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PROTECTIVE CONSTRUCTION CONCEPTS

HEADQUARTERS, U. S. AIR FORCE
DIRECTORATE OF CIVIL ENGINEERING

1 November 1968

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STATEMENT OF THE PROBLEM

- DEVELOP CONCEPTS TO PROTECT PERSONNEL, WEAPONS & EQUIPMENT FROM ATTACK FROM WEAPONS CONTAINED IN THE CURRENT THREATS (SURFACE TO SURFACE & AIR TO SURFACE)
  - DIRECT HITS
  - EFFECTS OF NEAR MISSES

FIGURE 1

ACKNOWLEDGMENT

Under the terms of this contract, examination of available literature pertaining to passive protection was to be made and the current state-of-the-art was to be used in preparing concepts for passive protection.

Three areas bear heavily on considering counters to enemy weapons. These are the effects of blast, the penetration of fragments and the direct hits on facilities by projectiles.

In examining the literature available to us which related to these three areas, it was found that no one document adequately treated all three subjects. Many outstanding documents treated each subject. Where such outstanding and easily understandable documents were found, the cogent features of each were extensively applied to arrive at concepts for passive protection for aircraft, personnel, command, control and communications facilities, and POL.

So that the rationale used in arriving at the concepts will be understood, and so that users of this document can, in turn, create their own passive protection plans, portions of the outstanding publications pertaining to the three areas have been incorporated herein. For detailed treatment of the subjects in question, however, the reader is referred to the basic documents. All of the fifty-two (52) documents listed in "References" were used in varying degrees; however, ten are worthy of special mention because of their "extensive application" and incorporation. They are highlighted and identified by an asterisk (*) immediately in front of their identification number in "References" beginning on page viii. Where data and/or figures from the references have been directly incorporated in this report, they have been identified on the applicable figure and also cross referenced on the "List of Figures" beginning on page iv.

The contribution of the authors of the outstanding publications is hereby credited along with our appreciation.

CONTENTS

LIST OF FIGURES

REFERENCES

* 1. Apgar, J. W., Data and Estimates of the Penetration Performance of Several Shaped Charge Warheads, 1968.

2. Apgar, J. W., and Regan, J. M., Effect of Shaped Charges Against Monolithic and Spaced Targets, July 1965.

3. Austin, C. F., and Prenzle, J. K., Damage to Concrete and Masonry vs. Linear Shaped Charge Aspect, DDC 379-797.

4. Austin, C. F., and Prenzle, J. K., Length of Charge vs. Target Damage for a Simple Linear Shaped Charge, DDC 377-820.

* 5. Ballistic Data Performance of Ammunition, TM 9-1907, Department of the Army, July 1948.

6. Burch, G. T., Multiplate Damage Study, Technical Report AFATL-TR-67-116, September 1967.

7. The Calibration of Wallboard for the Determination of Particle Speed, No. 61, May 1966, AD-485 059.

8. The Characteristics of Particles Formed During the Perforation of Steel Armor by Steel Fragments, Project Thor, Report No. 57 (c), AD-358 893, December 1964

9. Closures for Hardened Protective Hangars, AD-291 571, August 1962.

10. Closures for Hardened Protective Hangars, AD-358 682, January 1961.

*11. Cost Effectiveness of Revetments and Shelters for Aircraft in SEA PACAF Note 68-6 (S), J. Curtis Bevins, May 28, 1968.

12. Counterinsurgency Lessons Learned Number 60: Defense Against Mortar/ Recoilless Rifle Attacks, AD-375 840, September 1966.

13. David, F. L., Annotated Bibliography on the Vulnerability of Tactical Targets, NWL Report No. 1925, NAVWPS Report No. 839.

14. Design Analysis and Feasibility Study for Aircraft Protective Shelters, AD-383 703, May 1967.

15. Doors and Access Openings to Protective Structures, AD-358 761, October 1958.

*16. Draft of R&D Plans for Armor Materials (U) Z-655-5-67 Army Materials and Mechanics Research Center, November 15, 1967.

*17. Dunn, Dennis, unpublished paper, BRL, November 1967.

18. The Effect of Door Strength on the Vulnerability and Hardness of Hangar-Type Protective Alert Shelters, AD-327 659, January 1962.

19. Elements of Terminal Ballistics, Part 1 - Introduction, Kill Mechanism and Vulnerability; Part 2 - Collection and Analysis of Data Concerning Targets, AMC Pamphlets AMCP 706-160, AMCP 706-161.

20. Epsen, T. W., Guber, E. S., and Recht, R. F., Application of Ballistic Effectiveness Analysis, NWC, October 1967.

21. Evolutionary Base Defense, Volume 1, AD-385 400L, November 1967.

22. Feasibility Study of an Above-Ground Hardened Hangar, AD-358 739, June 1958.

23. Florence, A. L., and Ahrens, T. J. Stanford Research Institute, Watertown, Massachusetts, AMRA January 1967, Interaction of Projectiles and Composite Armor.

24. Fundamentals of Protective Design, AD-419 074.

* 25. Giere, Albert C., Calculating Fragment Penetration and Velocity Data for Use in Vulnerability Studies, U. S. Naval Ordnance Evaluation Unit, Albuquerque, New Mexico, NAVORD Report 6621.

26. .50 Launch Armor Piercing Projectile, Lethality Assessment Study, DDC 80709.

27. Lessons Learned, Headquarters, 92nd Engineer Battalion (Construction), AD-825 398, August 1967.

28. Lethality of Fragmenting Infantry Munitions, by W. W. Clifford, D. R. Flowers, February 1966, BRL TECH Note No. 1601.

29. Malich, Donald, The Characteristics and the Lethality of Particles Formed During the Perforation of Steel Armor by Steel Fragments, Supplement to 57, Report No. 63, AD-376 494.

30. Malich, Donald, The Characteristics of Particles Formed During the Perforation of Aluminum Alloy by Steel Fragments, Report No. 65, August 1967, AD-384 694.

** 31. Manual for Design of Protective Structures Used in Explosive Processing and Storage Facilities, Picatinny Arsenal, Dover, New Jersey, 1967.

32. Mascianica, Frances S., Ballistic Performance of Lightweight Armor, November 1, 1967, ABT-100 Special, Army Materials and Mechanics Research Center, Watertown, Massachusetts.

33. Mechanics of High Speed Projectile Perforation, J. Franklin Inst., August 1957.

34. Normal Perforation of a Thin Plate by Truncated Projectiles, J. Franklin Institute, April 1958

* 35. Protective Construction for SEA, a 45 Day Study, WLDC-67-189, December 1967.

36. Reaction of Mild Steel Targets to Exploding Munitions, Shock and Vibration Bulletin No. 37, January 1968, Information Center.

* 37. Recht, Rodney F., Ballistic Perforation Dynamics of Armor-Piercing Projectiles, Naval Weapons Center, China Lake, California, December 1967, NWC TP-4532.

38. Recht, R. F. and Ipson, T. W., "Ballistic Perforation Dynamics," Trans. ASME, J. APPL MECH, Vol. 30, Series E, September 1963, pp. 384-390.

39. Recht, R. F. and Ipson, T. W., The Dynamics of Terminal Ballistics, Department of the Army.

40. The Resistance of Various Metallic Materials to Perforation by Steel Fragments; Empirical Relationships for Fragment Residual Velocity and Residual Weight, Project Thor, Report No. 47, April 1961.

* 41. The Resistance of Various Non-Metallic Materials to Perforation by Steel Fragments; Empirical Relationships to Fragment Residual Velocity and Residual Weight, Project Thor, Report No. 51, April 1963.

* 42. The Resistance of Various Woods to Perforation by Steel Fragments and Small Caliber Projectiles, No. 62, June 1966, AD-374 926.

43. Special Study of Armor Kits, Small Arms Protection M151, and 1/4 Ton Truck, September 1966, DPS-R137.

* 44. Summary Technical Report of Division 2, National Defense Research Committee, Volume 1 and Volume 2.

45. Theoretical and Experimental Study of Low-Velocity Penetration Phenomena, E. T. Cannon, Utah Research and Development Company, Inc., Salt Lake City, Utah, November 1966, AD-646 457.

46. Transcript of the Symposium on Warhead Research, AD-344 596L.

47. U. S. Army Materials and Mechanics Research Center, Interaction of Projectiles and Composite Armor, by A. L. Florence and U. J. Ahrens, Stanford Research Institute, Watertown, Massachusetts, AMRA, January 1967, AMRA CR 67-05 (F) Contract DA-04-200 - AMC-1381(x).

48. U. S. Naval Ordnance Test Station. Compilation of Dynamic Equation of of State Data for Solids and Liquids, by J. S. Rinehart, China Lake, California, NOTS May 1965 (NOTS TP 3793).

49. Vincent, Alma R., Steel and Aluminum Armor Performance Capabilities of Soviet 14.5 mm API, BS-41, and U. S. Caliber .50 AP M2, Caliber .30 AP M2 and Caliber .30 Bullnose M2 Projectiles, BRL Report No. 1337, April 1961.

50. Weapons Effects Testing of the Steel-Bin-Type Revetment Aircraft Shelter, AD-367 901, November 1965.

51. Zaid, Melvin, and Burton, Paul, Oblique Perforation of a Thin Plate by a Truncated Conical Projectile, J. Franklin Inst., July 1959.

* 52. Besserer, C. W., Missile Engineering Handbook, Principles of Guided Missile Design, D. Van Nostrand Company, Inc., Princeton, New Jersey, Copyright 1958.

* See Acknowledgment

** Ammann and Whitney Study

A. GUIDE FOR OBTAINING EFFECTS OF WEAPONS

It may be necessary to determine the thicknesses of various materials required to attenuate the penetration of projectiles and/or fragments into various materials. To assist in making these determinations, "road maps" delineating procedures for arriving at thickness of materials were prepared and are located in Figures iii (page xiv) and v (page xvi) for fragments and direct hits by projectiles, respectively. The parameters associated with blast also have an effect on the materials used for passive protection. A "road map" leading to quick determinations of the parameters of blast is also included herein in Figure iv on page xv. These "road maps" or methodologies refer to figures within this report and/or to references where solutions may be found.

GUIDE FOR OBTAINING EFFECTS OF WEAPONS

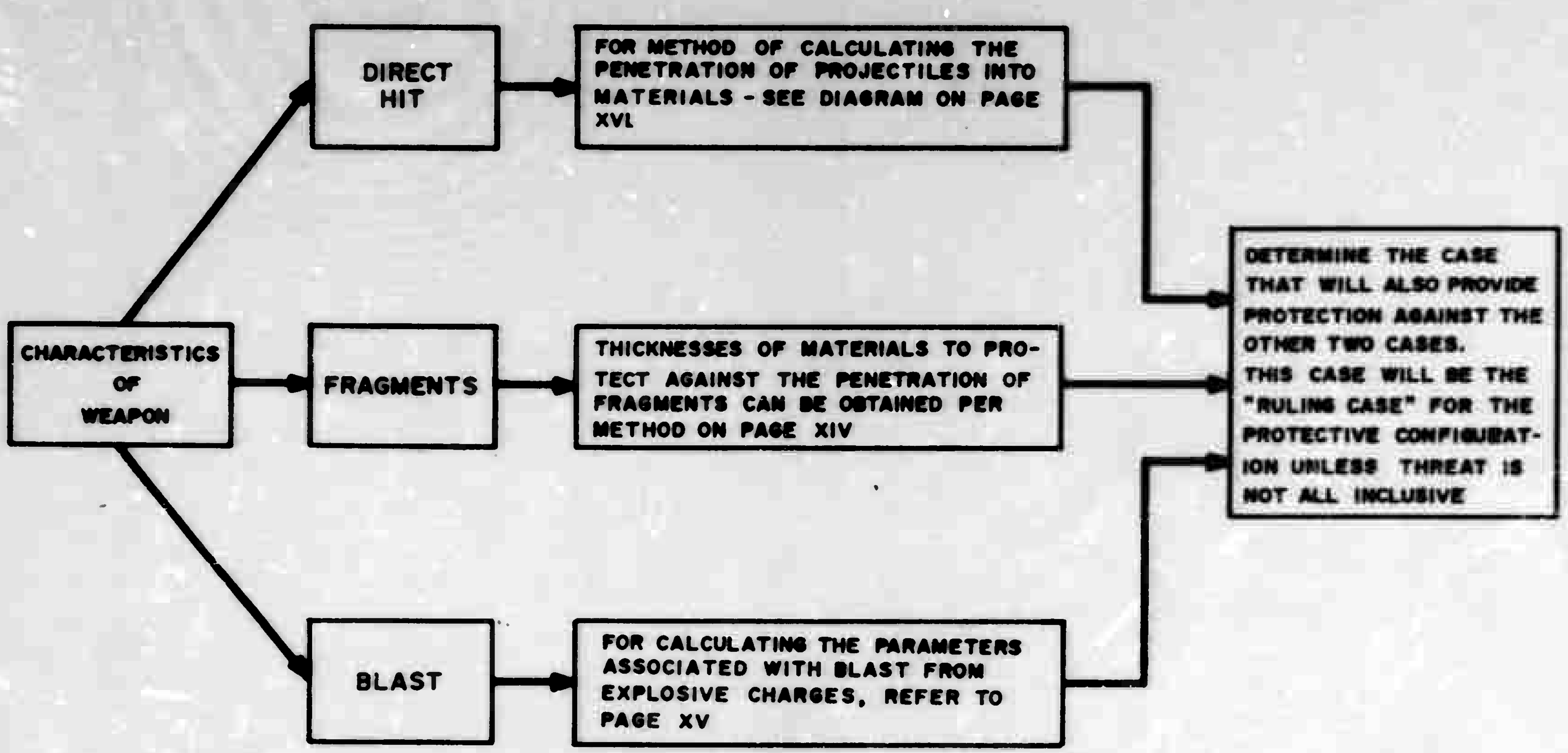
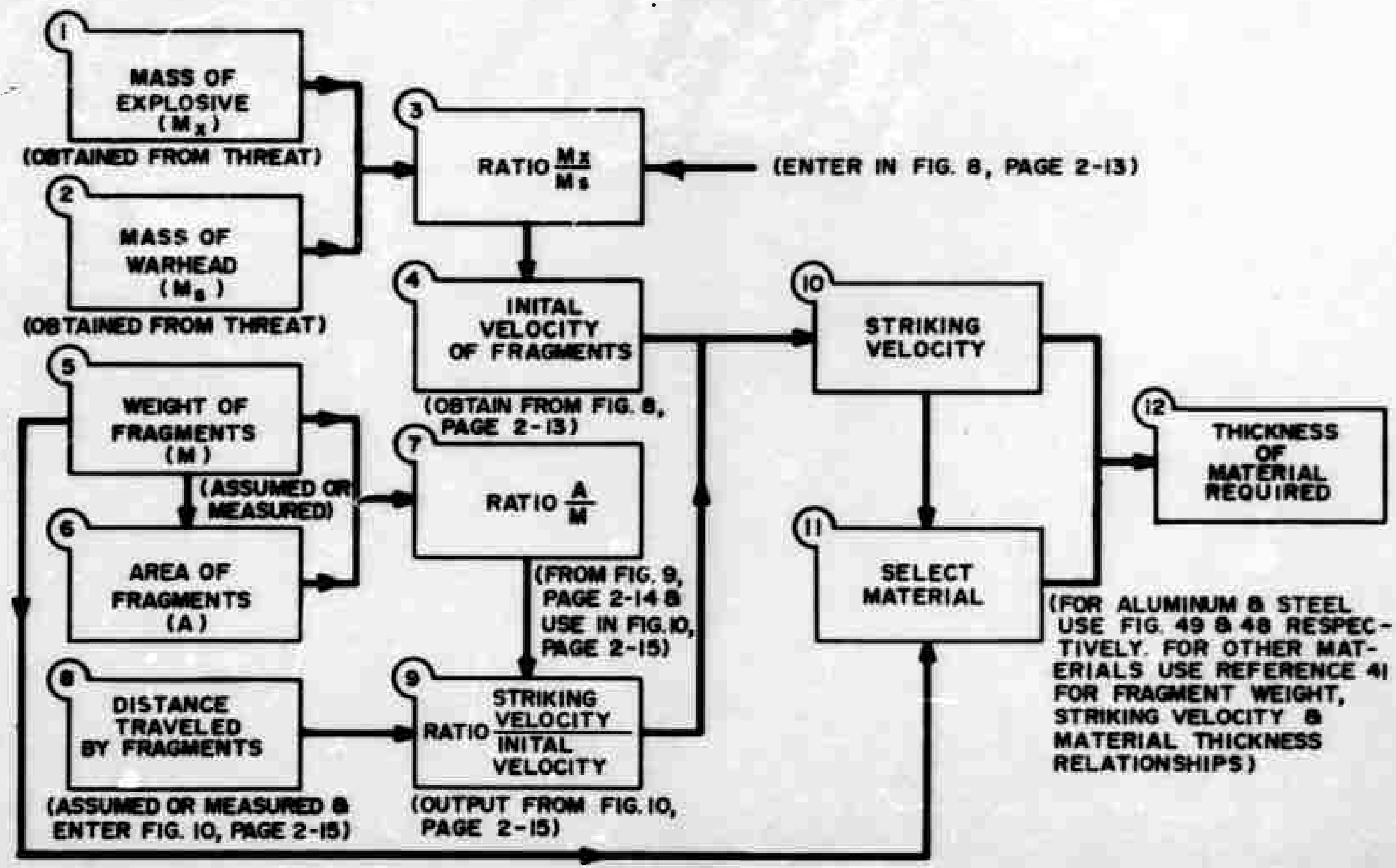
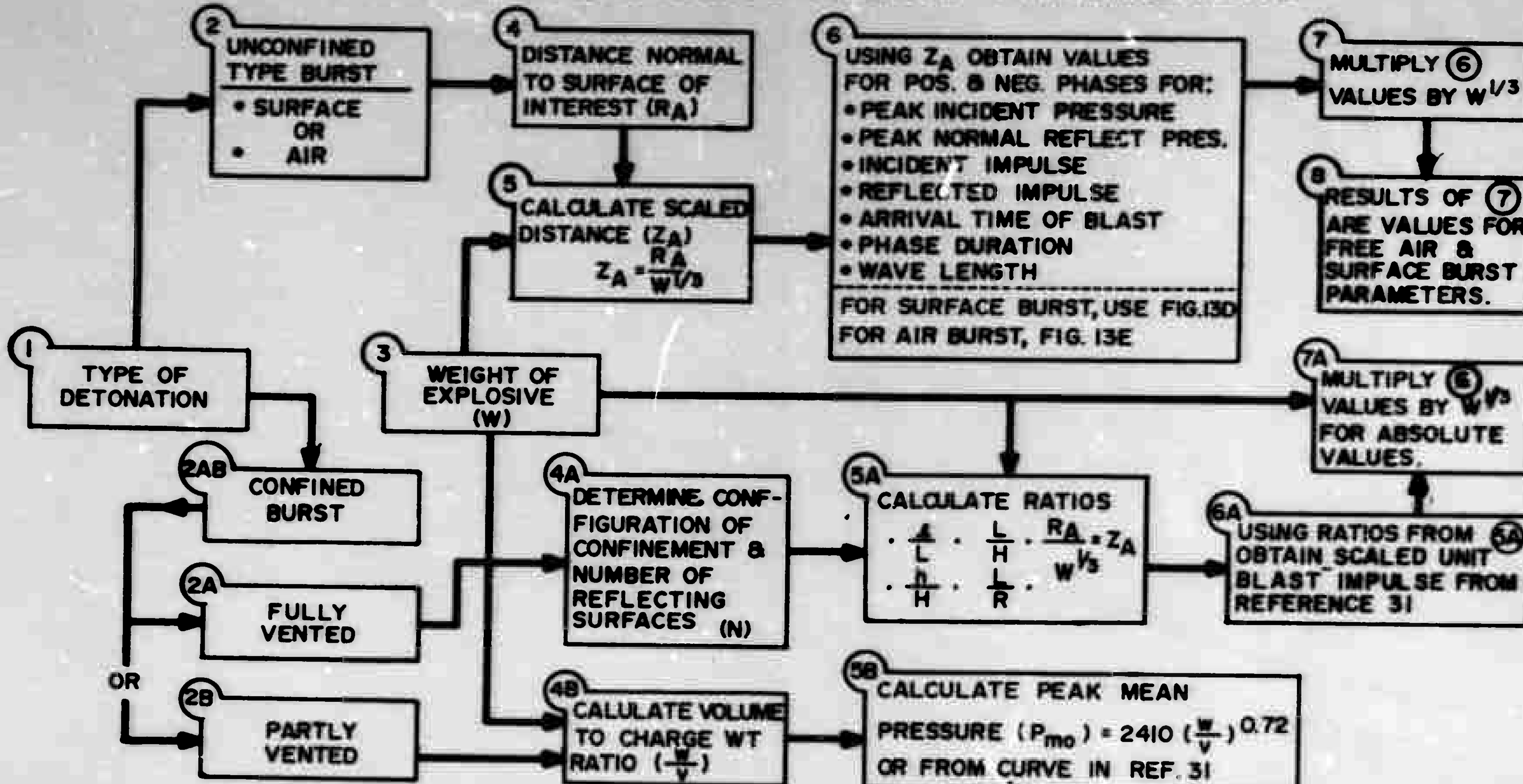


FIGURE II

METHOD FOR CALCULATING PROTECTION FROM FRAGMENTS



METHOD OF OBTAINING BLAST PARAMETERS



SYMBOLS

ℓ = DISTANCE OF CHARGE TO NEAREST REFLECTING SURFACE (ONE DIRECTION)

L = LENGTH OF REFLECTING SURFACE

h = DISTANCE OF CHARGE TO NEAREST REFLECTING SURFACE (OTHER DIRECTION)

H = LENGTH OF REFLECTING SURFACE

R_A = PERPENDICULAR DIST. OF CHARGE TO SURFACE OF INTEREST

W = WEIGHT OF EXPLOSIVE CHARGE

V = VOLUME OF CONFINED SPACE

$Z_A = R_A \div W^{1/3}$ (SCALED DISTANCE)

GEOMETRICS: BLAST ON SURFACE OF INTEREST

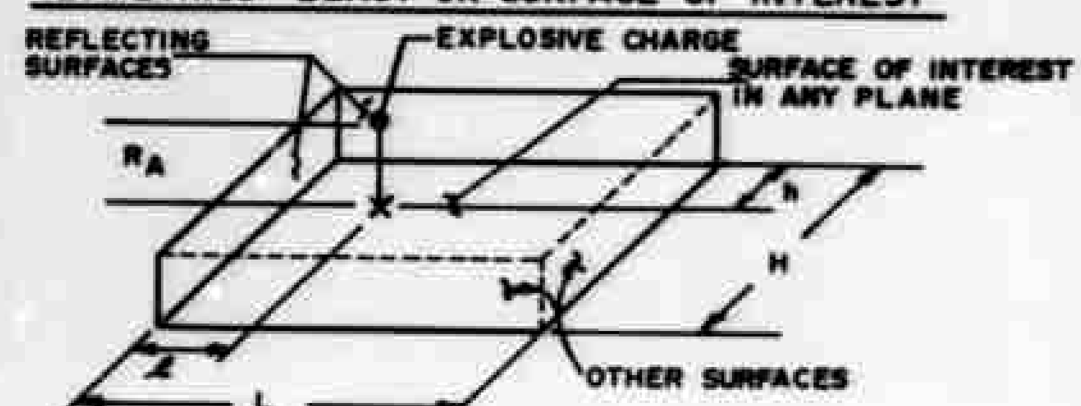
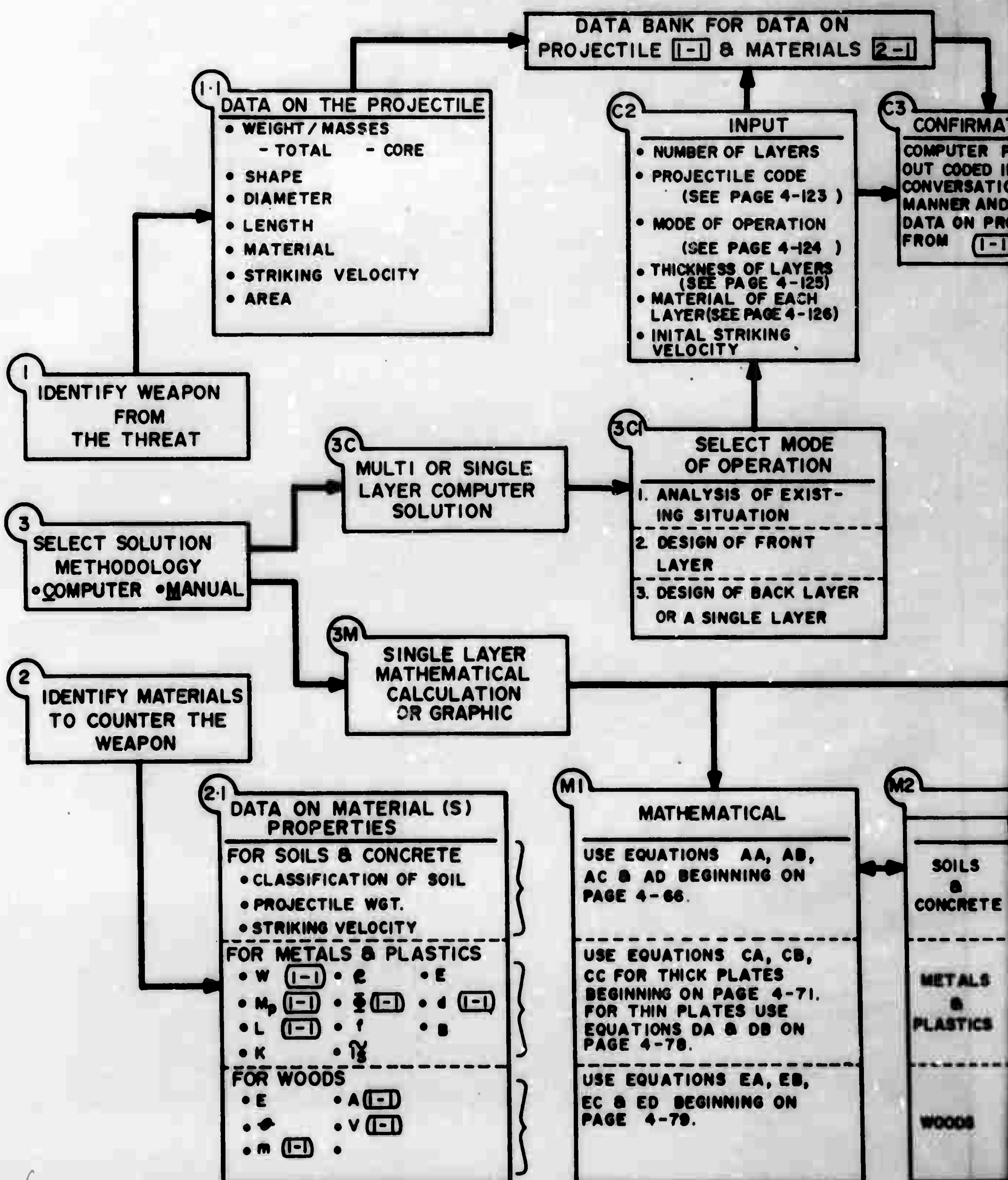


