3 (CEILING)...................	0	
SURFACE 4 (RIGHT SIDEWALL)...........	0	
H. REDUCED SURFACE CALCULATION.............	YES	
CORNERS OF REDUCED AREA; X, Y; FT		
UPPER LEFT CORNER....................	222.50	18.00
UPPER RIGHT CORNER...................	247.50	18.00
LOWER LEFT CORNER....................	222.50	0.00
LOWER RIGHT CORNER...................	247.50	0.00

IMPULSE GRID

NUMBER OF VERTICAL GRID LINES ON BLAST SURFACE	49
NUMBER OF HORIZONTAL GRID LINES ON BLAST SURFACE	25
NUMBER OF VERTICAL LINES ON REDUCED SURFACE	6
NUMBER OF HORIZONTAL LINES ON REDUCED SURFACE	10

DISTANCE BETWEEN VERTICAL GRID LINES = 5.21 FT
DISTANCE BETWEEN HORIZONTAL GRID LINES = 2.08 FT

		SPECIFIED COORDINATE (FT)	CLOSEST GRID POINT	GRID POINT COORDINATE (FT)
AREA UPPER LEFT CORNER	X	222.50	44	223.96
	Y	18.00	10	18.75
AREA LOWER RIGHT CORNER	X	247.50	49	250.00
	Y	0.00	1	0.00

FULL IMPULSE GRID IN PSI-MS/LBS**1/3

Y GRID COORDS	X GRID COORDINATES 223.96	229.17	234.37	239.58	244.79	250.00
18.75	44.9	43.9	42.9	41.9	40.9	~~20.0~~
16.67	44.9	43.9	42.9	41.9	41.0	~~20.0~~
14.58	44.9	43.9	42.9	41.9	41.0	~~20.0~~
12.50	44.9	43.9	42.9	41.9	41.0	~~20.0~~
10.42	44.9	43.9	42.9	41.9	41.0	~~20.0~~
8.33	44.9	43.9	42.9	41.9	41.0	~~20.0~~
6.25	44.9	43.9	42.9	41.9	41.0	~~20.0~~
4.17	44.9	43.9	42.9	41.9	41.0	~~20.0~~
2.08	44.9	43.9	42.9	41.9	41.0	~~20.0~~
0.00	~~22.5~~	~~22.0~~	~~21.5~~	~~21.0~~	~~20.5~~	~~10.0~~

→ AVG = 42.9

ANALYSIS RESULTS

AVERAGE SHOCK PRESSURE AND SCALED SHOCK IMPULSE ON REDUCED SURFACE

SURFACE	DUE TO WAVES OFF REFLECTING SURFACES 1	2	3	4	DUE TO INCIDENT WAVE
IMPULSE	18.7	0.0	0.0	0.0	18.5
PRESSURE	99.7	0.0	0.0	0.0	97.1

MAXIMUM AVERAGE SHOCK PRES. AND TOTAL AVERAGE SHOCK IMPULSE ON REDUCED SURFACE

SCALED IMPULSE	~~37.2~~ 42.9	PSI-MS/LB**(1/3)
IMPULSE	~~2782.4~~	PSI-MS → 3212 psi-ms
PRESSURE	99.7	PSI
DURATION	~~55.81~~	MS → 64.4 MS

SCALED IMPULSES HAVE BEEN DIVIDED BY W**(1/3) - 74.89

PROGRAM SHOCK
VERSION 1.0

****
PROGRAM FOR CALCULATION OF AVERAGE BARRIER REFLECTED SHOCK PRESSURES AND IMPULSES DUE TO AN INCIDENT WAVE AND REFLECTED WAVES FROM ONE TO FOUR REFLECTION SURFACES.
ORIGINAL PROGRAM "PAIMPRES" DEVELOPED BY AMMANN AND WHITNEY
MODIFIED INPUT AND OUTPUT BY NAVAL CIVIL ENGINEERING LAB