FIGURE IV

METHOD FOR PREDICTING PENE



FIGURE

A

PENETRATION OF MATERIALS

...NFIRMATION

...PUTER PRINTS ... CODED INPUT IN ...VERSATIONAL ...NNER AND GIVES ...A ON PROJECTILE ...N (1-1)

C4 — OUTPUT

MODE 1:
- RESIDUAL VELOCITY THRU EACH LAYER
- DEPTH OF PENETRATION
- PENETRATION TIMES

MODE 2:
- THICKNESS OF FIRST LAYER REQUIRED TO STOP PROJECTILE IN LAST LAYER OF MATERIAL
- RESIDUAL VELOCITIES THRU EACH LAYER
- PENETRATION TIMES

MODE 3:
- THICKNESS OF MATERIAL IN LAST LAYER REQUIRED TO STOP PROJECTILE

OR

- THICKNESS OF A SINGLE LAYER OF MATERIAL REQUIRED TO STOP PROJECTILE
- PENETRATION TIMES
- RESIDUAL VELOCITIES THRU SUCCEEDING LAYERS IF MULTILAYERED

4 — COSTS

COST PER SQUARE FOOT OF PROTECTION (SEE PAGE 4-41 FOR EXAMPLE)

5 — OBLIQUITY CONSIDERATIONS

USE FIGURES 20, 42, 43, 44 & 45 PLUS FORMULAS

6 — TRADE-OFF

GIVEN EQUAL LEVEL OF PROTECTION SELECT LEAST EXPENSIVE OPTION

GRAPHICAL			
	AID	INPUT &/OR OUTPUT	
...OILS & ...NCRETE	FIG. 52 FIG. 13A FIG. 13C FIG. 47A } FIG. 13B }	• PROJECTILE WGT • STRIKING VELOCITY • RANGE & NO. ROUNDS • TERMINAL VELOCITY • TYPE PROJECTILE	• THICKNESS • THICKNESS • PENETRATION • THICKNESS • PENETRATION
...TALS & ...ASTICS	FIG. 47A FIG. 50 FIG. 61 & 62 FIG. 28 FIG. 63 FIG. 64, 65 & 66	• TYPE PROJECTILE • MILD STEEL • AP PROJECTILE • PENETRATION • INITIAL VELOCITY & V_{50} • BAL. LIMIT VELOCITY	• THICKNESS • PENETRATION BEHAVIOR OF [illegible] • PERFORATION OF STL • INSTANT. VELOCITY • RESIDUAL VELOCITY • PENETRATION
...OODS	REF 42 & REF 5	• RANGE • TYPE OF PROJECTILE	• PENETRATION

...GURE V

SYMBOLS FOR 2-1

WOODS

E = AREAL DENSITY
θ = OBLIQUITY
m = PROJECTILE WGT.
A = AREA OF PROJECTILE
H = HARDNESS OF WOODS

METALS & PLASTICS

M_p = PROJECTILE CORE MASS
L = LENGTH OF PROJECTILE
K = DYNAMIC BULK MODULUS
ρ = DENSITY OF MATERIAL
Φ = PROJECTILE HALF-ANGLE
f = SLIDING COEFFICIENT OF FRICTION
$\tilde{\tau}_s$ = DYNAMIC COMPRESSIVE SHEAR
E = YOUNGS MODULUS
σ_y = STATIC TENSILE YIELD STRENGTH
d = DIAMETER OF PROJECTILE
B = BRINELL HARDNESS
W = WGT OF PROJECTILE

B1

1. INTRODUCTION

The enemy surface-to-surface attack activity on tactical air bases in Viet Nam has highlighted the deficiencies in passive defense. Other countries have the potential to attack existing or future tactical air bases outside Viet Nam with surface-to-surface weapons as well as with air-to-surface weapons. The combination of the present combat attack activities in Viet Nam and the potential of other countries dictates that the Air Force have an ability to adopt effective passive defensive measures. The objective of this study is to develop concepts from which a capability can be derived to survive direct hits from surface-to-surface projectiles and near misses from aerial bombs and missiles. (See Figure i.) Surface-to-surface missiles with a damage equivalent to aerial bombs have not been treated in this effort. To obtain the desired capability, the proper protective and/or structural materials can be combined with a "shaped" facility in a terrestrial environment which will enhance passive protection. In arriving at the preferred concept, it was first necessary to evaluate the threat. Second, counters to the threat were postulated and the desired capabilities of the facilities were defined. Third, alternative configurations of facilities were devised which might meet the counters to the threat. Fourth, the alternative configurations were traded off against selection criteria. Fifth, a computer code was designed to assist in calculating the penetration of weapons in the threat into various materials. Sixth, the selected materials were applied to the facility configuration. Finally, the preferred concept(s) were defined. Figure 1 entitled "Approach to the Effort" graphically portrays the generalized flow used in this study.

APPROACH TO THE EFFORT

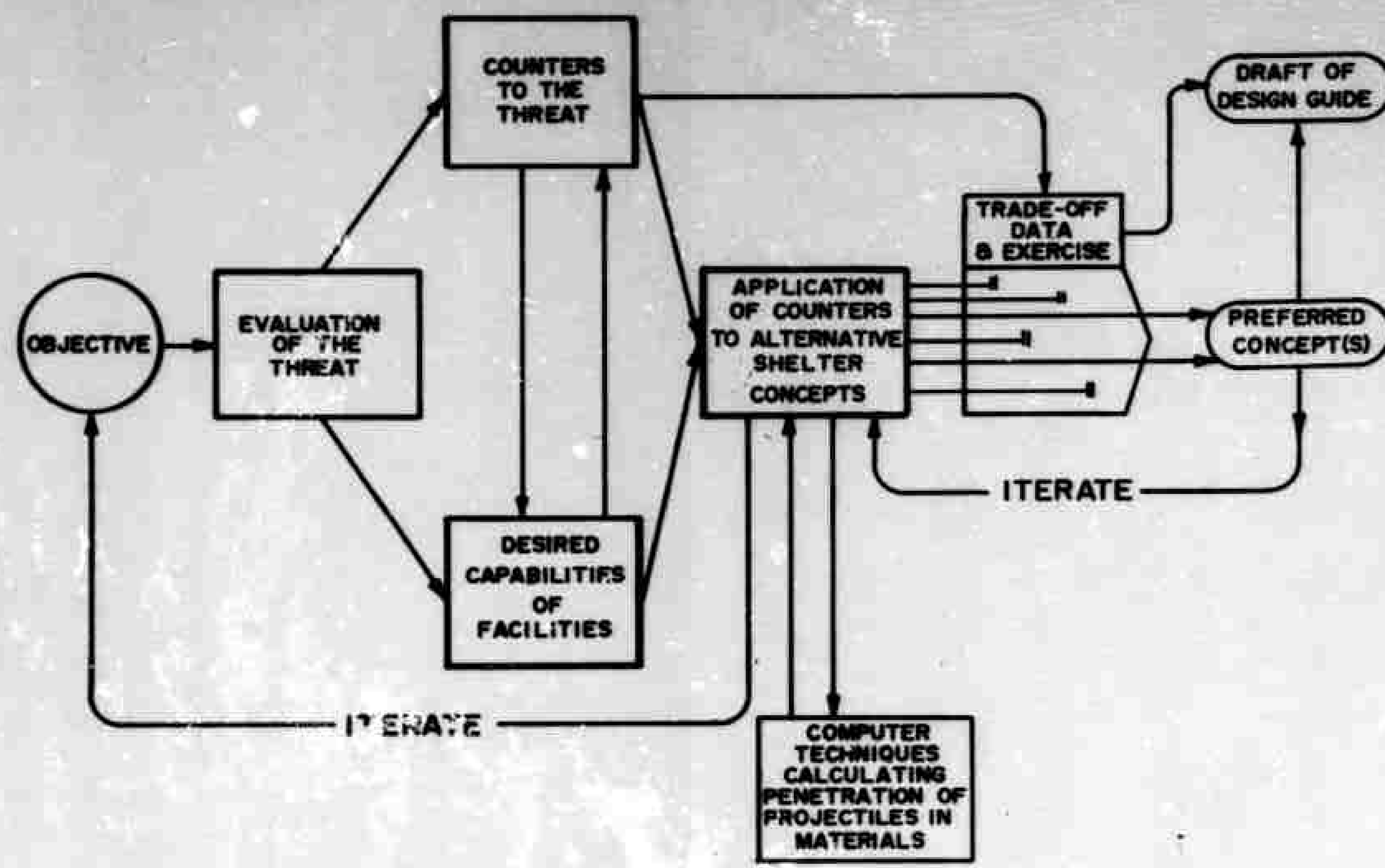


FIGURE 1

2. THE THREAT

a. Flexible Response

Small war-like activities may develop into larger actions through escalation. The entire spectrum of war ranging from Technological Wars through Nuclear Holocaust was examined to frame the threat. The types of weapons and their employment vary as the intensity of offense increases.

To have a reasonable chance for survival without spending large initial sums for massive structures, the facilities should have the flexibility to increase their resistance to the effects of weapons as the intensity of attack increases. The purpose of this section of this report is to identify the various intensities of conflict and the associated weapons. (See Figure 2.) At the lowest end of the spectrum is Technological War; however, it is waged throughout the entire spectrum. This war is characterized by research, development, study, innovations and by activities relating to the next generation of weapon systems or the facilities to support them. While closely allied to the present Viet Nam conflict, this study, though small, could be classified as one of the many elements comprising the Technological War. Cold War, so named because of the absence of firing on both sides, is recognized by diplomatic confrontations, intimidation, provocative actions and shows of armed strength. The area of concern of this study, however, covers those parts of the conflict spectrum ranging from initial infiltration through conventional non-nuclear war. The classes of weapons associated with conflicts covering this broad "band" are mutually inclusive. They are listed below:

FLEXIBLE RESPONSE TO ESCALATION OF THE THREAT

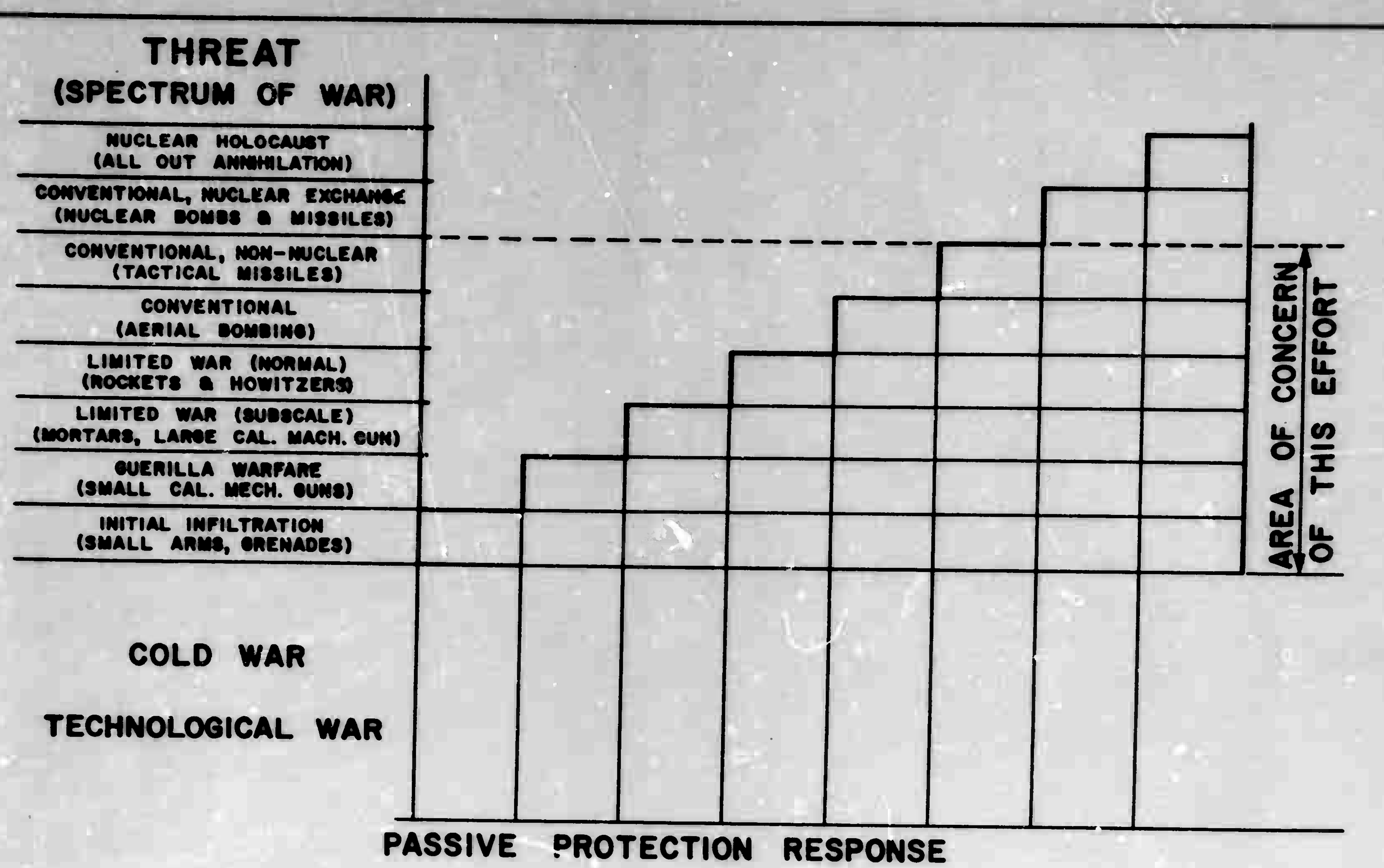


FIGURE 2

TYPES OF OFFENSIVE ACTIVITY BY THE ENEMY	CLASSES OF WEAPONS
Initial Infiltration	Grenades and Small Arms
Guerrilla Warfare	Small Caliber Machine Guns
Subscale Limited War	Mortars and Large Caliber Machine Guns
Limited War	Rockets and Howitzers
Conventional War	Aerial Bombs
Conventional, Non-nuclear	Tactical Missiles with the Damage Equivalent of Aerial Bombs

One of our national policies states that conflicts should end as soon as possible and at the lowest practicable level of intensity. To construct massive structures for passive defense at the outset of each "brush fire" war is inconsistent with national policy. It may also be uneconomical. Nevertheless, the military services must plan for and be prepared to implement actions in case of escalation. Therefore, a flexible response in passive defense for each successive escalation of the threat is needed. A knowledge of specific characteristics of projectiles is required to design structures which will counter each successive threat. To design such a facility, a "Basic Core" is constructed first. As the intensity of conflict increases, additional protective materials are successively added until a specified limit of protection is reached beyond which it would be uneconomical to continue. In case of de-escalation from the lower levels of intensity, reclamation and reuse of passive defense structures should be considered.

THE THREAT

- GRENADES
- 30 CALIBRE
- 50 CALIBRE & 20 MM
- 102 MM CHICOM ROCKET
- 140 SOVIET SPIN STABILIZED ROCKET
- 60 MM MORTAR
- 82 MM MORTAR
- 120 MM REGIMENTAL MORTAR
- 57 MM RECOILLESS RIFLE
- 75 MM RECOILLESS RIFLE
- 122 MM ROCKET
- 152 MM HOWITZER
- 160 MM HOWITZER/ROCKET
- BOMBS & MISSILES DELIVERED BY AIRCRAFT (USE U.S. EQUIVALENTS)

FIGURE 3

b. Elements of the Threat

The specific weapons posing a threat to tactical air bases are:

1. Grenades
2. 30 Caliber
3. 50 Caliber
4. 20 mm
5. 120 mm Chicom Rocket
6. 140 Soviet Spin Stabilized
7. 60 mm Mortar
8. 82 mm Mortar
9. 120 mm Mortar
10. 57 mm Recoilless Rifle
11. 75 mm Recoilless Rifle
12. 122 mm Rocket
13. 152 mm Howitzer
14. 160 mm Howitzer/Rocket
15. Bombs and Missiles Delivered by Aircraft

The weapons which place the most severe requirements on structures are the 102 mm Chicom Rocket, the 140 mm Soviet Spin Stabilized Rocket, the 122 mm Rocket and aerial bombs (Refer to Figure 3). By 1973 it is postulated that weapons of 200 mm, 240 mm and 250 mm may be used. These weapons will place increased passive protection demands on structures to be employed in that time frame.

The accuracies of weapons have a distinct bearing on their effectiveness and the degree of passive protection which must be provided. Figure 4 gives the accuracies of a variety of weapons contained in the threat. It is pointed out at this juncture, that the weapon CEP's shown in Figure 4 are smaller than system CEP's. For example, the weapon CEP for the 122 mm rocket at two-thirds maximum range is approximately 58 meters or 180 feet. The system CEP is slightly more than 600 feet.

THIS FIGURE IS CLASSIFIED

S E C R E T

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FIGURE 4

EXAMPLES OF ACCURACIES

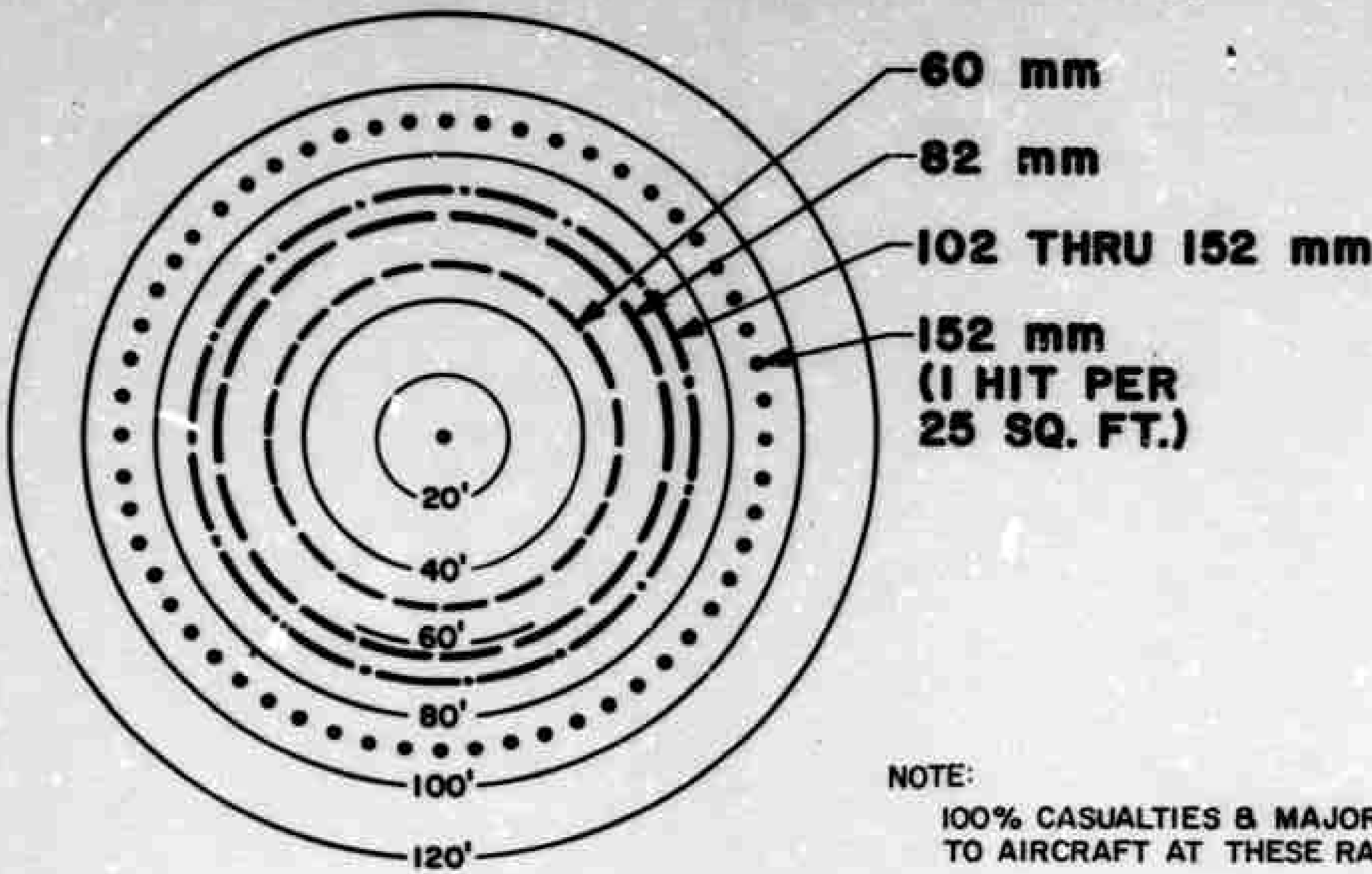
c. Approximate Areas of Damage by Surface-to-Surface Weapons

Paragraph 2b above dealt with whole projectiles and their accuracies. Of equal importance is the size, number and velocity of projectile fragments and the area over which they will be effective. (See Figure 5 and Table I.) Data similar to those in Table I are also available for hand grenades, 20 mm, 75 mm, 76 mm, 81 mm, 90 mm, 105 mm, 120 mm, 8 inch, 240 mm and 4.5 inch rocket. Reference 5 should be consulted for these data. The criterium used in arriving at the effective area is that there will be at least one hit by a fragment for each 10 square feet. The size of such a fragment will be large enough and have sufficient velocity to cause casualties to personnel (incapacitate, not necessarily kill) and major damage to aircraft ($100,000 damage per aircraft). The orientation of the damage pattern for each weapon varies with respect to the line of flight of the projectile. In conflicts such as Viet Nam, the location of the weapon being fired with respect to the target is not generally known. Therefore, Figure 5, "Approximate Areas of Damage by Various Surface-to-Surface Weapons and their Fragments" depicts the effective areas of weapons from 60 mm through 152 mm without regard to their firing origin or the orientation of the damage pattern.

A 60 mm weapon, for example, will scatter fragments capable of inflicting 100% casualties and major damage to aircraft approximately 50 feet from the point of impact. The 152 mm, on the other hand, will inflict the same damage at 70 feet. At one hit for each

APPROXIMATE AREAS OF DAMAGE BY VARIOUS SURFACE-TO-SURFACE WEAPONS & THEIR FRAGMENTS

(AT LEAST ONE HIT BY FRAGMENT PER 10 SQ. FT.- WORSE CASE BURST AGAINST PERSONNEL)



NOTE:

100% CASUALTIES & MAJOR DAMAGE TO AIRCRAFT AT THESE RANGES.