INPUT DATA

DATA SET TITLE:
Type M Magazine, Headwall Load, W-420000, Refl - floor, r. sidewall

```
A. CHARGE WEIGHT, LBS...................... 420000.00
B. DISTANCE TO BLAST SURFACE, FT...........     64.80
C. WIDTH OF BLAST SURFACE, FT..............    250.00
D. HEIGHT OF BLAST SURFACE, FT.............     50.00
E. HORIZONTAL (X) DISTANCE TO CHARGE
   FROM REFLECTING SURFACE NO. 2, FT.......      5.12
F. VERTICAL (Y) DISTANCE TO CHARGE
   FROM REFLECTING SURFACE NO. 1, FT.......      4.00
G. REFLECTING SURFACES
     "1" FOR FULL REFLECTION, "0" FOR NONE
     SURFACE 1 (FLOOR).....................         1
     SURFACE 2 (LEFT SIDEWALL).............         0
     SURFACE 3 (CEILING)...................         0
     SURFACE 4 (RIGHT SIDEWALL)............         1
H. REDUCED SURFACE CALCULATION.............       YES
     CORNERS OF REDUCED AREA; X, Y;  FT
       UPPER LEFT CORNER...................    222.50     18.00
       UPPER RIGHT CORNER..................    247.50     18.00
       LOWER LEFT CORNER...................    222.50      0.00
       LOWER RIGHT CORNER..................    247.50      0.00
```

IMPULSE GRID

```
NUMBER OF VERTICAL GRID LINES ON BLAST SURFACE     49
NUMBER OF HORIZONTAL GRID LINES ON BLAST SURFACE   25
NUMBER OF VERTICAL LINES ON REDUCED SURFACE         6
NUMBER OF HORIZONTAL LINES ON REDUCED SURFACE      10

DISTANCE BETWEEN VERTICAL GRID LINES   -  5.21 FT
DISTANCE BETWEEN HORIZONTAL GRID LINES -  2.08 FT
```

		SPECIFIED COORDINATE (FT)	CLOSEST GRID POINT	GRID POINT COORDINATE (FT)
AREA UPPER LEFT CORNER	X	222.50	44	223.96
	Y	18.00	10	18.75
AREA LOWER RIGHT CORNER	X	247.50	49	250.00
	Y	0.00	1	0.00

FULL IMPULSE GRID IN PSI-MS/LBS**1/3

Y GRID COORDS	X GRID COORDINATES 223.96	229.17	234.37	239.58	244.79	250.00
18.75	62.8	62.1	61.6	61.0	60.5	~~30.0~~
16.67	62.7	62.1	61.6	61.0	60.5	~~30.0~~
14.58	62.7	62.1	61.6	61.0	60.5	~~30.0~~
12.50	62.7	62.1	61.5	61.0	60.5	~~30.0~~ → AVERAGE = 61.57
10.42	62.7	62.1	61.5	61.0	60.5	~~30.0~~
8.33	62.7	62.1	61.5	61.0	60.5	~~30.0~~
6.25	62.7	62.1	61.5	61.0	60.5	~~30.0~~
4.17	62.7	62.1	61.5	61.0	60.5	~~30.0~~
2.08	62.7	62.1	61.5	61.0	60.5	~~30.0~~
0.00	~~31.4~~	~~31.1~~	~~30.8~~	~~30.5~~	~~30.2~~	~~15.0~~

ANALYSIS RESULTS

AVERAGE SHOCK PRESSURE AND SCALED SHOCK IMPULSE ON REDUCED SURFACE

SURFACE	DUE TO WAVES OFF REFLECTING SURFACES 1	2	3	4	DUE TO INCIDENT WAVE
IMPULSE	18.7	0.0	0.0	16.3	18.5
PRESSURE	99.7	0.0	0.0	71.8	97.1

MAXIMUM AVERAGE SHOCK PRES. AND TOTAL AVERAGE SHOCK IMPULSE ON REDUCED SURFACE

SCALED IMPULSE	~~53.5~~ 61.57	PSI-MS/LB**(1/3)
IMPULSE	~~4006.5~~	PSI-MS → 4610.9 PSI-MS.
PRESSURE	99.7	PSI
DURATION	~~80.37~~	MS → 92.5 ms