FIGURE 5

25 square feet, the 152 mm weapon would scatter effective fragments out to 90 feet from impact. Under these conditions, the apparent desirability of dispersal of facilities should be carefully examined. Such factors as the added cost of dispersal, availability of real estate, ability to protect the dispersed site from infiltrators, and added time for ground movements should be included in the examination. To emphasize this point, assume a 140 mm weapon misses its intended target by 50 feet, an actual impact occurring 50 feet from the intended target would throw effective fragments against personnel 70 feet from the impact point or 120 feet from the intended target. (See Figure 6, "Effect of Near Miss and Damage Area on Personnel") Consideration of the probability of damage to adjacent facilities, i.e., "bonus effect," is necessary in the siting of protected as well as unprotected facilities.

d. <u>Damage Pattern for 500 Pound General Purpose Bomb</u>

The threat from aerial bombardment was also assessed. For illustrative purposes, a 500 pound general purpose bomb was used. A "worst case" analysis was performed. In this case, the bomb was burst 30 feet above the ground and its angle of attack with respect to the horizontal was 75 degrees. The release altitude of the bomb was 20,000 feet and its velocity remaining at 30 feet above the ground was 990 feet per second. The bomb was launched on a westerly heading (270 degrees) at the time of bomb release. Figure 7, "Damage Pattern for 500 Pound General Purpose Bomb" shows that casualties can be expected out to 160 feet from the impact point.

EFFECT OF NEAR MISS & DAMAGE AREA ON PERSONNEL

140 mm

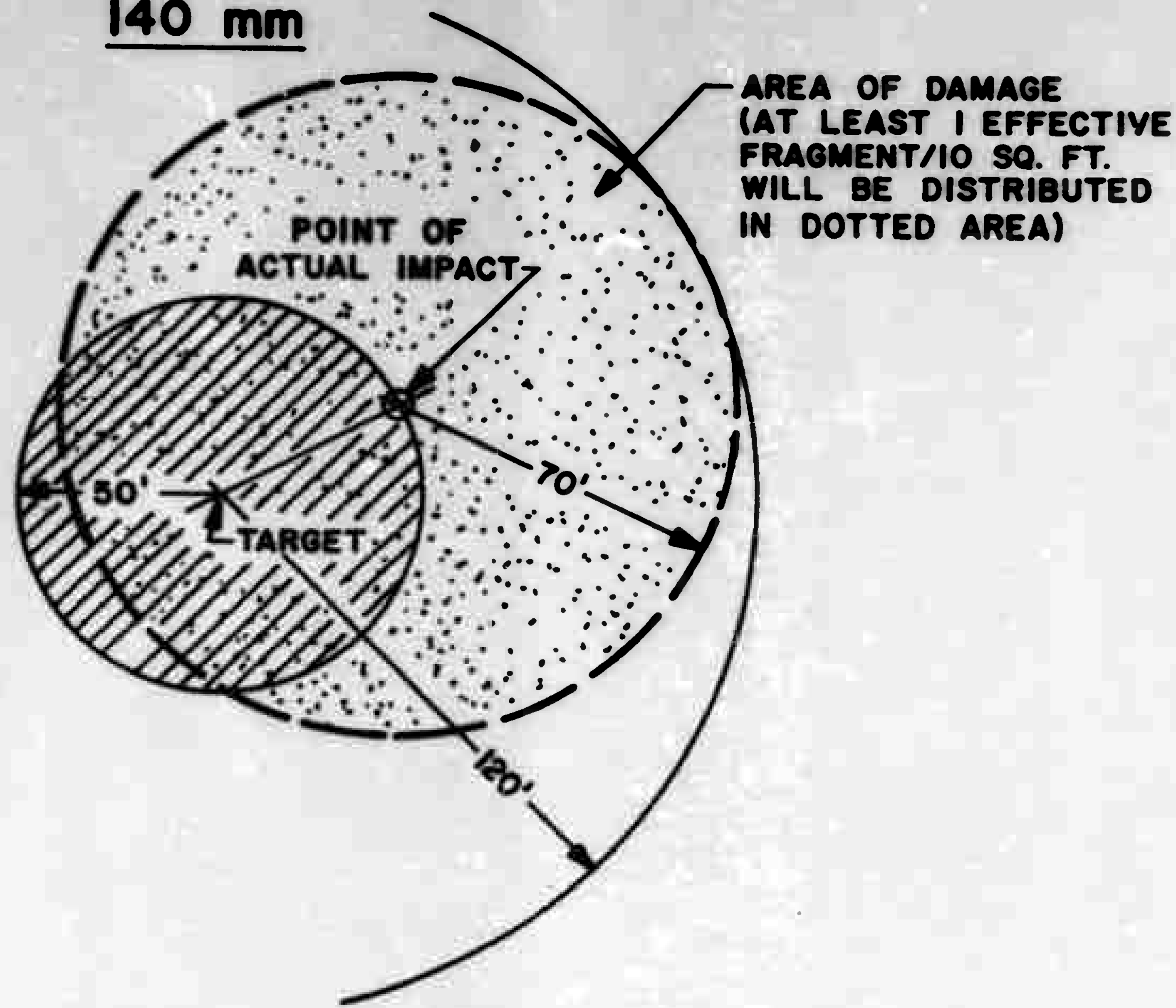


FIGURE 6

DAMAGE PATTERN FOR 500 LB G. P. BOMB

HEIGHT OF BURST 30 FT
REMAINING VELOCITY 990 f/s
ALTITUDE OF RELEASE 20,000 FT.

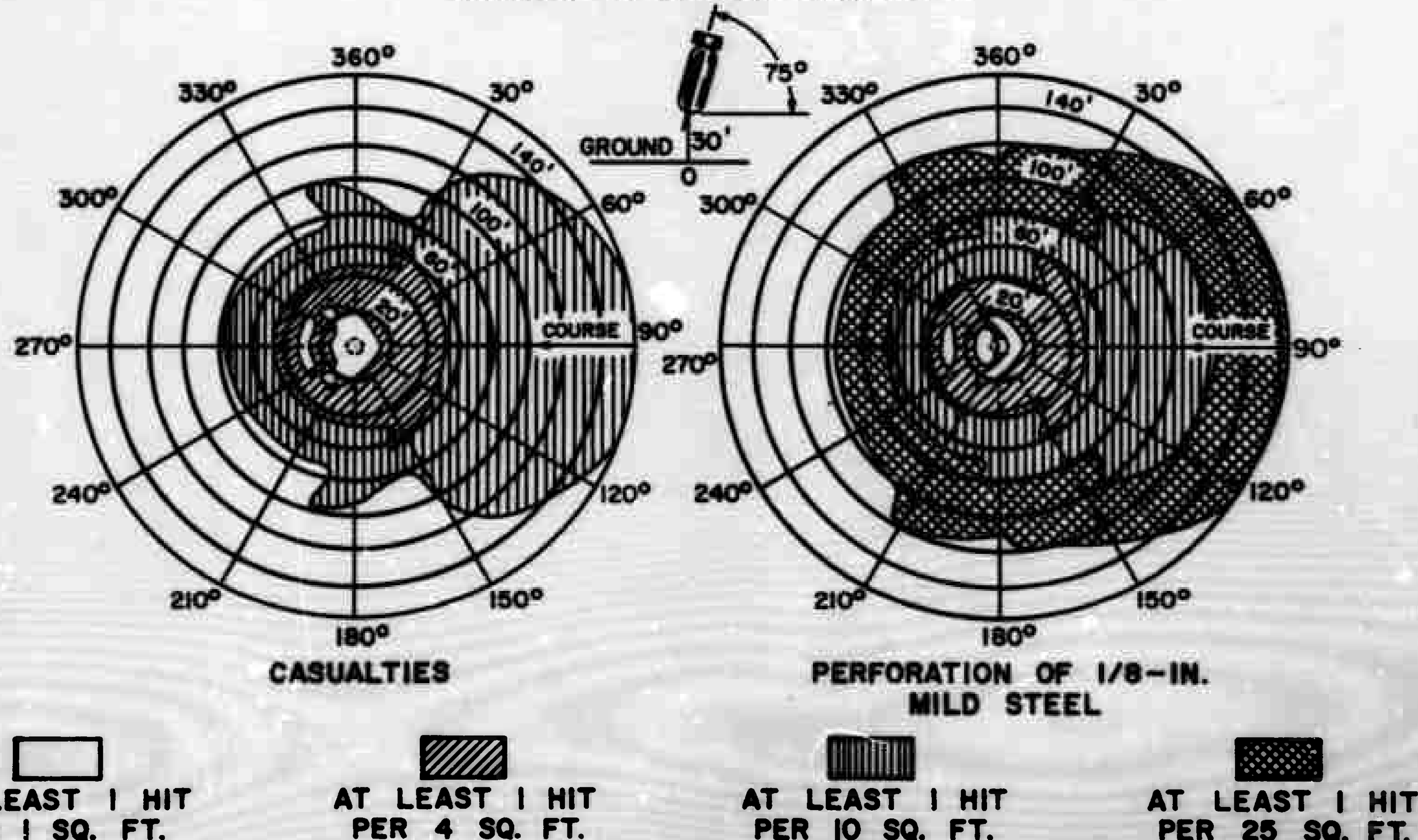


FIGURE 7

REF 5

Again, the criteria of at least one hit per 10 square feet for casualties was used. It is interesting to note that fragments from the bomb would perforate one-eighth inch of mild steel out to 165 feet once every 25 square feet. This could also cause major damage to aircraft.

e. Calculation of Fragment Data

The above data on fragments are based on actual data. If, however, fragment data are not known for a particular weapon in the threat, the following theoretical procedure can be followed for predicting the size, velocity and dispersal of fragments.

(1) If the explosive mass, M_x, and the steel mass, M_s, of the projectile are known, Figure 8 will enable one to predict the initial velocity, V_o, of all fragments generated by the blast. For example, a TNT filled cylinder with a M_x to M_s ratio of 2.1 has an initial velocity of approximately 8,000 feet per second.

(2) Data from Figure 9 will yield area to grain size ratios for various fragment weight. Thus:

$A/m = 0.15$ for a 50 grain fragment

$A/m = 0.6$ for a 0.8 grain fragment

(3) Figure 10 yields the ratio of striking velocity to initial velocity for various A/m ratios for specified distances.

An A/m of 0.6 at 200 feet for example yields $V = 0$ whereas an A/m of 0.15 at 200 feet yields a velocity of $0.5xV_o$ or 4,000 feet per second.

INITIAL VELOCITY OF FRAGMENTS AS A FUNCTION OF RATIO M_X / M_S

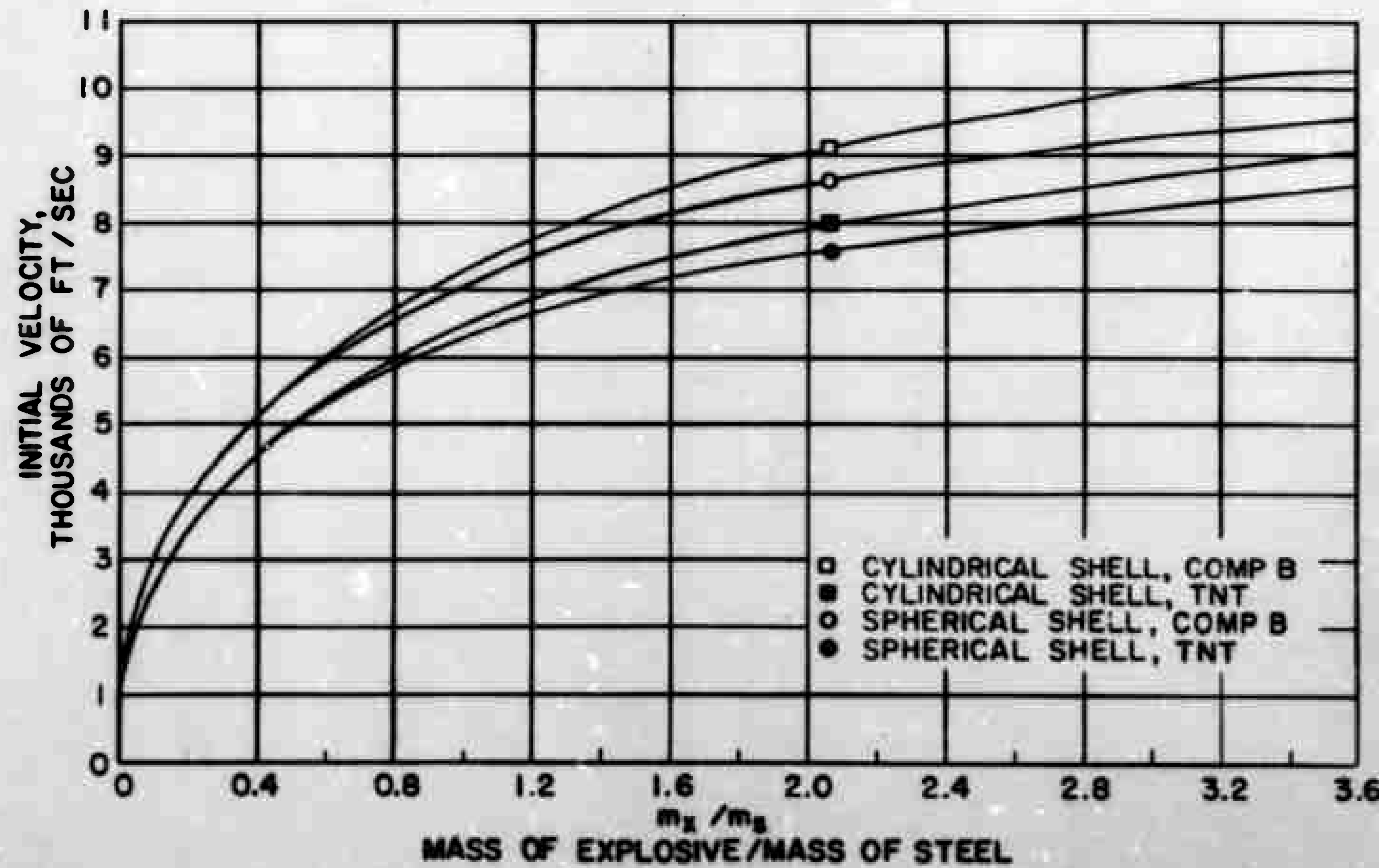


FIGURE 8

REF 24

RATIO OF AREA, TO GRAINS
AS A FUNCTION OF GRAIN WEIGHT FOR RANDOM STEEL FRAGMENTS

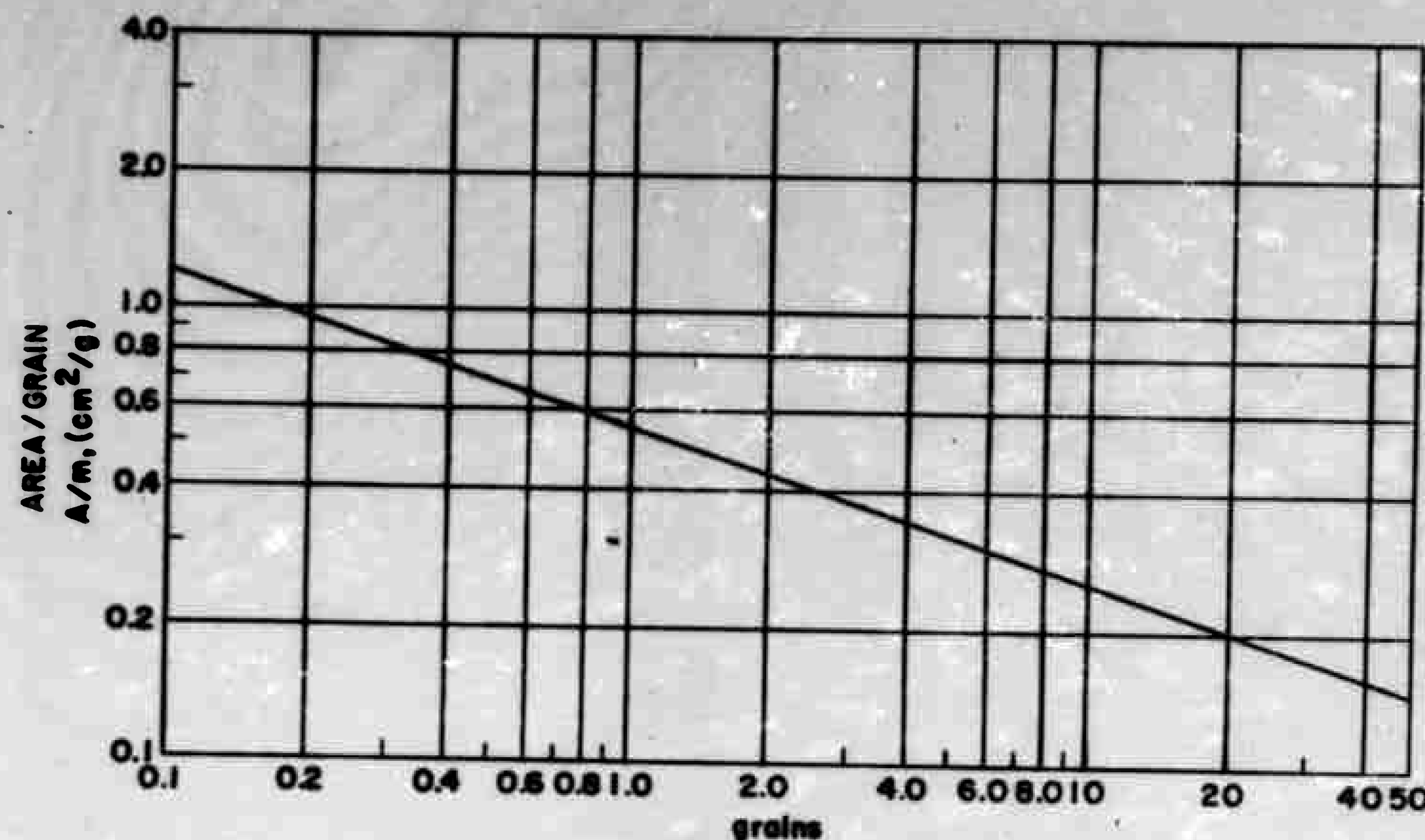


FIGURE 9

REF 24

RATIO V/V_O AS A FUNCTION OF DISTANCE TRAVELED BY FRAGMENTS

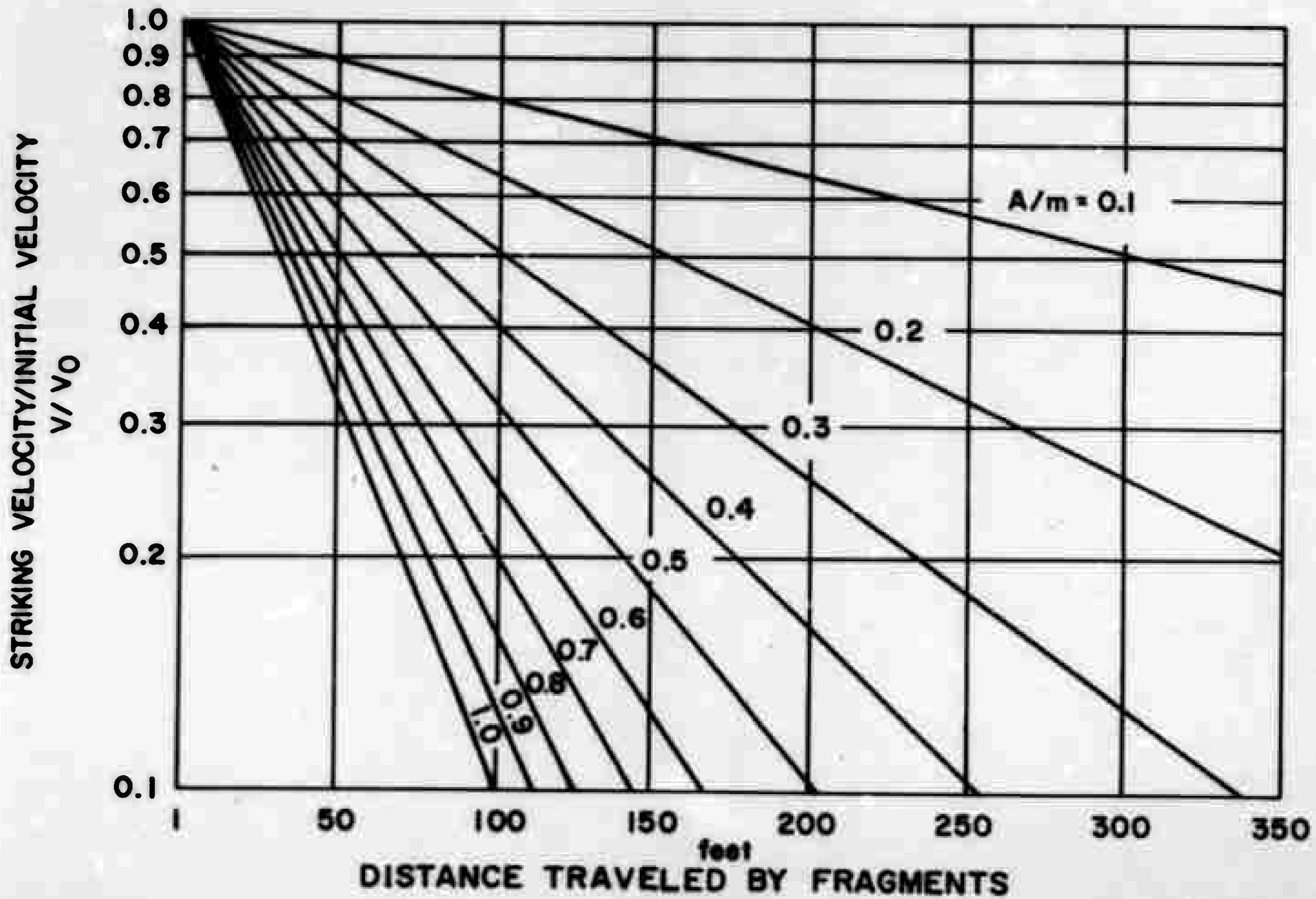


FIGURE 10

REF 24

f. Consolidated Data on Elements of the Threat

(1) A precise description of each of the projectiles contained in the enemy inventory is necessary to bound the problem of the passive protection. To this end, Figure 11, "Consolidated Data on Elements of the Threat" shows pertinent data on each element of the threat. The data sheet contains the following types of information:

(a) Name of Projectile
(b) Angles of Impact
(c) Ranges
(d) Velocities
(e) Radii of Fragment Effectiveness
(f) Dimensions
(g) Ratios of Weights
(h) Penetration into Various Single Materials

g. **Cost Effectiveness of Shelters**

The location of U. S. military aviation bases in friendly or passive foreign territory is conducive to the adoption of procedures for good operating efficiency. For example, the aircraft can be parked closely together in the open and close to servicing and maintenance facilities. Structures need be built only for weather protection in some cases. Under these conditions, with sufficient air superiority, the likelihood of an attack on an airdrome can be minimized. As the probability

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Headquarters, U.S. Air Force
AFOCE-KA
Pentagon, Room 5E425
Washington, D.C., 20330

THIS FIGURE IS

CLASSIFIED SECRET

AND IS, THEREFORE, CONTAINED

IN THE CLASSIFIED

ANNEX TO THIS REPORT

FIGURE 11

"CONSOLIDATED DATA ON ELEMENTS OF THE THREAT" of an attack from the air increases, dispersal of the aircraft becomes more attractive. However, where attack is likely from the ground and sabotage and infiltration are serious considerations, it is not attractive to use dispersal for passive protection of aircraft or facilities. Therefore, the construction of shelters for aircraft becomes a consideration. Figure 12 compares the cost of damage to aircraft versus number of 122 mm rockets and 82 mm mortars expended against a parking ramp containing 70 aircraft spaces. This comparison can serve as an example of one case of the level of cost which may be allocated to shelters used for passive protection of aircraft. The letters R and S refer to revetments and shelters respectively. The subscripts to R&S refer to the number of protection surfaces. In the case of shelters, a top is always included plus 3 or 4 sides. For example, S_3 is a shelter with 3 sides and R_0 corresponds to aircraft parked in the open with no protection. The curves are based on the assumption that the rounds are equally distributed and that the shelters can defeat the mortars and rockets with instantaneous fuzes but not delayed fuzed rockets. Delay fuzes for mortars were not used. It can be seen in this example that recovery of the costs of shelters begins at about 34 cumulative rounds. Protection against higher numbers of rounds requires that more cost be allocated to shelters. This can be seen by sliding the S_4 and S_3 lines up at the same slope. Improvements in shelter capability can have the effect of decreasing the slope of the curves relating to shelters to zero.

COST OF SHELTERS FOR AIRCRAFT

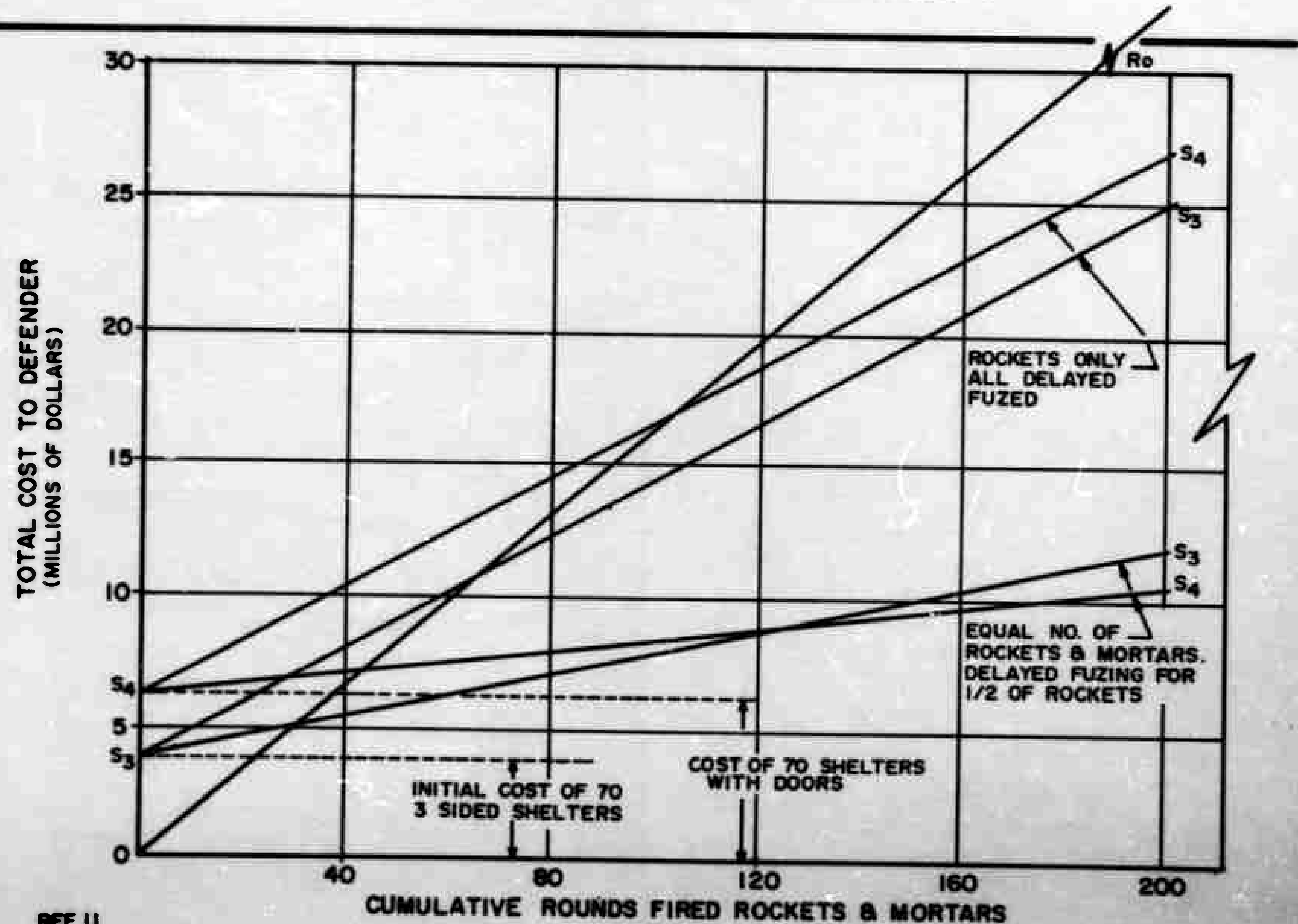


FIGURE 12

REF 11

TABLE I: Fragment Damage of HE, 155 mm Projectile; Initial Fragment Velocity 3,500 f/s

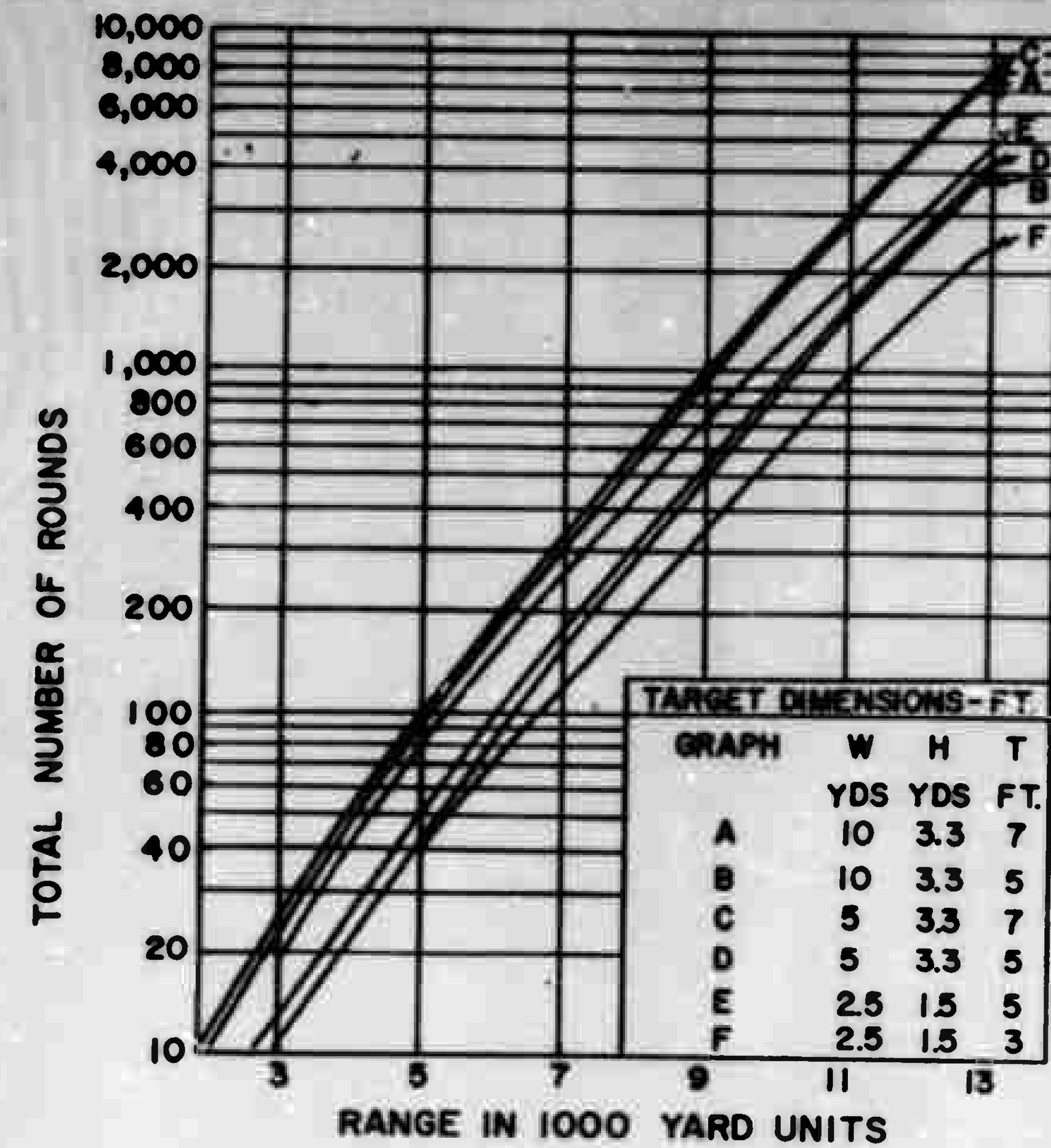
Distance from burst in feet	Total number of effective fragments	Average number of effective fragments per sq.ft.	For the lightest effective fragments	
			Weight ozs.	Vel f/s
Casualties				
20	1880	.374	.0108	2340
30	1740	.154	.0148	2000
40	1640	.0816	.0195	1740
60	1450	.0321	.0310	1380
80	1300	.0162	.0440	1160
100	1220	.00971	.0562	1030
150	1040	.00368	.0832	845
200	940	.00187	.109	738
300	770	.00068	.166	598
400	640	.00032	.235	503
700	420	.00007	.515	340
Perforation of 1/8 inch mild steel				
20	1400	.278	.0350	2690
30	1290	.114	.0460	2410
40	1210	.0602	.0591	2210
60	990	.0219	.0940	1910
80	840	.0104	.139	1690
100	720	.00573	.195	1530
150	500	.00177	.370	1260
200	390	.00078	.590	1100
300	280	.00025	1.05	935
400	220	.00011	1.52	845
700	72	.00001	3.44	685
Perforation of 1/4 inch mild steel				
20	710	.141	.198	3040
30	676	.0598	.236	2850
40	600	.0298	.277	2680
60	510	.0113	.372	2430
80	440	.00547	.485	2220
100	385	.00306	.614	2060
120	336	.00186	.760	1920
140	300	.00122	.932	1800
160	265	.00082	1.12	1690
180	240	.00059	1.32	1610
200	212	.00042	1.55	1530
300	88	.00008	2.75	1270

Improvements in weapon accuracy and penetration capability have the effect of increasing the slope of all the curves. Ideally, the slope of the curves relating to shelters should be less than a curve plotted showing cost of active offensive and logistics operations relating to the delivery of rounds on a selected target.

In connection with the above, Figure 13A gives the number of rounds required to insure a 90% probability of at least one 155 mm projectile perforating various thicknesses of concrete targets of different sizes. Similar data on other projectiles can be obtained by consulting Reference 5.

Figure 13B, "Projectile Penetration into Clay-Sand Soils," shows the depths of penetration of various weapons into clay-sand soils as a function of the angle of impact and striking velocity. In the extreme cases, a 75 mm shell striking the ground at 36° and a velocity of 525 feet per second will penetrate 3.9 feet; the 240 mm projectile, on the other hand, will penetrate 29 feet into the soil when the striking velocity is 1,170 feet per second and the impact angle is 48.5 degrees. The change in direction of the various projectiles during penetration, however, causes the aforementioned projectiles to bury themselves only 3.7 feet and 11 feet below the surface respectively. For comparative purposes, the depth of penetration of a 155 mm projectile into concrete was plotted against various terminal velocities and ranges. At 1,000 feet per second and 15,000 yards range, this projectile will penetrate 1.4 feet of concrete. This same projectile at 1,000 feet per second would penetrate about 11 feet of earth. Figure 13C, "Penetration of Concrete by Projectiles," shows the behavior of the 155 mm and 105 mm projectiles against concrete.

NUMBER OF ROUNDS REQUIRED FOR SINGLE PERFORATION OF CONCRETE WALL



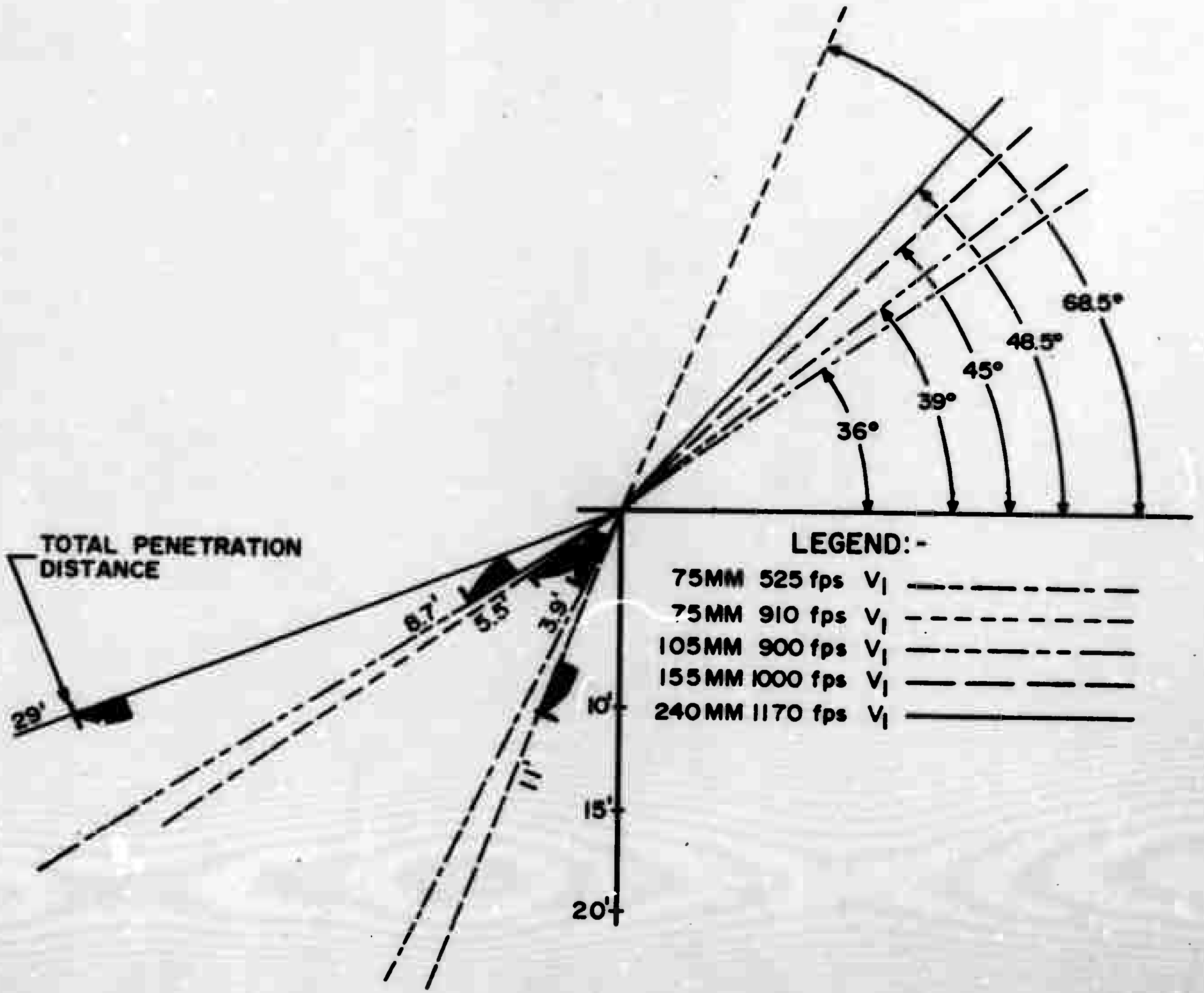
TARGET DIMENSIONS-FT.			
GRAPH	W	H	T
	YDS	YDS	FT.
A	10	3.3	7
B	10	3.3	5
C	5	3.3	7
D	5	3.3	5
E	2.5	1.5	5
F	2.5	1.5	3

NOTE:-
COMPRESSIVE STRENGTH 5,000 PSI, 90 PERCENT PROBABILITY OF ONE OR MORE PERFORATIONS. BY A 155MM PROJECTILE

FIGURE 13A

REF 5

PROJECTILE PENETRATION INTO CLAY-SAND SOILS



REF 35

FIGURE 13B

PENETRATION OF CONCRETE BY PROJECTILES
(ZERO OBLIQUITY)

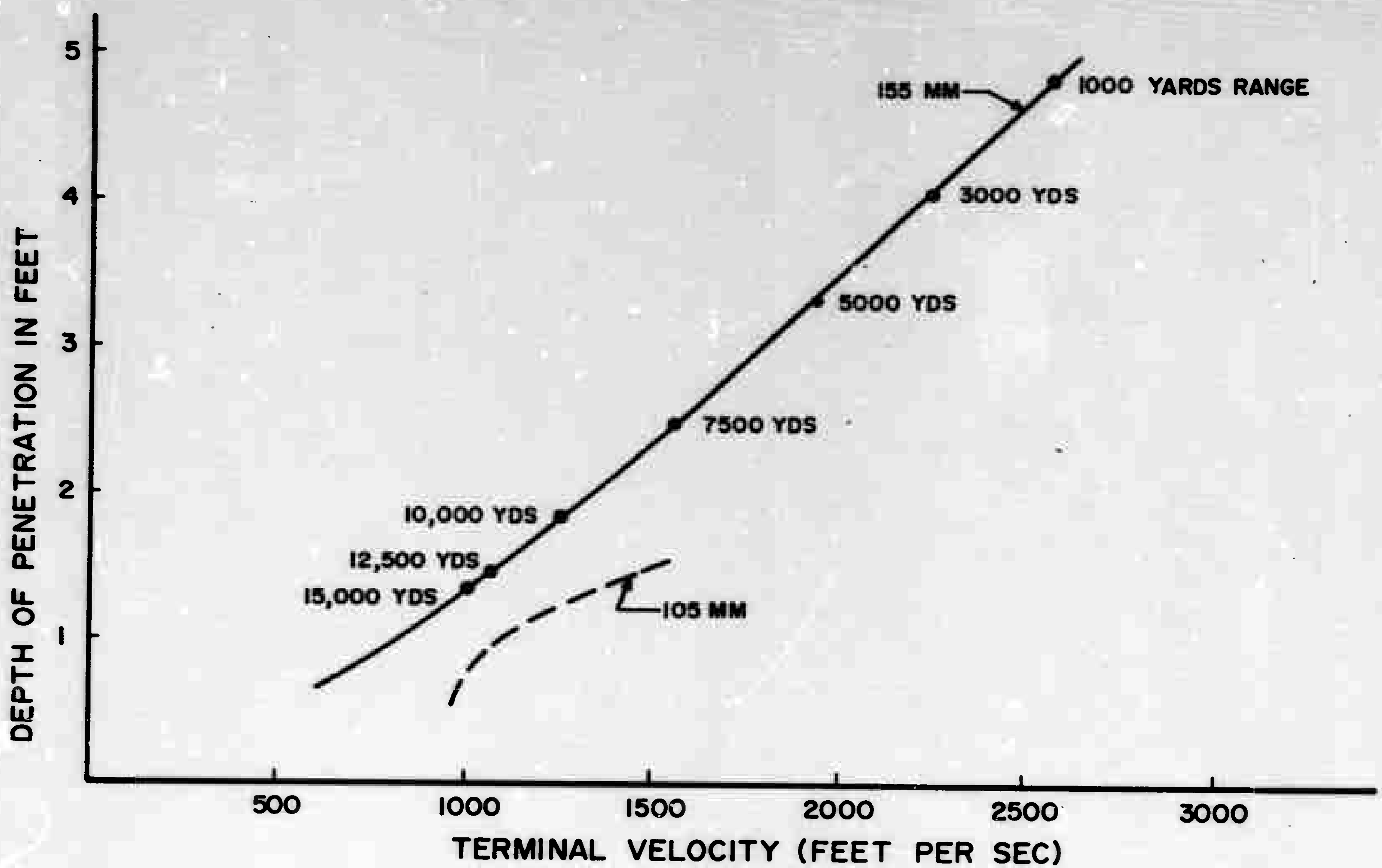


FIGURE 13C

h. Blast

(1) General

Thus far in the discussion of the threat, the basic elements that have been considered are the effects of fragments and the penetration capabilities of whole projectiles into various materials. In the case of explosive projectiles and the near miss of bombs, which was also a part of this study, blast effects on structures are also a part of the basic threat. Discussion of phenomena of blast is developed in the following paragraphs.

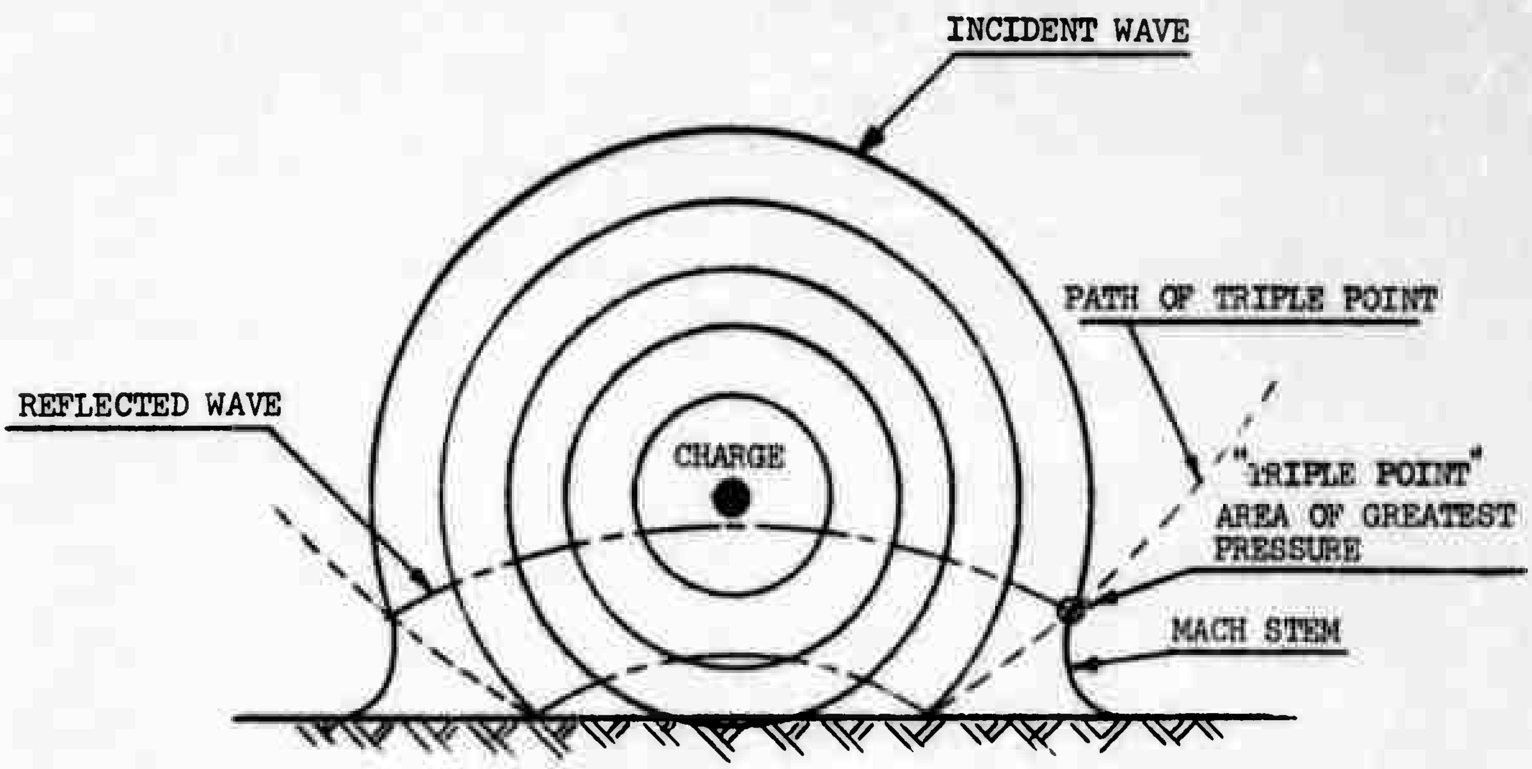
(2) The Explosive Process

High explosives release their energy by a process called detonation, and low explosives or propellants by a process called rapid burning. The time required for the detonation of a quantity of high explosives is much less than that for burning of a like amount of propellant. Particle size has little effect on the rate of detonation of high explosives; however, particle size directly affects the energy released by burning propellants. Some high explosives such as mercury fulminate are very sensitive to shock and heat and can be easily detonated by a spark or other local applications of heat. These explosives are used to initiate less sensitive explosives and are called primers. Other explosives which are less sensitive to shock and heat than primers but in which detonation can be initiated are called boosters. These are intermediates between primers and a main body of explosive and are capable of initiating the main explosive and being initiated by the primer. Tetryl is an example of a booster used extensively during World War II. The main body of explosive is very insensitive to shock, heat and friction and must be detonated by a booster. Explosion of the booster results in a compression wave which initially passes through the main explosive body at about the velocity of sound. This wave provides enough compression to start chemical reaction of the main explosive which is rapid and produces products at very high temperatures and pressures. A zone thus develops called the detonation wave which travels through the explosive considerably in excess of the speed of sound (16,000 to 26,000 feet per second), the velocity depending on the physical properties of the explosive on its dimension and the degree of confinement. When the detonation wave reaches the interface between the explosive and the air the products of the detonation, largely gases, expand with very high velocity, pressures, and temperatures. The boundary between the air and hot gases is sharply defined. Behind this layer the pressure and temperature, at a short time interval later, decrease rapidly to lower values toward the interior of the charge. The rate of expansion of the luminous zone, presumably the hot burnt gases, continually decreases. Eventually, another discontinuity emerges from the luminous zone and thereafter leaves it behind. This is the shock wave which travels outward spherically from the charge. The pressure in the front of the wave called the peak pressure steadily decreases. At great distances, the peak pressure is infinitesimal and may be treated as a sound wave. Behind the shock wave front, the pressure decreases from its initial peak value. Near to the charge, the pressure in the tail of the wave is greater than atmospheric. However, as the wave propagates outward from the charge, a rarefaction wave is formed which follows the shock wave. At some distance from the charge, the pressure behind the shock wave front falls to a value below that of the atmosphere and then rises again to a steady value equal to that of the atmosphere. That portion of this action where the pressure is above atmospheric is called the positive phase and below atmospheric the negative phase. The velocity at which the shock wave is propagated is uniquely determined by the pressure in the shock wave front and the pressure, temperature and composition of the undisturbed medium. The greater the excess of peak pressure, the greater the shock velocity. Since the pressure at the shock front is greater than that at any point behind it, the wave tends to lengthen as it travels away from the charge. If the charge is confined by a metal case, the case is expanded by the pressure of the hot gases. At first, the metal flows plastically until the volume of the case has been increased about twice (in the case of steel) and then rupture occurs. The resulting fragments of the case are propelled at high velocity and proceed the shock wave over a great distance from the charge. Acceleration of the fragments requires energy and a considerable fraction of the detonation energy may be carried away by the fragments. As a result, the pressure of the shock wave of a confined charge is considerably less than from an uncased charge. At the boundary between the burning gases and the surrounding air, oxygen comes in contact with the hot reaction products. Combustion is not complete at this juncture and further slower oxidation takes place and additional energy is released and the shock wave energy is enhanced. This process is called "after burning" and if it in itself were complete, the energy from this source would be about twice that released by the detonation.