SCALED IMPULSES HAVE BEEN DIVIDED BY W**(1/3) = 74.89

PROGRAM SHOCK
VERSION 1.0

****

PROGRAM FOR CALCULATION OF AVERAGE BARRIER REFLECTED SHOCK PRESSURES AND IMPULSES DUE TO AN INCIDENT WAVE AND REFLECTED WAVES FROM ONE TO FOUR REFLECTION SURFACES.
ORIGINAL PROGRAM "PAIMPRES" DEVELOPED BY AMMANN AND WHITNEY
MODIFIED INPUT AND OUTPUT BY NAVAL CIVIL ENGINEERING LAB

INPUT DATA

DATA SET TITLE:
Type M Magazine, Personnel Door Load, W=420000, Refl - floor

```
A. CHARGE WEIGHT, LBS....................... 420000.00
B. DISTANCE TO BLAST SURFACE, FT...........     64.80
C. WIDTH OF BLAST SURFACE, FT..............    250.00
D. HEIGHT OF BLAST SURFACE, FT.............     50.00
E. HORIZONTAL (X) DISTANCE TO CHARGE
   FROM REFLECTING SURFACE NO. 2, FT.......      5.12
F. VERTICAL (Y) DISTANCE TO CHARGE
   FROM REFLECTING SURFACE NO. 1, FT.......      4.00
G. REFLECTING SURFACES
     "1" FOR FULL REFLECTION, "0" FOR NONE
     SURFACE 1 (FLOOR).....................         1
     SURFACE 2 (LEFT SIDEWALL).............         0
     SURFACE 3 (CEILING)...................         0
     SURFACE 4 (RIGHT SIDEWALL)............         0
H. REDUCED SURFACE CALCULATION.............       YES
     CORNERS OF REDUCED AREA; X, Y;  FT
       UPPER LEFT CORNER...................    211.50        6.20
       UPPER RIGHT CORNER..................    215.00        6.20
       LOWER LEFT CORNER...................    211.50        0.00
       LOWER RIGHT CORNER..................    215.00        0.00
```

IMPULSE GRID

```
NUMBER OF VERTICAL GRID LINES ON BLAST SURFACE      49
NUMBER OF HORIZONTAL GRID LINES ON BLAST SURFACE    25
NUMBER OF VERTICAL LINES ON REDUCED SURFACE          1
NUMBER OF HORIZONTAL LINES ON REDUCED SURFACE        4

DISTANCE BETWEEN VERTICAL GRID LINES   =  5.21 FT
DISTANCE BETWEEN HORIZONTAL GRID LINES =  2.08 FT
```

	SPECIFIED COORDINATE (FT)	CLOSEST GRID POINT	GRID POINT COORDINATE (FT)
DISTANCE FROM SURFACE 2 (X)	211.50	42	213.54
DISTANCE FROM SURFACE 1 (Y)	6.20	1	0.00

FULL IMPULSE GRID IN PSI-MS/LBS**1/3

Y GRID COORDS	X GRID COORDINATES 213.54
6.25	47.1
4.17	47.1
2.08	47.1
0.00	~~23.5~~

} AVERAGE = 47.1

ANALYSIS RESULTS

AVERAGE SHOCK PRESSURE AND SCALED SHOCK IMPULSE ON REDUCED SURFACE

	DUE TO WAVES OFF REFLECTING SURFACES				DUE TO INCIDENT WAVE
SURFACE	1	2	3	4	
IMPULSE	20.7	0.0	0.0	0.0	20.5
PRESSURE	126.8	0.0	0.0	0.0	123.4

MAXIMUM AVERAGE SHOCK PRES. AND TOTAL AVERAGE SHOCK IMPULSE ON REDUCED SURFACE

SCALED IMPULSE	~~41.2~~ → 47.1	PSI-MS/LB**(1/3)
IMPULSE	~~3085.6~~ → 3527 PSI-MS	PSI-MS
PRESSURE	126.8	PSI
DURATION	~~48.67~~ → 55.6 ms.	MS