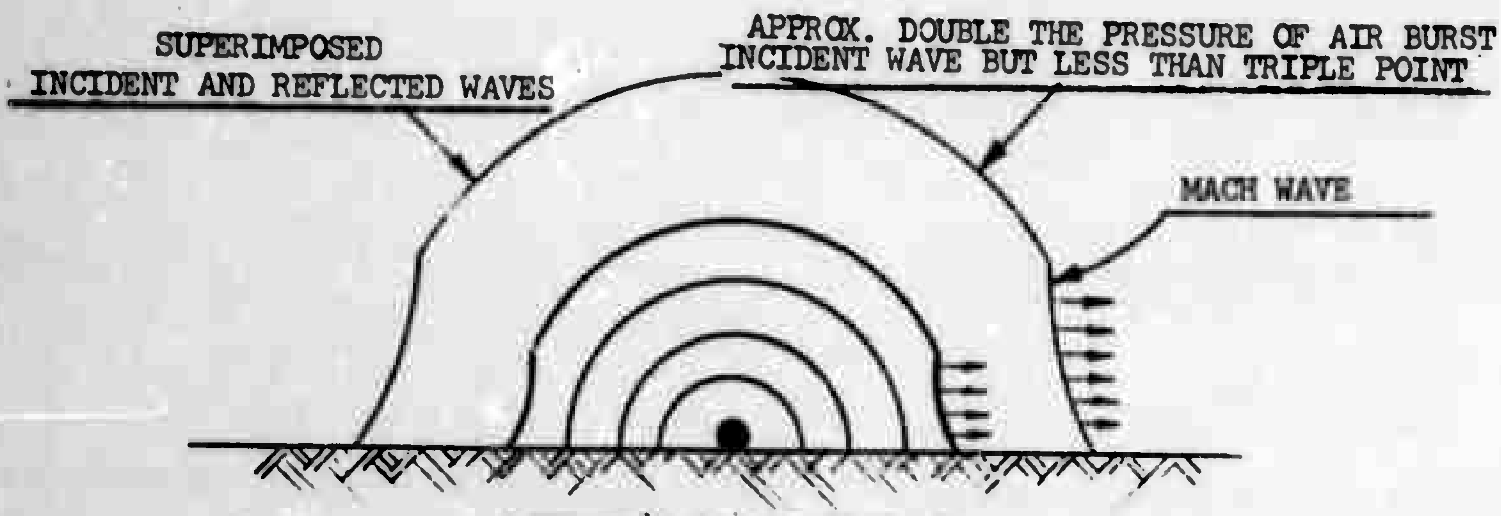
(3) Shock Wave Interaction

When the pressure in the shock wave is weak, or nearly at acoustic strengh the pressure at the reflected surface is very nearly double the pressure of the incident wave. However, when the pressure in the shock wave is appreciably above atmospheric pressure, the excess pressure on the reflected surface is much higher. For example, if the incident pressure is about 100 psi, the reflected shock pressure will be about 500 psi. As the incident wave expands to greater size, the reflected wave also expands, not in a spherical shape, but in the shape of a flat elipse. At some distance from the charge, which is determined by the height of the explosion and by the strength of the incident shock wave, the intersection of the reflected wave and the incident wave occurs above the surface.

This is the point of origin of a pressure wave which connects that point and the surface. This is called the Mach stem and the intersection of the Mach stem, the incident and reflected wave is called the "triple point." As the shock system expands further, the Mach stem grows rapidly tending to encompass the two shock systems above it. If the explosion occurs very close to the surface, the Mach stem is formed almost directly under the explosion and in a short time it has grown so that most of the shock system is a Mach stem. If the explosion occurs on the surface, no separate reflection wave is formed and it can be considered that the shock wave is a Mach wave. The pressure and positive impulse in the neighborhood of the triple point and in the Mach stem are considerably greater than the pressure in the incident shock wave or in the shock emitted when the burst is on the ground.



EXPLOSION ABOVE THE SURFACE



EXPLOSION ON THE SURFACE

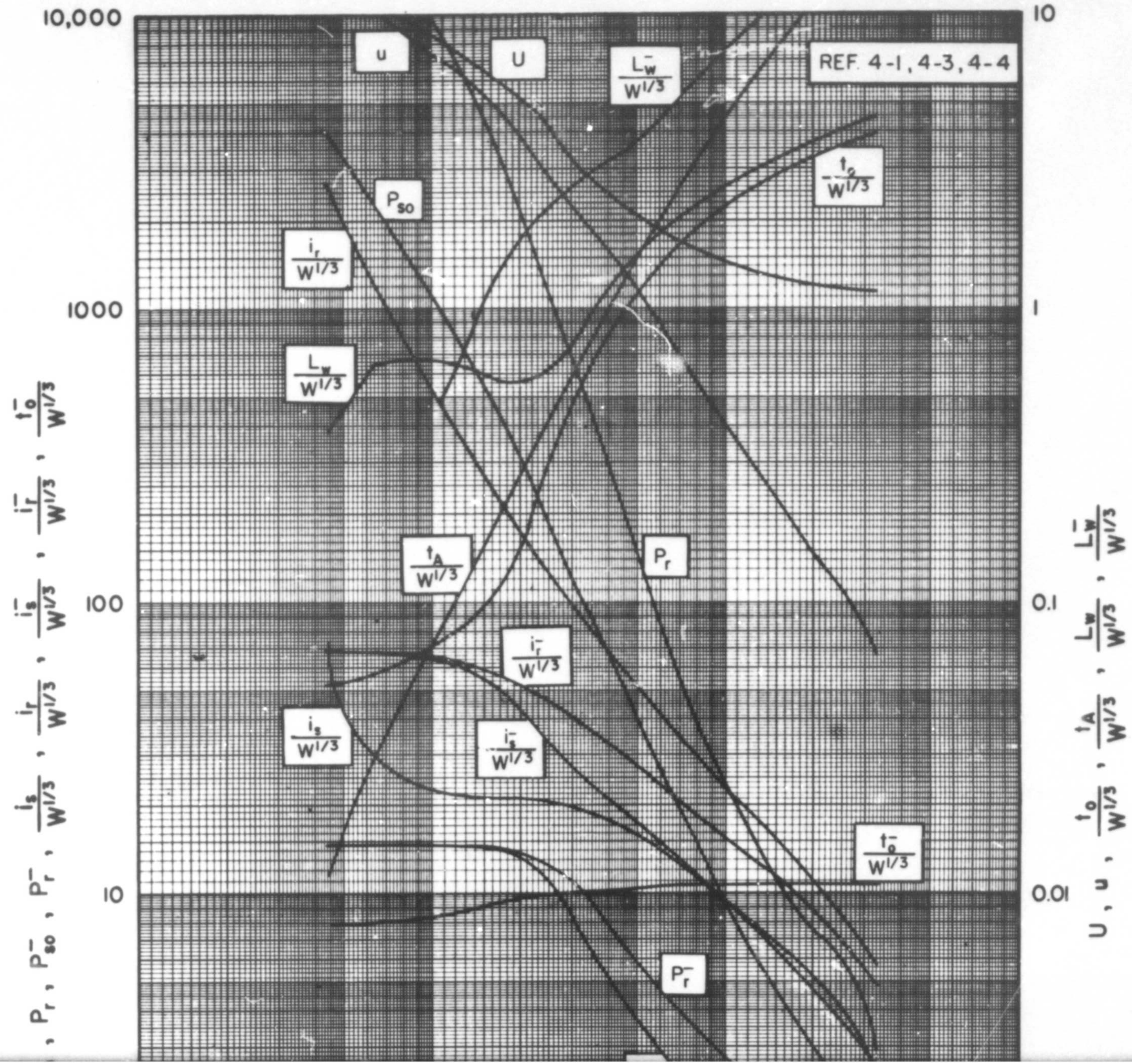
When a shock wave strikes a non-rigid obstacle such as a building, the wave is reflected by the surface of the building in the various ways described above. The reflection from a non-rigid surface will not, however, conform quantitatively to that from a rigid surface such as that discussed above. At the instant the wave strikes the wall, the wall is accelerated and continues to accelerate as long as there is excess pressure on its outer surface. At first, the wall deforms elastically so that, for insufficient excess pressure or insufficient positive duration, there may be no permanent deformation of the wall. If the blast is of sufficient intensity, the wall deforms inelastically and suffers permanent displacement. If a very long wall with a certain natural period of vibration is struck by a shock wave of long duration, the wall can be considered to be suddenly subjected to a blast of constant pressure equal to the pressure in the shock wave enhanced by reflection. For sufficiently small pressures, the wall will deform elastically (the amount of displacement being about twice that from a static pressure equal to the pressure in the reflected blast) and will not rupture. Some pressure must exist, however, such that the wall will collapse. For shock waves of finite duration, the walls may not collapse even though the pressure is equal to the critical pressure. Instead, the wall will acquire momentum from the shock wave and will vibrate without reaching the amplitude corresponding to collapse. If the duration of the wave is very short compared with the time required for collapse, the momentum imparted to the wall must be sufficient to deform it beyond the critical limit. On the basis of reasoning such as this, the peak pressure is usually considered to be the determining factor in the damage produced in blast from very large bombs such as atomic bombs. For small bombs, it is generally assumed that the positive impulse is the important quality since the duration of the blast is quite short.

(4) Basis for Structural Design Against Blast

The dynamic behavior and, therefore, the response of a protective structure (barrier or shelter) and its elements to the blast output, as indicated above, depend on (a) the properties (type, weight, shape, etc.) and location of the explosion, and (b) the physical properties and configuration of the structure itself. The response of a protective structure to blast can be described in terms of structural design ranges, such as (a) close-in, (b) intermediate, and (c) far. With "close-in" design range, the initial pressures acting on the protective structure are usually extremely high and further amplified by their reflections from the barrier. Also, the duration of the applied loads are short in comparison to the response time (time to reach maximum deflection) of the individual elements of the structure. Therefore, structures which are to withstand near miss explosions are designed for dynamic impulse rather than for the peak pressure associated with longer duration blast pressures. Structures subjected to blast effects associated with the intermediate design range sustain blast pressures of smaller intensity than those associated with the close-in range. However, because the duration of these pressures (which are long in comparison to those for the close-in design range) are in the order of magnitude of the response time of the structure, structural elements designed for the intermediate range respond to the combined effects of both the pressure and impulse associated with the blast output. Protective structures designed using the far-range criteria are designed for duration of blast loads which are extremely long in comparison to those associated with the other two design ranges. Here the structures respond primarily to the peak pressure in a similar manner as those structures designed to resist the effects of nuclear detonation. Although each design range is distinct in itself, no clear cut division between these ranges exists and each structure must be analyzed for a predicted blast protection environment based on the threat and degree of acceptable risk.

The quantitative values relating to the parameters discussed above can be obtained by referring to Figure 13D, "Shock Wave

Parameters for Hemispherical TNT Surface Explosion at Sea Level," and Figure 13E, "Shock Wave Parameters for Spherical TNT Explosion in Free Air at Sea Level."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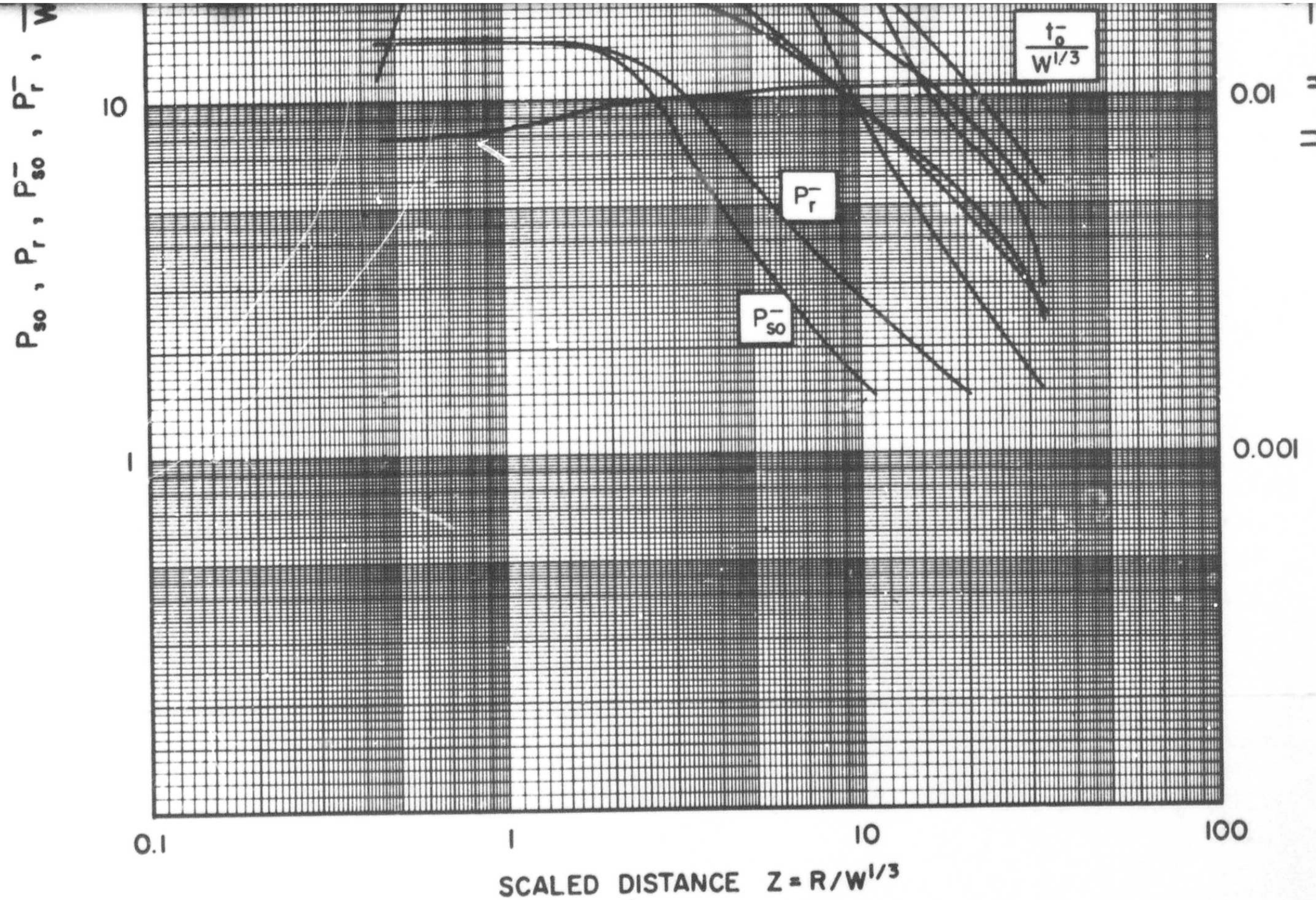
u
U
$\frac{\bar{L}_w}{W^{1/3}}$
$\frac{t_o}{W^{1/3}}$
P_{so}
$\frac{i_r}{W^{1/3}}$
$\frac{L_w}{W^{1/3}}$
$\frac{t_A}{W^{1/3}}$
P_r
$\frac{\bar{i}_r}{W^{1/3}}$
$\frac{i_s}{W^{1/3}}$
$\frac{\bar{i}_s}{W^{1/3}}$
$\frac{\bar{t}_o}{W^{1/3}}$
$\bar{P}_r$
10,000
1000
100
10
10
1
0.1
0.01
P_r, $\bar{P}_{so}$, $\bar{P}_r$, $\frac{i_s}{W^{1/3}}$, $\frac{i_r}{W^{1/3}}$, $\frac{\bar{i}_s}{W^{1/3}}$, $\frac{\bar{i}_r}{W^{1/3}}$, $\frac{\bar{t}_o}{W^{1/3}}$
U, u, $\frac{t_o}{W^{1/3}}$, $\frac{t_A}{W^{1/3}}$, $\frac{L_w}{W^{1/3}}$, $\frac{\bar{L}_w}{W^{1/3}}$



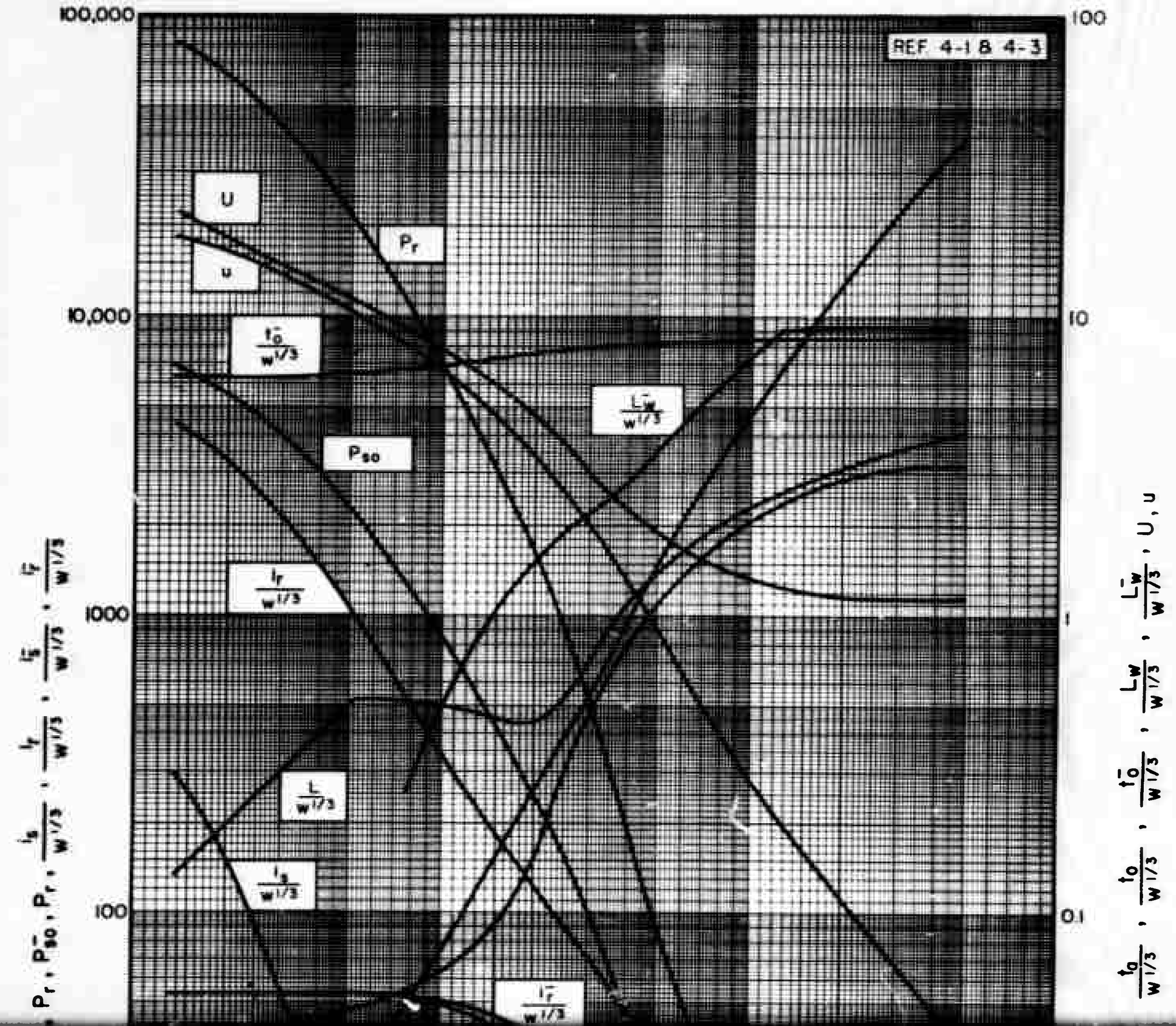
P_{so} = Peak Positive Incident Pressure, psi
P_{so}^- = Peak Negative Incident Pressure, psi
P_r = Peak Positive Normal Reflected Pressure, psi
P_r^- = Peak Negative Normal Reflected Pressure, psi
$i_s/W^{1/3}$ = Scaled Unit Positive Incident Impulse, psi-ms/lb$^{1/3}$
$i_s^-/W^{1/3}$ = Scaled Unit Negative Incident Impulse, psi-ms/lb$^{1/3}$
$i_r/W^{1/3}$ = Scaled Unit Positive Normal Reflected Impulse, psi-ms/lb$^{1/3}$
$i_r^-/W^{1/3}$ = Scaled Unit Negative Normal Reflected Impulse, psi-ms/lb$^{1/3}$
$t_A/W^{1/3}$ = Scaled Time of Arrival of Blast Wave, ms/lb$^{1/3}$

$t_o/W^{1/3}$ = Scaled Positive Duration of Positive Phase, ms/lb$^{1/3}$
$t_o^-/W^{1/3}$ = Scaled Negative Duration of Positive Phase, ms/lb$^{1/3}$
$L_w/W^{1/3}$ = Scaled Wave Length of Positive Phase, ft/lb$^{1/3}$
$L_w^-/W^{1/3}$ = Scaled Wave Length of Negative Phase, ft/lb$^{1/3}$
U = Shock Front Velocity, ft/ms
u = Particle Velocity, ft/ms
W = Charge Weight, lbs
R = Radial Distance from Charge, ft
Z = Scaled Distance, ft/lb$^{1/3}$