SCALED IMPULSES HAVE BEEN DIVIDED BY W**(1/3) = 74.89

PROGRAM SHOCK
VERSION 1.0

****
PROGRAM FOR CALCULATION OF AVERAGE BARRIER REFLECTED SHOCK PRESSURES AND IMPULSES DUE TO AN INCIDENT WAVE AND REFLECTED WAVES FROM ONE TO FOUR REFLECTION SURFACES.
ORIGINAL PROGRAM "PAIMPRES" DEVELOPED BY AMMANN AND WHITNEY
MODIFIED INPUT AND OUTPUT BY NAVAL CIVIL ENGINEERING LAB

INPUT DATA

DATA SET TITLE:
Type M Magazine, Personnel Door Load, W=420000, Refl - floor, r. sidewall

A. CHARGE WEIGHT, LBS......................	420000.00		
B. DISTANCE TO BLAST SURFACE, FT...........	64.80		
C. WIDTH OF BLAST SURFACE, FT..............	250.00		
D. HEIGHT OF BLAST SURFACE, FT.............	50.00		
E. HORIZONTAL (X) DISTANCE TO CHARGE FROM REFLECTING SURFACE NO. 2, FT.......	5.12		
F. VERTICAL (Y) DISTANCE TO CHARGE FROM REFLECTING SURFACE NO. 1, FT.......	4.00		
G. REFLECTING SURFACES "1" FOR FULL REFLECTION, "0" FOR NONE			
SURFACE 1 (FLOOR).....................	1		
SURFACE 2 (LEFT SIDEWALL).............	0		
SURFACE 3 (CEILING)...................	0		
SURFACE 4 (RIGHT SIDEWALL)............	1		
H. REDUCED SURFACE CALCULATION.............	YES		
CORNERS OF REDUCED AREA; X, Y; FT			
UPPER LEFT CORNER..................	211.50	6.20	
UPPER RIGHT CORNER.................	215.00	6.20	
LOWER LEFT CORNER..................	211.50	0.00	
LOWER RIGHT CORNER.................	215.00	0.00	

IMPULSE GRID

NUMBER OF VERTICAL GRID LINES ON BLAST SURFACE	49
NUMBER OF HORIZONTAL GRID LINES ON BLAST SURFACE	25
NUMBER OF VERTICAL LINES ON REDUCED SURFACE	1
NUMBER OF HORIZONTAL LINES ON REDUCED SURFACE	4

DISTANCE BETWEEN VERTICAL GRID LINES - 5.21 FT
DISTANCE BETWEEN HORIZONTAL GRID LINES - 2.08 FT

	SPECIFIED COORDINATE (FT)	CLOSEST GRID POINT	GRID POINT COORDINATE (FT)
DISTANCE FROM SURFACE 2 (X)	211.50	42	213.54
DISTANCE FROM SURFACE 1 (Y)	6.20	1	0.00

FULL IMPULSE GRID IN PSI-MS/LBS**1/3

Y GRID COORDS	X GRID COORDINATES 213.54	
6.25	64.0	AVERAGE =64
4.17	64.0	
2.08	64.0	
0.00	~~32.0~~	

ANALYSIS RESULTS

AVERAGE SHOCK PRESSURE AND SCALED SHOCK IMPULSE ON REDUCED SURFACE

	DUE TO WAVES OFF REFLECTING SURFACES				DUE TO INCIDENT WAVE
SURFACE	1	2	3	4	
IMPULSE	20.7	0.0	0.0	14.8	20.5
PRESSURE	126.8	0.0	0.0	56.2	123.4

MAXIMUM AVERAGE SHOCK PRES. AND TOTAL AVERAGE SHOCK IMPULSE ON REDUCED SURFACE

SCALED IMPULSE	~~56.0~~ → 64.0	PSI-MS/LB**(1/3)
IMPULSE	~~4196.5~~ → 4793 PSI-MS	PSI-MS
PRESSURE	126.8	PSI
DURATION	~~66.19~~ → 75.6 ms	MS

SCALED IMPULSES HAVE BEEN DIVIDED BY W**(1/3) = 74.89