REF 31

FIG 13D SHOCK WAVE PARAMETERS FOR HEMISPHERICAL TNT SURFACE EXPLOSION AT SEA LEVEL

B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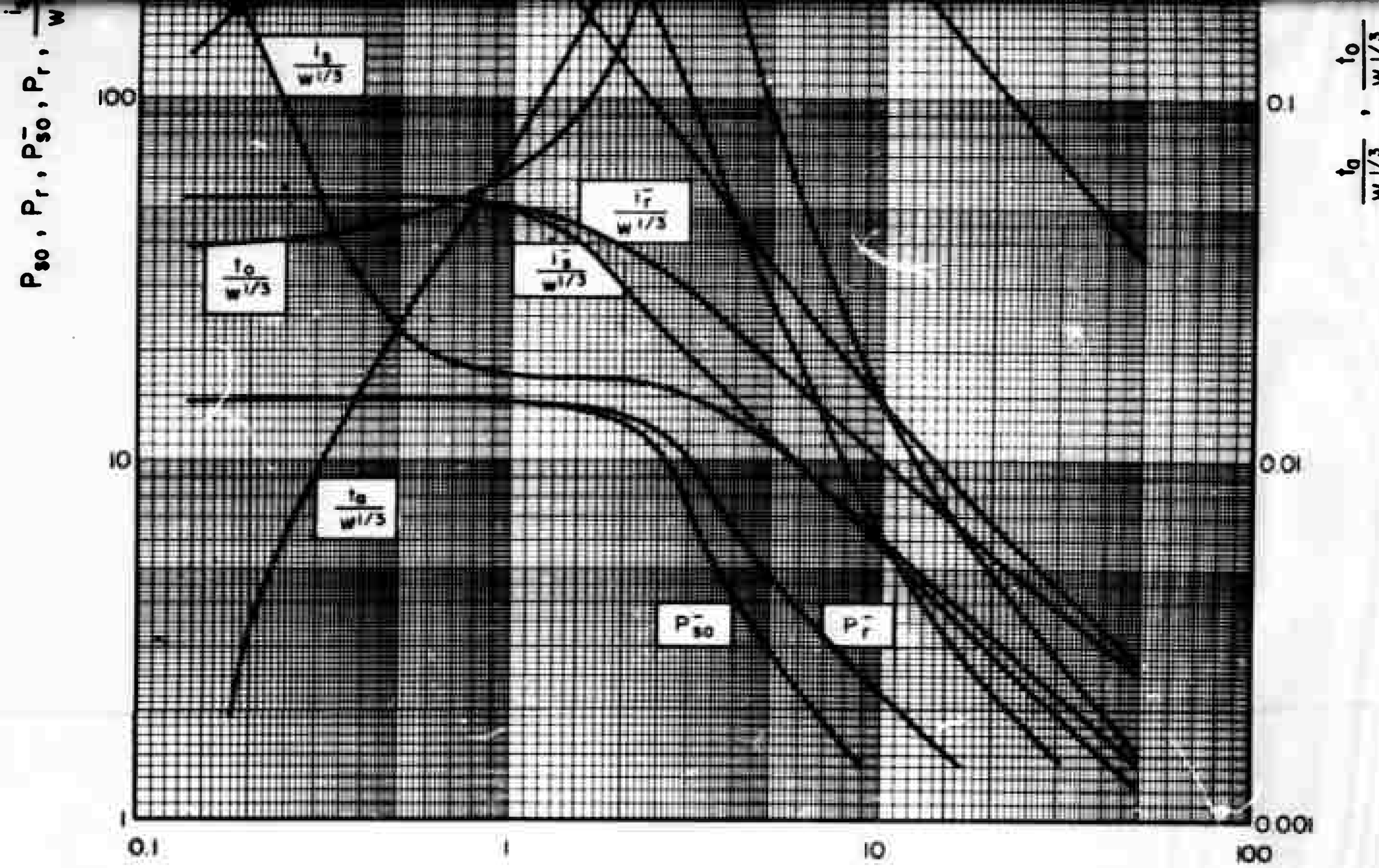


P_{so} = Peak Positive Incident Pressure, psi

P_{so}^- = Peak Negative Incident Pressure, psi

P_r = Peak Positive Normal Reflected Pressure, psi

P_r^- = Peak Negative Normal Reflected Pressure, psi

$i_s/W^{1/3}$ = Scaled Unit Positive Incident Impulse, psi-ms/lb$^{1/3}$

$i_s^-/W^{1/3}$ = Scaled Unit Negative Incident Impulse, psi-ms/lb$^{1/3}$

$i_r/W^{1/3}$ = Scaled Unit Positive Normal Reflected Impulse, psi-ms/lb$^{1/3}$

$i_r^-/W^{1/3}$ = Scaled Unit Negative Normal Reflected Impulse, psi-ms/lb$^{1/3}$

$t_A/W^{1/3}$ = Scaled Time of Arrival of Blast Wave, ms/lb$^{1/3}$

$t_o/W^{1/3}$ = Scaled Positive Duration of Positive Phase, ms/lb$^{1/3}$

$t_o^-/W^{1/3}$ = Scaled Negative Duration of Positive Phase, ms/lb$^{1/3}$

$L_w/W^{1/3}$ = Scaled Wave Length of Positive Phase, ft/lb$^{1/3}$

$L_w^-/W^{1/3}$ = Scaled Wave Length of Negative Phase, ft/lb$^{1/3}$

U = Shock Front Velocity, ft/ms

u = Particle Velocity, ft/ms

W = Charge Weight, lbs

R = Radial Distance from Charge, ft

Z = Scaled Distance, ft/lb$^{1/3}$

B

REF 31 FIG 13E SHOCK WAVE PARAMETERS FOR SPHERICAL TNT EXPLOSION IN FREE AIR AT SEA LEVEL

3. COUNTERS TO THE THREAT

The remote siting of tactical air bases beyond the range of enemy tactical fighters (arm's length concept) has been effective against attack from the air but ineffective against attacks from the ground. This deficiency in our tactical air base defenses has not gone unnoticed by other potential enemies. Therefore, the likelihood of future ground attacks is high. The specific objective of this effort, as stated in Paragraph 1, is to develop facility concepts to protect personnel, weapons and equipment from offensive weapons contained in the threat (Figure 11, "Consolidated Data on Elements of the Threat"). The measures taken to counter the threat are derived from the size and shape, obliquity, strength location, environment and degree of acceptable risk associated with the facilities under attack (Figure 14, "Passive Protection Counters to the Threat"). Definitions of these terms are shown below:

Size refers to the length, width and height of the structure. Size is an important consideration because it influences the probability of the structure being hit.

Shape is the geometric form of the structure.

Obliquity of a facility is an important parameter since it can influence the angle at which a projectile (or its fragments) intercepts the structure. Properly sloped or angled shapes tend to increase the obliquity and encourage ricochet. A reduction in the thicknesses of materials designed to defeat missiles can be made when the deflection of projectiles or their fragments is highly probable. Another

PASSIVE PROTECTION COUNTERS TO THE THREAT

- SIZE
- OBLIQUITY
- STRENGTH
- LOCATION
- TERRESTRIAL ENVIRONMENT
- DEGREE OF ACCEPTABLE RISK

FIGURE 14

example of the importance of obliquity is the bending stresses it produces on the projectiles prior to substantive impact.

Strength of the structure, as used in this report, refers to anti-weapon strength rather than structural strength. It influences the ability to reject, arrest, or deflect the attacking missile, projectile or fragment.

Location of a facility is defined as its proximity with respect to other structures and urban features. Location is important in over-all tactical air base planning, and must be considered a passive defense function. It should be the subject of another study since this effort deals primarily with facility concepts.

Degree of Acceptable Risk may be largely a military judgment factor. However, if the degree of risk can be reduced to percentages or cost variables, judgments can be more productive. For the purpose of this effort, it is defined as the per cent of damage that is acceptable if near total protection cannot be given to a facility and hence its contents. Risk is influenced by, among other things, the cost of providing near total protection, the "utile" value of the items to be protected, the time necessary to obtain a given level of protection, the availability and cost of materials. The degree of acceptable risk influences the extent to which a given facility must be protected.

Environment. The parameter which has the greatest impact on each of the above variables is the terrestrial environment selected for the physical placement of the structure. The terrestrial environment can be classified in six categories as follows:

a. Entirely above ground

b. Above ground and revetted (The category includes Earth Cover over the entire structure.)

c. Partly buried

d. Partly buried and revetted

e. Partly buried and covered

f. Totally underground

Each of the above parameters, i.e. size, obliquity, strength, location and environment, are discussed in the following paragraphs.

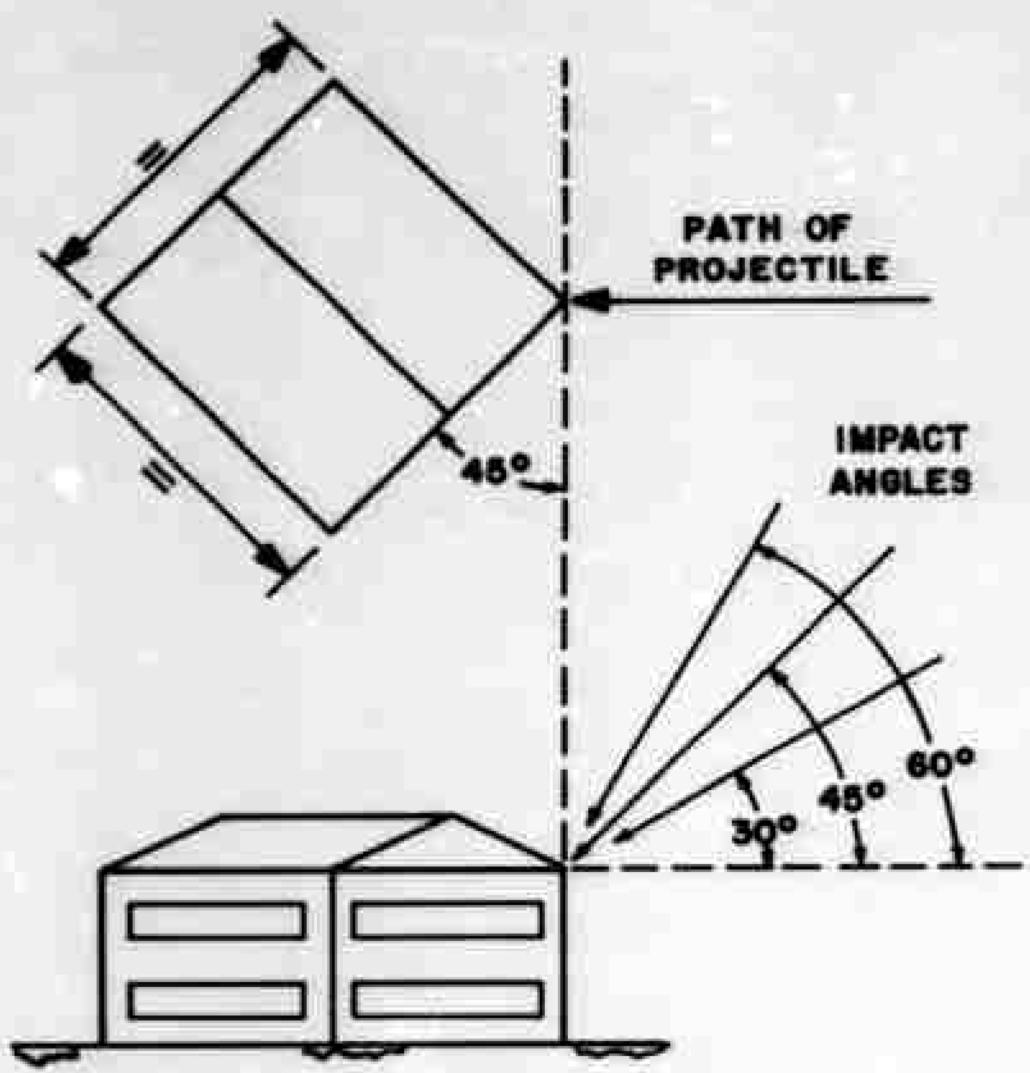
a. Size - Building Areas and Probabilities of Hit

The targets associated with the threat are buildings and their contents (people, POL, command and control, aircraft and other parts of weapons systems). The target presenting a small area is less likely to be hit than a large one. The quantitative values of the size of targets versus the circular error probable of weapons attacking the targets have been identified so that acceptable sizes of structures can be related. In the case where a building is the target (Figure 15, "Rules for Computing Areas and Probabilities"), the presented area of the top of the building is given by:

Presented Area of Top = (Floor Area) (Sine of Impact Angle)

In calculating the presented area of the sides of a structure, the building (target) is assumed to be rotated so that the line of flight of the projectile intercepts a corner. Thus the presented area of the sides is given by:

RULES FOR COMPUTING AREAS & PROBABILITIES
(DIRECT HIT)



PRESENTED AREAS

TOP = (FLOOR AREA) (SINE OF IMPACT ∠)

SIDES = 2(BLDG. HT.) ($\sqrt{AREA}$) (COS 45°) (COS IMP ∠)

PROBABILITY OF HIT

$$P_{(HIT)} = 1 - e^{-0.693\left(\frac{r}{CEP}\right)^2}$$

$$= 1 - e^{\left(\frac{-0.22\ AREA}{CEP^2}\right)}$$

FIGURE 15

Presented Area of Sides = 2(Building Height)($\sqrt{\text{Area}}$)(Cos 45°)(Cos Impact∠)

The probability of a structure being hit by a single shot is given by:

$$P_{(hit)} = 1 - e^{-0.693\left(\frac{r}{CEP}\right)^2}$$

$$= 1 - e^{\left(\frac{-0.22\ \text{Area}}{CEP^2}\right)}$$

where the area of the building presented to the line of flight of the projectile is approximately a circle whose radius is "r." H. H. Germond has shown in his report, "Target Coverage," RAND RM-149, April 1949, that this is a good approximation. Throughout this study buildings have been used as most representative of target areas. Utilizing the above equations, three figures were prepared as follows:

FIGURE	TITLE
16a (Linear) and 16b (Log)	Single Shot P_h vs. Presented Area of Building
17a (Linear) and 17b (Log)	Single Shot P_h vs. Area and Height of Building
18a (Linear) and 18b (Log)	Single Shot P_h vs. Circular Error Probable

From the above family of curves, it can be seen that the probability of a structure being hit is a function of its size and the accuracy of the attacking weapon. In the illustrative hypothetical example below, the assumption is made that a 15 per cent probability of direct hit for each shot fired exists. This is an exceedingly high probability and it is used to illustrate the sensitivity of building size to weapon accuracy.

SINGLE SHOT P_H VS PRESENTED AREA OF BUILDING

(DIRECT HIT)

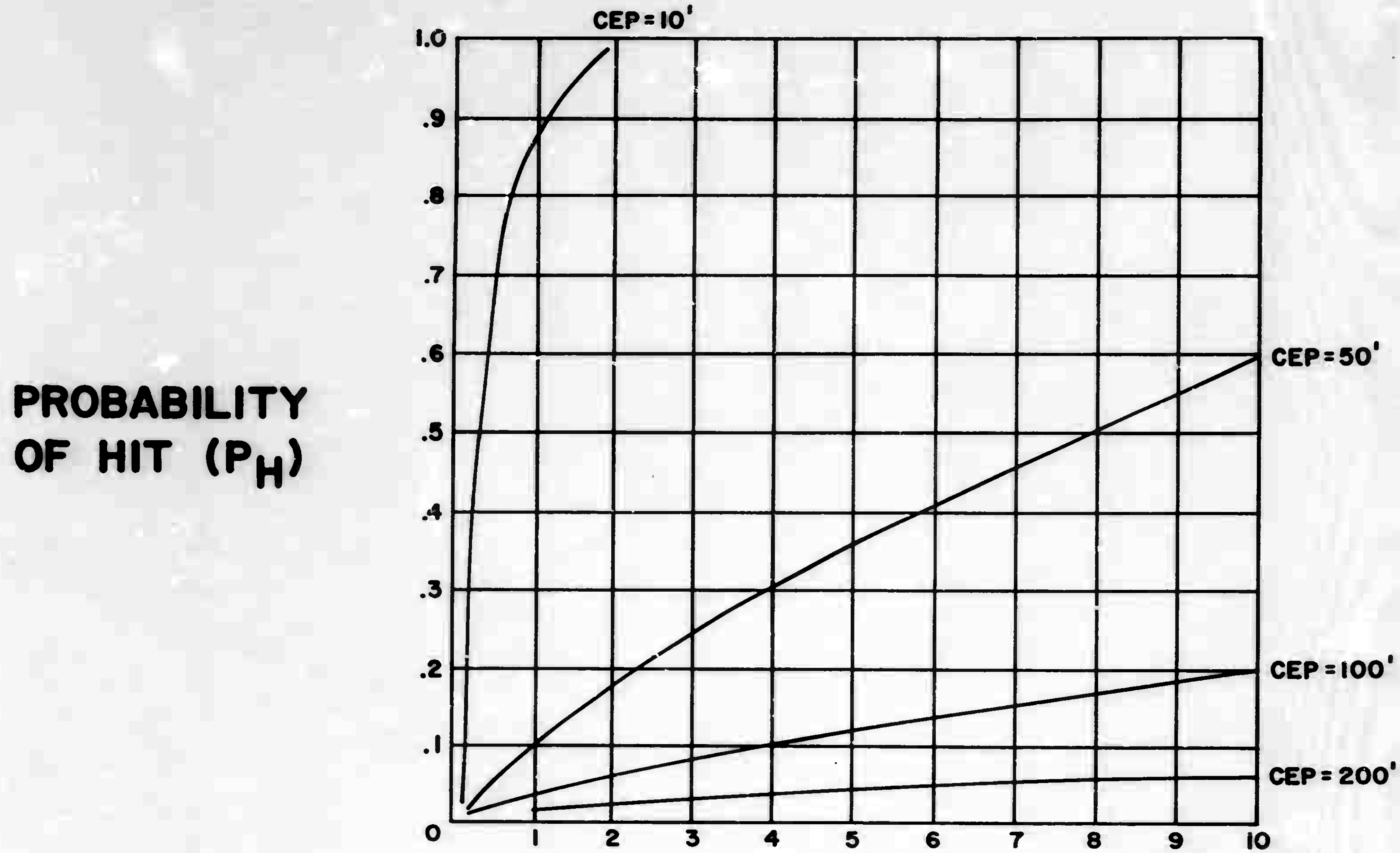


FIGURE 16.

SINGLE SHOT P_H VS PRESENTED AREA OF BUILDING

(DIRECT HIT)

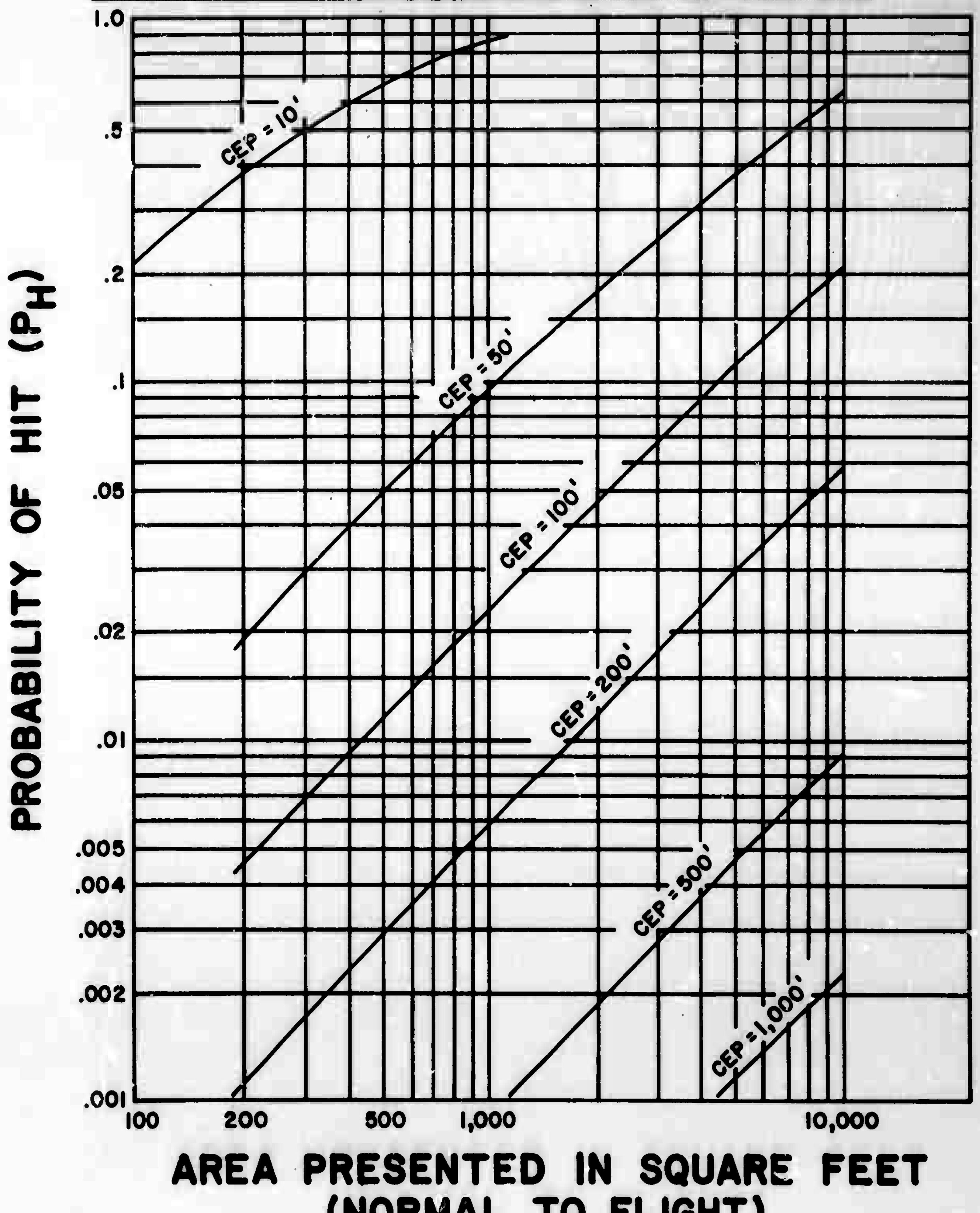


FIGURE 16B

SINGLE SHOT P_H VS AREA & HEIGHT OF BUILDING

(DIRECT HIT)

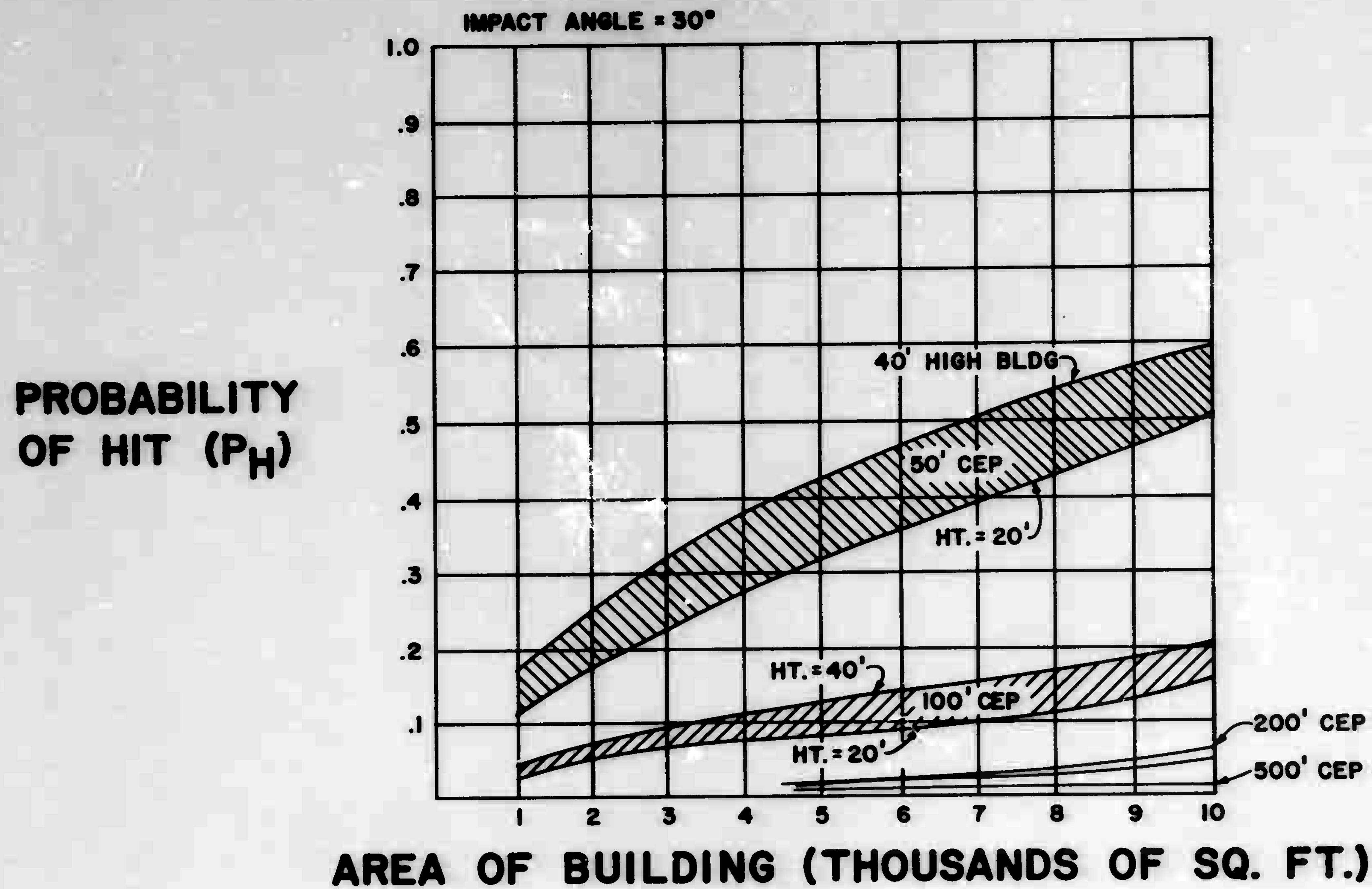
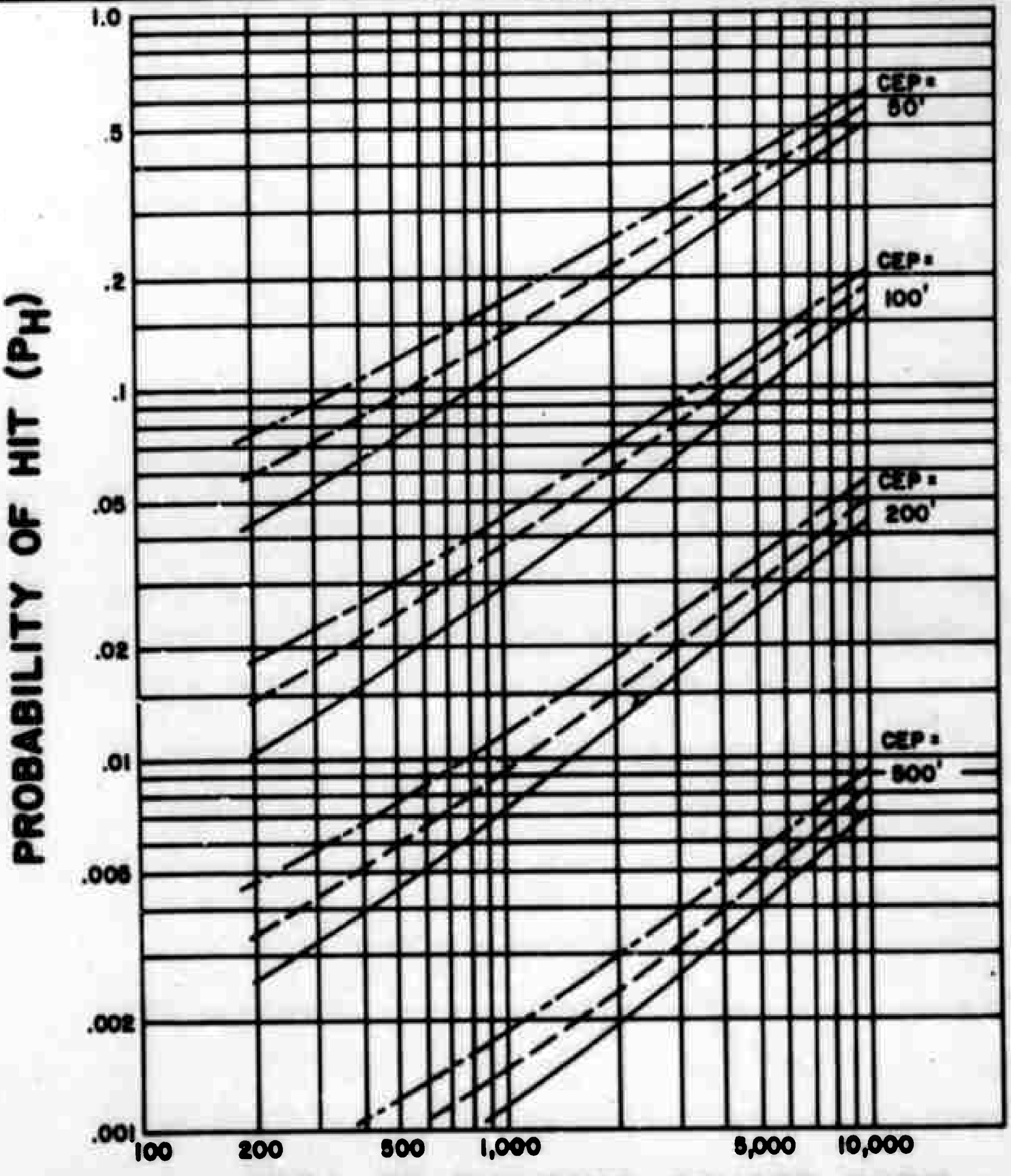


FIGURE 17

SINGLE SHOT P_H VS AREA OF BUILDING AND HEIGHT OF BUILDING. ANGLE OF IMPACT=30°

(DIRECT HIT)



AREA OF BUILDING, SQUARE FEET

LEGEND: ——— 20' HIGH BLDG. — — — 30' —·—·— 40'

FIGURE 17B

SINGLE SHOT PROB. OF HIT (P_H) VS CIRCULAR ERROR PROBABLE

(DIRECT HIT)

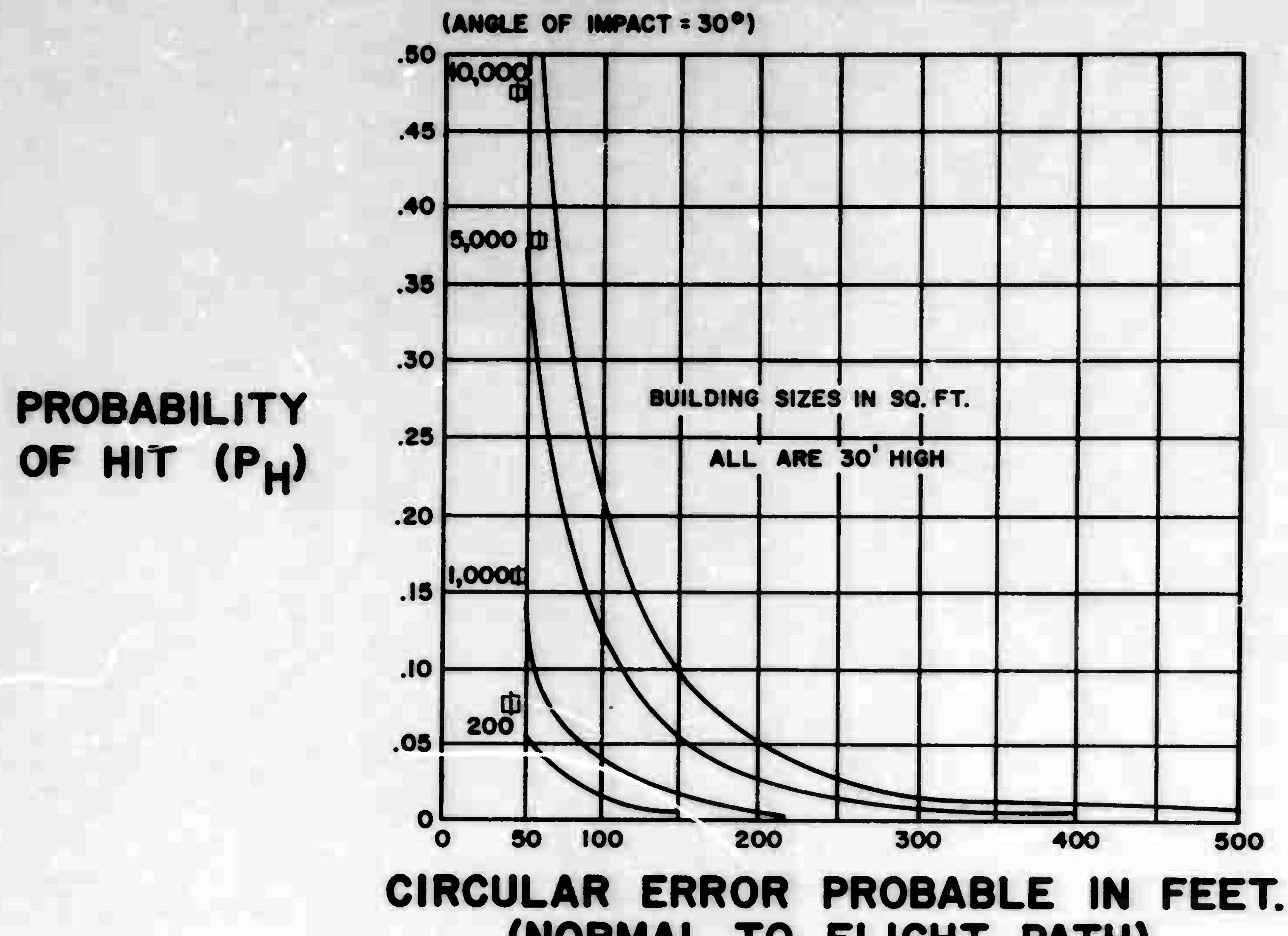


FIGURE 18

SINGLE SHOT P_H VS C.E.P.
(ANGLE OF IMPACT = 30°)
(DIRECT HIT)

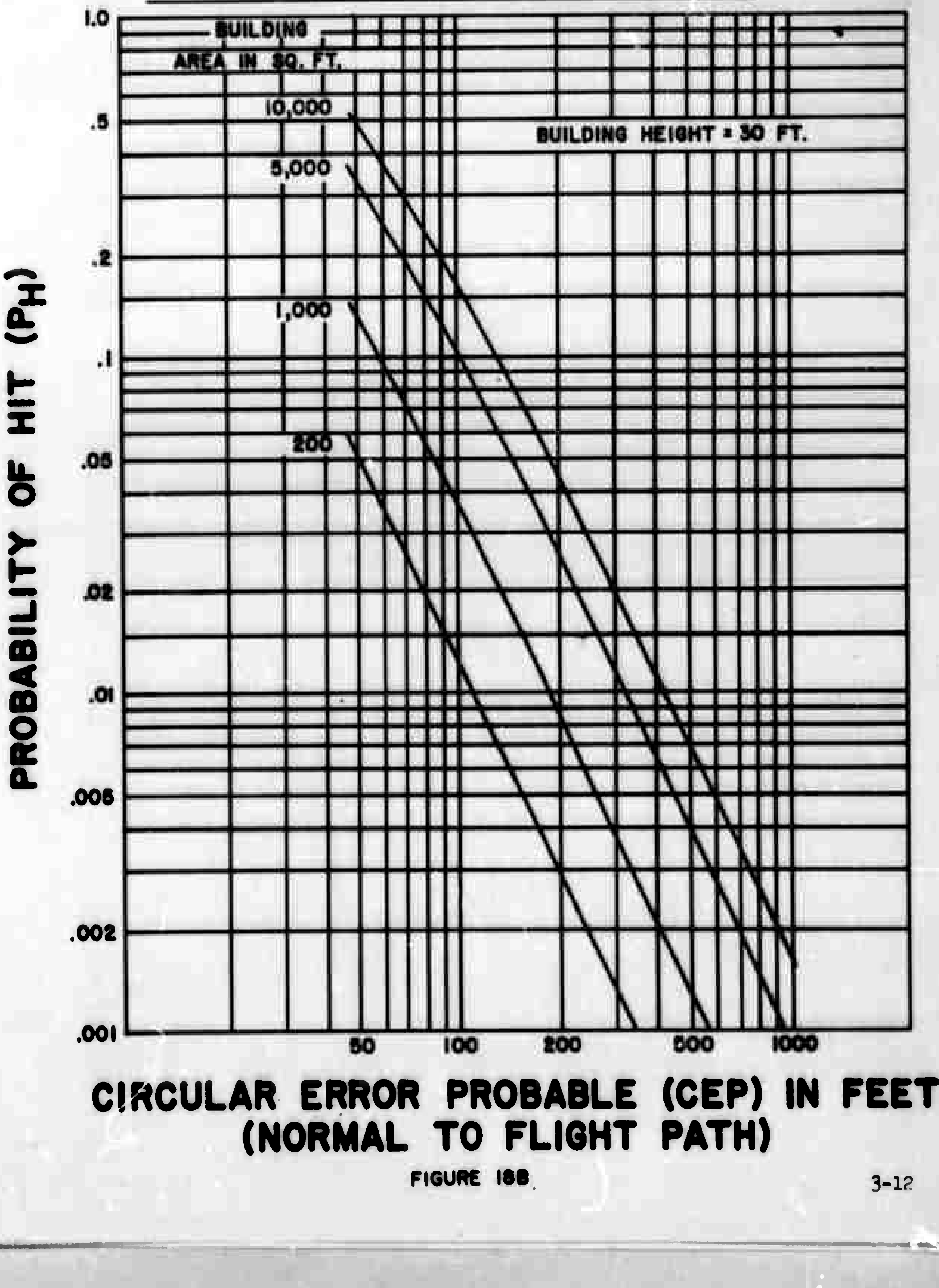


FIGURE 18B

The options are to construct buildings with the following characteristics given the Circular Errors Probable (CEP) as indicated.

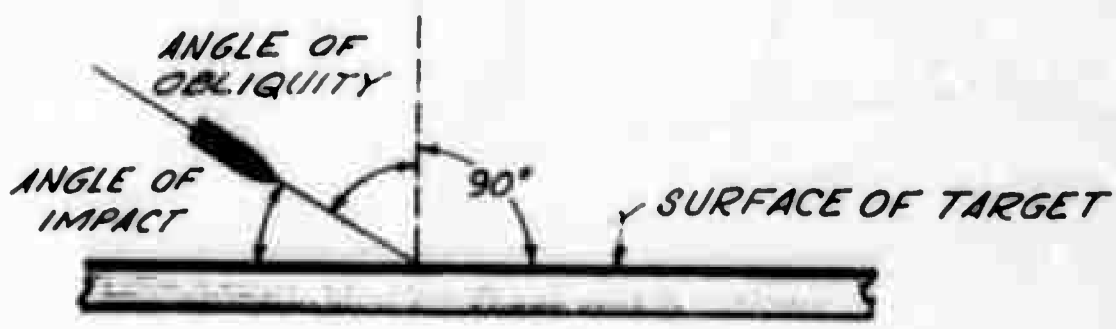
AREA	HEIGHT	CEP
750 Square Feet	40 Feet	50 Feet
1,000 Square Feet	30 Feet	50 Feet
1,800 Square Feet	20 Feet	50 Feet
7,000 Square Feet	40 Feet	100 Feet
8,600 Square Feet	30 Feet	100 Feet
9,800 Square Feet	20 Feet	100 Feet

From the above it can be seen that no building larger than 1,800 square feet in area and 20 feet high can be erected without exceeding a probability of hit of 15 per cent for each shot fired from a weapon having a 50 foot CEP. It is unrealistic to place such a restriction on structures. Hangars, POL Dumps, and Communications all require facilities larger than 1,800 square feet. To be practical in arriving at the proper size structure vis-a-vis survivability, it is first necessary to determine the accuracies of the weapons in the threat and then develop concepts for facilities of an area that will minimize the probability of hit and also resist the attacking weapons. The structures should be configured so that they will have as low a silhouette as possible and they should also encourage ricochet. These actions will enhance the probability of survival.

To place the above in realistic perspective, the weapon CEP's for projectiles are shown in Figure 4, "Examples of Accuracies." The 102 mm has a CEP of 37 meters, the 122 mm, 58 meters; and the 140 mm, 48 meters. Given these data, the problem takes on a different hue. This time assume that the structure will be attacked by 102 mm with a 30 degree impact angle. The weapon CEP (as differentiated from the system CEP, system CEP's are larger than weapon CEP's sometimes by a factor of 4) is 37 meters or about 120 feet. A structure with a floor area of 5,000 square feet and 30 feet high must be erected to properly perform its designated function, as for example, a hangar. By referring to Figure 18b, it can be seen that a single shot P_h of 8 per cent prevails. The addition of protective materials to the building would significantly increase its probability of survival. Methods for doing this are discussed in Paragraph 4c of this report.

b. Obliquity

Obliquity is defined as the angle measured from a line normal to a target surface at which a projectile is directed to that target surface. The angle of obliquity is the complement of the angle of impact. Therefore, the angle of obliquity plus the angle of impact is equal to 90 degrees.



The configuration of the facilities is influenced by the threat, the capabilities desired, the terrestrial environment in which it will be placed and the materials to be applied to the structure. One of the dominant things that influence the shape of a structure is the angle at which target surfaces are presented to an attacking weapon. This is important because ricochet is encouraged by oblique presentation of the building surfaces to the projectile path. If proper attention is given to obliquity, projectiles may be deflected and savings in thicknesses of protective materials on the structure can be made. In this regard, Figures 19 and 20 are useful in determining the angles for the sides and roof of a building. From Figure 19, entitled "Relationships between Parts of Building and Angles of Attack by Projectiles," it can be seen that howitzers tend to attack targets at angles centered on 30 degrees to the horizontal. Rockets and mortars, on the other hand, predominate at angles of attack between 45 and 60 degrees. The angles which encourage ricochet are those from the angle of attack through the limit of the critical angle. Critical angles are those angles of obliquity at which projectiles (or fragments) start to ricochet. Critical angles are velocity dependent and increase as velocity increases. The critical angles* for mortars start at angles of obliquity of about 22 degrees (68 degree angle of impact). Their velocities are on the order of 720 feet per second. Artillery shells approach at velocities of 1,000 to 1,500 feet per second. Their critical angles are 33 degrees and 43 degrees for the aforementioned velocities respectively. Rockets have velocities between 800 and 1,200 feet per second; therefore, critical angles for rockets should fall between mortars and artillery shells. Hence, the walls for structures should be inclined toward the attack (outward) 10 degrees or more to encourage ricochet from projectiles approaching at or

*For impact on concrete

RELATIONSHIPS BETWEEN PARTS OF BUILDING AND ANGLES OF ATTACK BY PROJECTILES

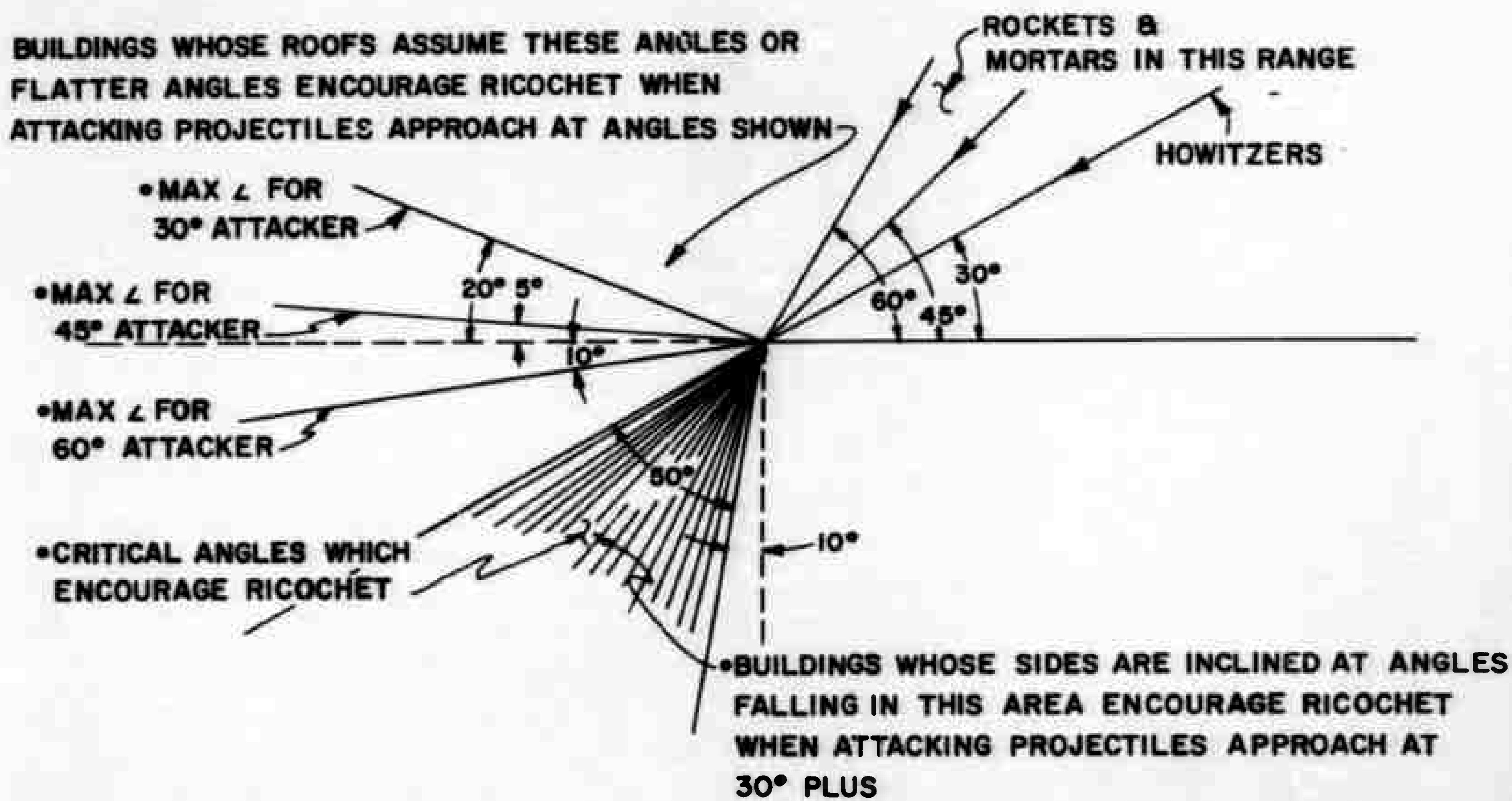


FIGURE 19

above 30 degrees. By referring to Figure 20, "Angle Associated with Breakup," it can be seen that 20 degrees obliquity is in the "knee of the curve" and that the ratio of the thickness of the wall (T_s) to the diameter of the projectile (d) is 0.8. In view of these findings, it is determined that the walls of the "basic core" should be inclined 20 degrees toward the direction of the attack. By the same token, roofs should have pitches varying from the horizontal 10 degrees downward in a single direction to 20 degrees upward. On balance, it appears that a flat roof accommodates the essential elements of the threat relative to ricochet.

c. Strength

(1) Materials

Atoms join in a solid state to make materials. The fact that atoms come in a large number of sizes and have different bonds of strength between them accounts for the wide variety of materials. The pattern of atoms in a structure dictates the general properties of materials. (Note: During the course of this work, it was found that it would be advantageous to be able to determine when properties of materials are the "ruling" parameters regarding penetration. By specifying the desirable properties and showing the effects of these properties on penetration, the laboratories can perform research to "invent" new materials for armor which will perform approximately according to pre-determined standards. The method for doing this is discussed in Paragraph 4f,

ANGLE ASSOCIATED WITH BREAKUP FOR 0.30-CAL. AP

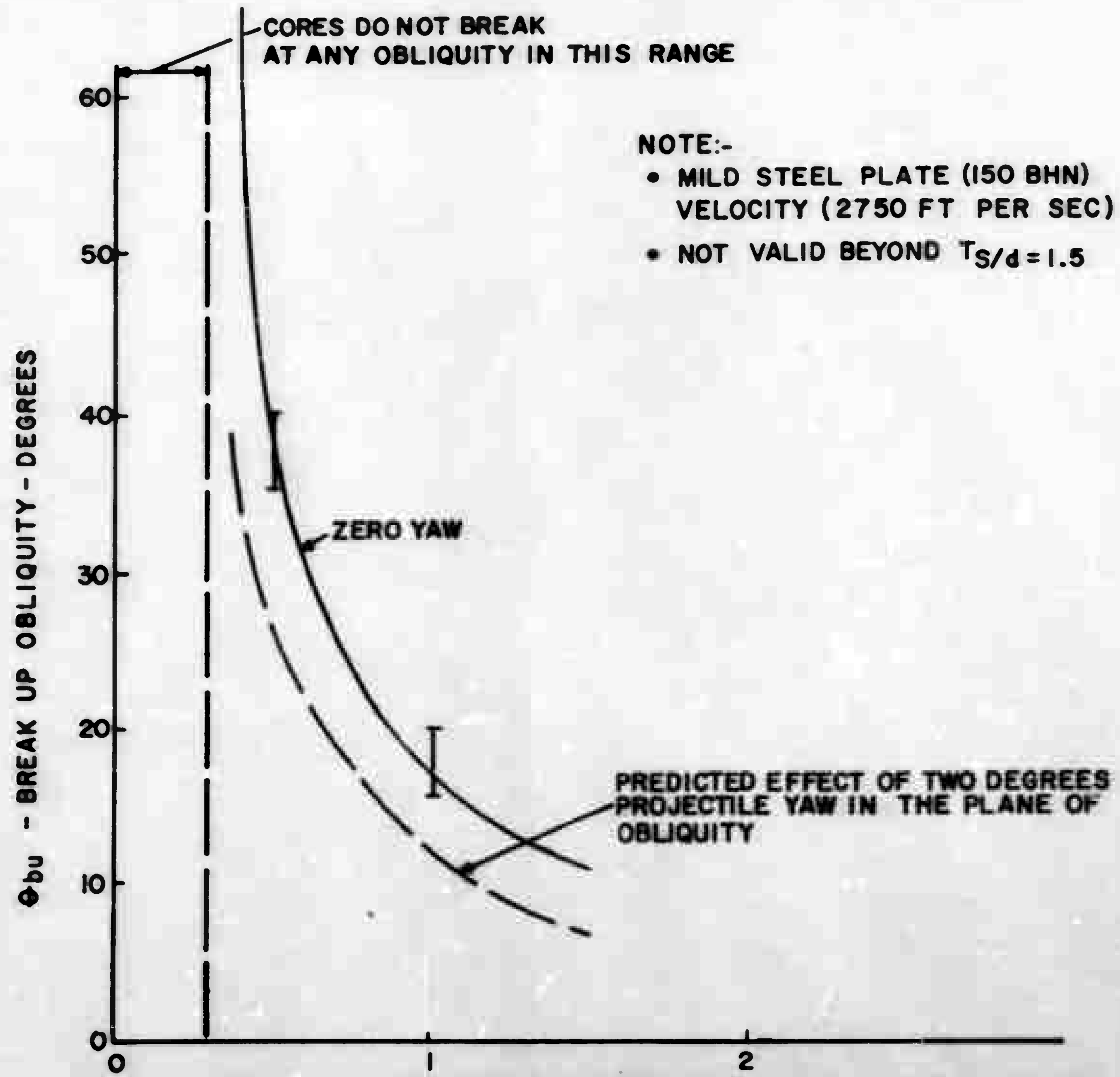


FIGURE 20

REF 37

"Penetration Analysis," and Paragraph 4g, "Computer Techniques for Prediction of Penetration.")

With the above in mind, by working backward from end-use to the choice of materials for passive defense structures, a wide variety of materials, their combinations and composites are found to be applicable.

The end-use of materials for application to passive defense structures fall in five categories (Figure 21, "Functions of Materials"); namely, rejecting, arresting, deflecting, triggering and the support of other materials. A combination of these functions into a single system may be desirable.

Rejecting

A desirable quality for a material to have is the ability to outrightly reject penetration of a projectile or fragments thereof (Figure 22, "Reject"). Materials which fall into this category are those possessing high mass densities. Some of those found to be applicable to structures used for passive protection are:

- o Dual Hardened Steel
- o Mild Steel (Installed at an Angle)
- o Ceramics backed with Metal or Reinforced Fibre Plastic
- o Aluminum (Various)
- o Magnesium
- o Beryllium
- o Boron

FUNCTIONS OF MATERIALS

FUNCTIONS

- REJECT
- ARREST
- DEFLECT
- COMBINATION
- TRIGGER
- SUPPORT OF OTHER MATERIALS

FIGURE 21

REJECT

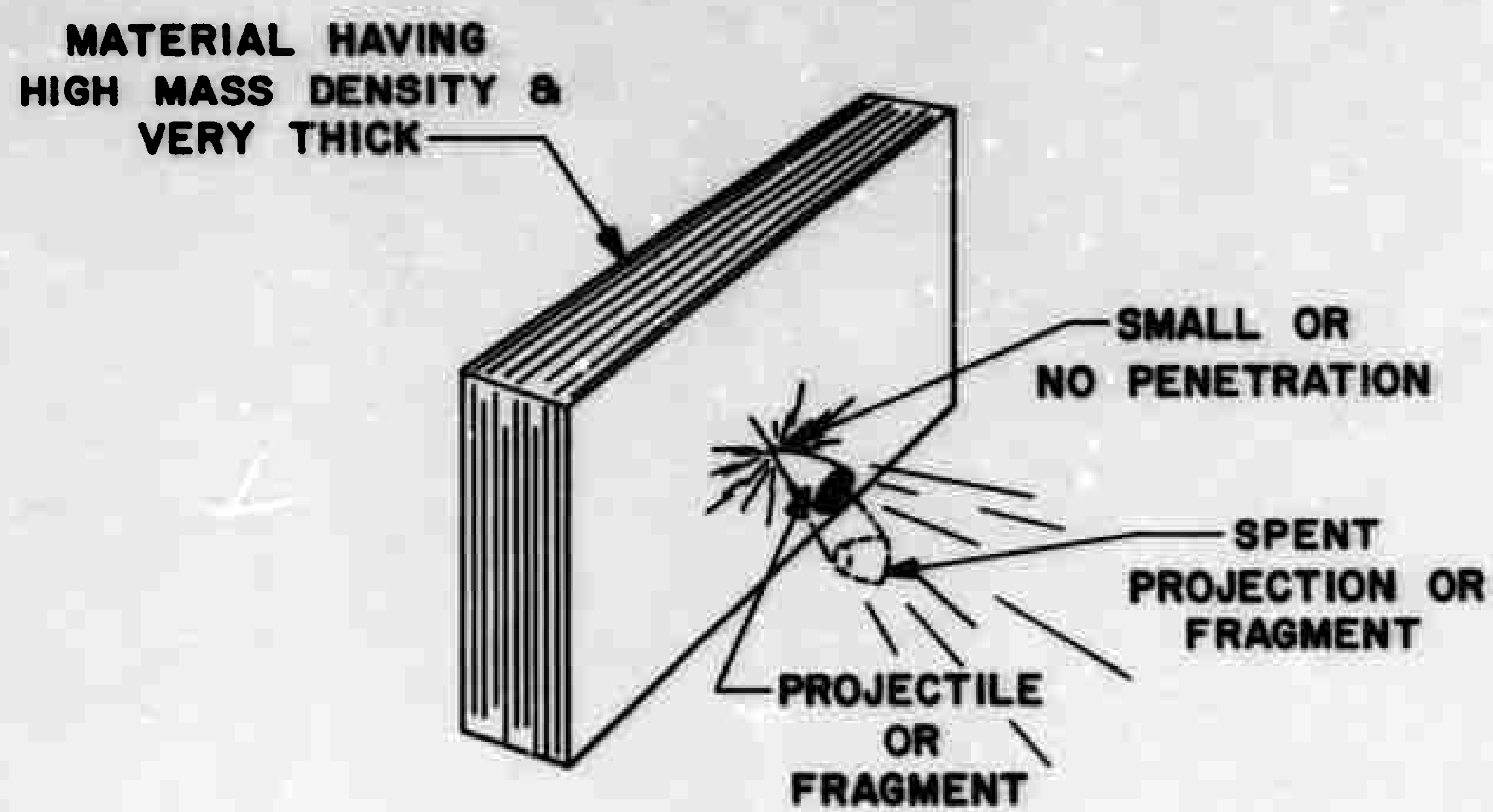


FIGURE 22

- Concrete
- Doron
- Lexan
- Titanium

Arresting

In some instances, the cost of rejecting a missile may be prohibitive or materials which perform well in the Rejecting function will not be readily available. In these cases, absorbing the energy of the missile would have the same effect; that is, defeat of the attacking missle (Figure 23, "Arrest"). On other occasions, economies may be obtained by first slowing down the attacking missile and then rejecting it. In either case, materials that arrest the projectiles or their fragments have a place in the protective construction field.

Some of the materials that possess qualities which would arrest enemy projectile attack are:

- Concrete
- Soils (Various Classifications--Sand, Silt, Clay, Gravel, and Combinations)
- Asphalt
- Metal Grit
- Mild Steel
- Water
- Aluminum
- Metal, Mineral and Plastic Honeycomb (Sandwiched)

ARREST

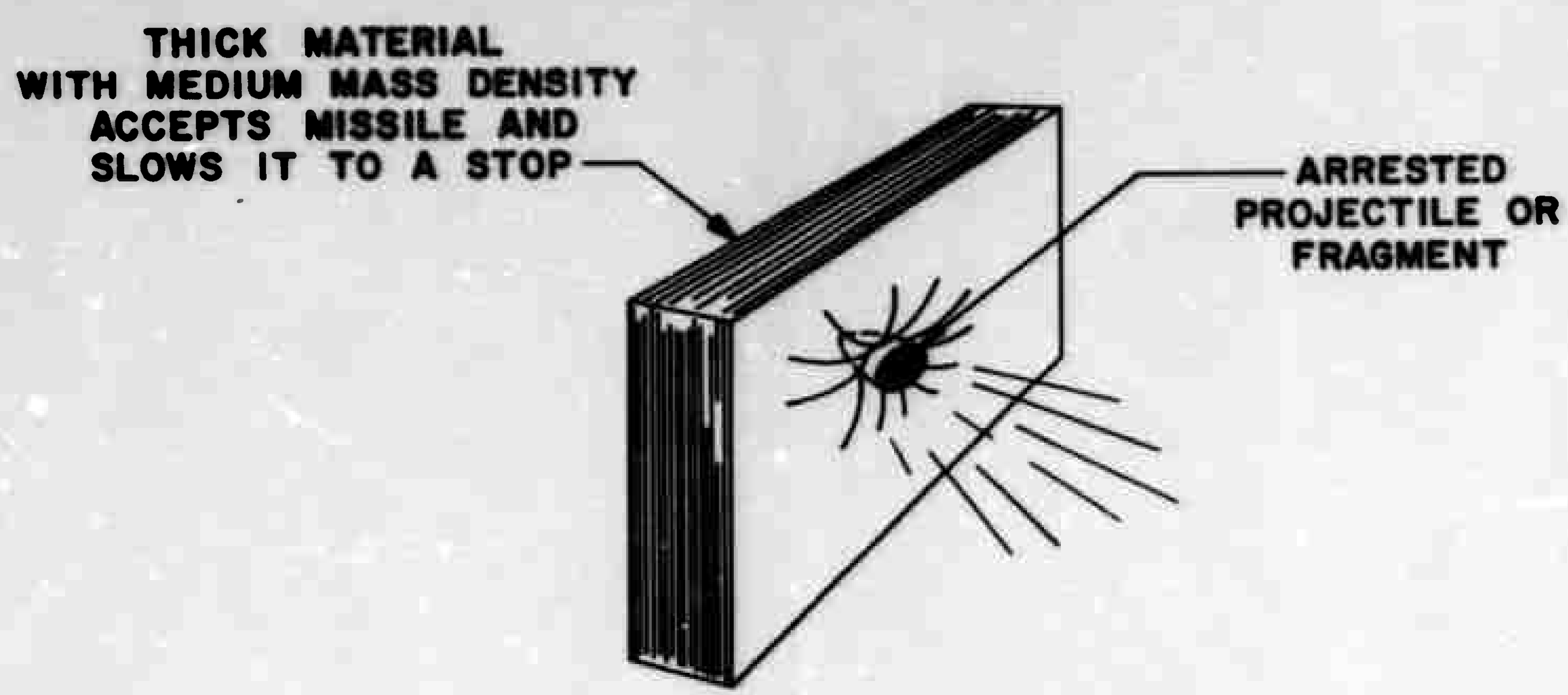


FIGURE 23

- o Ballistic Nylon Cloth
- o Ballistic Felts

Deflection

The angle at which a missle hits an object is an important parameter because at certain velocities and angles of obliquity, ricochet can be encouraged. It is important, therefore, that materials be placed so that ricochet is a high probability (Figure 24, "Deflect"). Generally, the materials which perform well in the Rejecting function also perform well in the Deflecting mode. For continuity, however, those materials which would deflect projectiles on their fragments are those listed in the paragraph entitled "Rejection" above.

Combination (Figure 26)

By experiment, using mathematical models, it has been found that layers of different materials reduce the velocity of projectiles more efficiently than a single material. It was also found that a combination of materials performing the functions of arresting, deflecting and rejecting was more effective than employing materials which do not perform all these functions. However, the sequence of the materials is an important factor. As a general rule, against weapons equipped with instantaneous fuses, it is apparently better to place "triggering" materials first so that they activate the fuse and arresting materials

DEFLECT

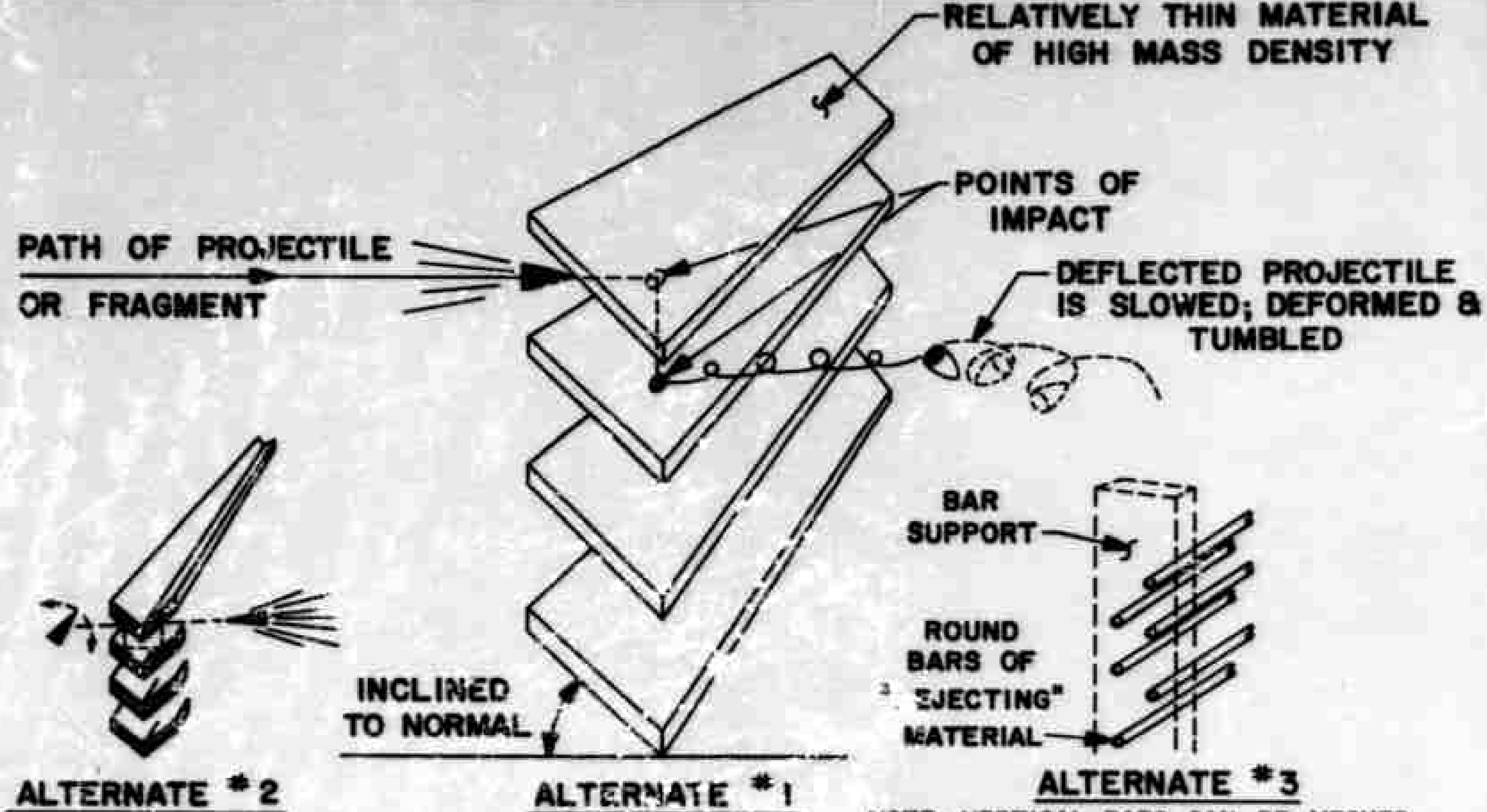
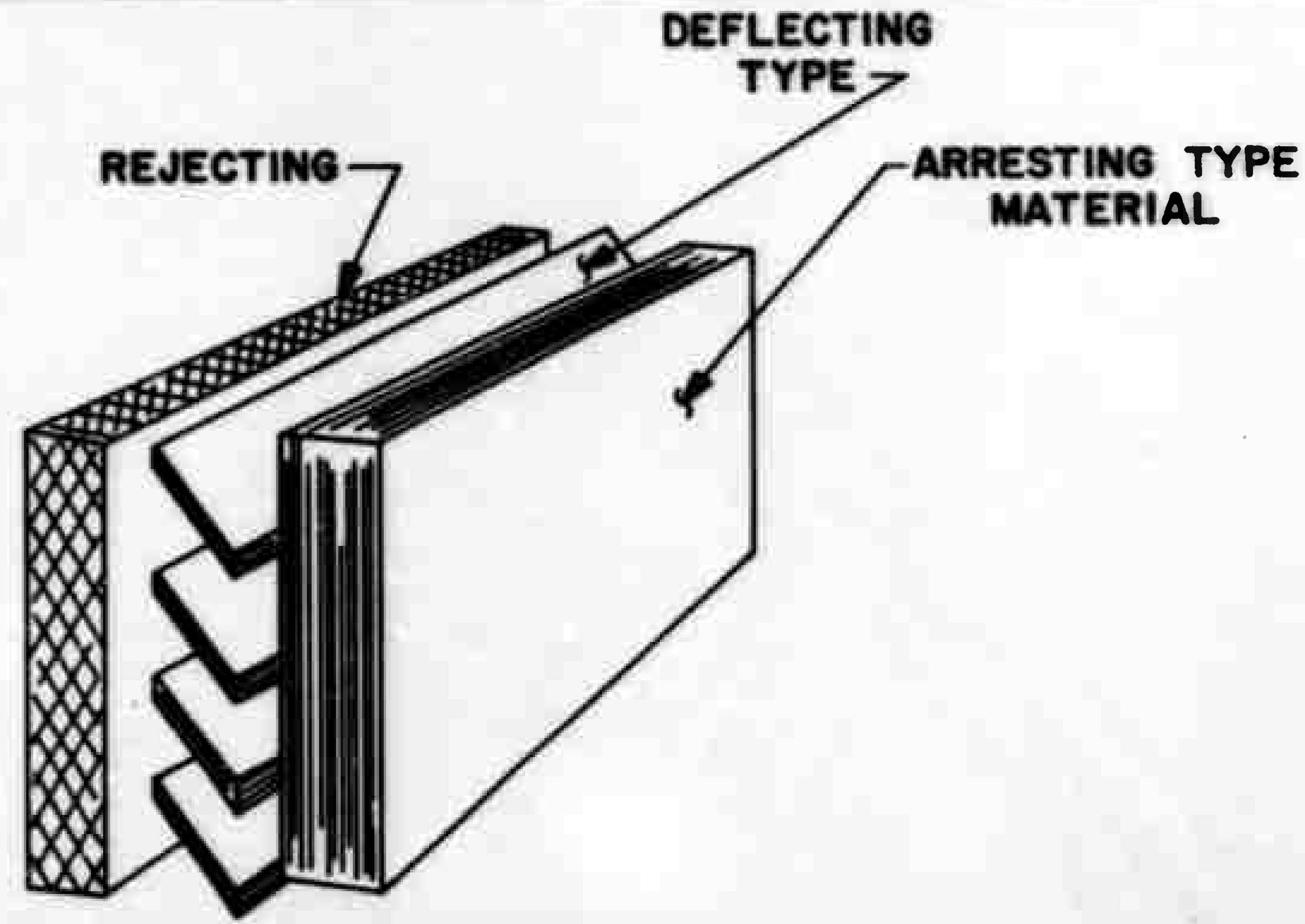


FIGURE 24

COMBINATION



- IS A COMBINATION MORE EFFECTIVE THAN A SINGLE MATERIAL?
- ARE ALL THREE MATERIALS NEEDED? WILL TWO DO THE JOB?
- DOES IT MAKE A DIFFERENCE WHICH MATERIAL COMES FIRST? SECOND? LAST?
- WHAT ARE THE MOST EFFECTIVE MATERIALS IN EACH CATEGORY? WILL THEY VARY WITH PLACEMENT?
- CAN THE BEST QUALITIES OF EACH BE COMBINED INTO A SINGLE MATRIX OR LAMINATE?

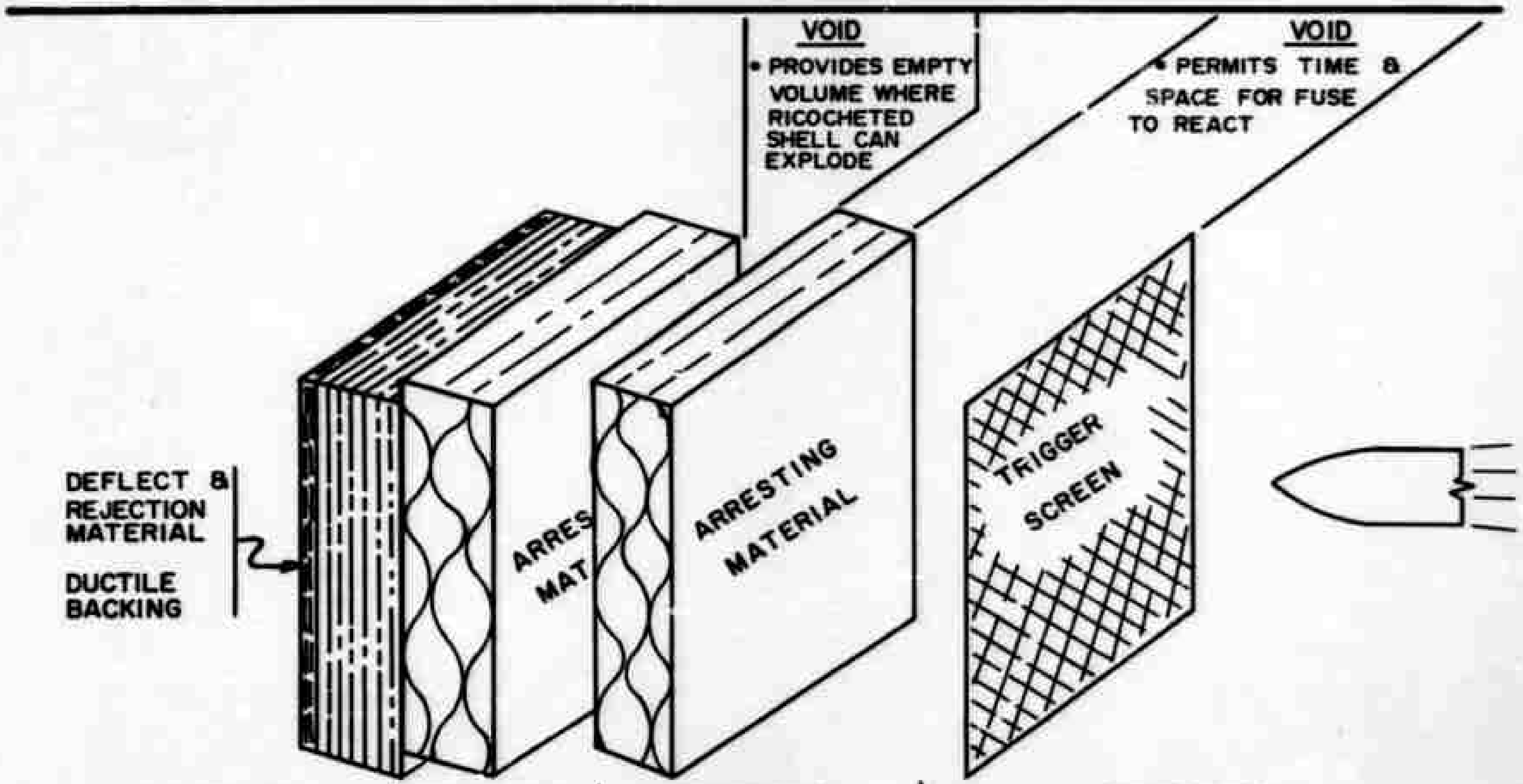
FIGURE 25

can then absorb the fragments. To validate this sequence, a computer program was devised so that large numbers of projectile "runs" could be made through various combinations of materials. In essence, it was found that materials should be exposed to projectiles in the following sequence (Figure 26, "Sequence of Materials")

First Layer - Trigger materials should be placed at a distance from the facility such that instantaneous fused projectiles will be activated but explosion will not occur before the projectile imbeds itself in arresting material installed on the structure. The trigger screen should also be installed to activate delayed fuses so that fusing action is started and explosion occurs prior to full penetration of the protective materials on the structure. The trigger material will also serve as a mechanism to topple or disorient 20 mm and smaller projectiles so that they arrive at the second layer of protective materials with obliquity and/or yaw.

Second Layer-Arresting material would absorb the fragments from the instantaneous fused projectiles. This should reduce the area over which effective fragments would be scattered or it will completely contain the fragments. In the case of delayed fuses, the complete projectile would be slowed down by the arresting material so that penetration of the third layer of protective materials would be more difficult. The arresting materials would also absorb fragments when the

SEQUENCE OF MATERIALS



FUNCTIONS

- RICOHETS PROJECTILE INTO ARRESTING MATERIAL OR THE VOID SPACE
- STOPS PROJECTILE

FUNCTIONS

- VELOCITY RETARDANT
- DIRECTION CHANGER
- FRAGMENT ABSORBER
- BLAST ATTENUATOR

FUNCTIONS

- ABSORBS FRAGMENTS
- RETARDS VELOCITY
- CHANGES DIRECTION OF PROJECTILE

FUNCTIONS

- ACTIVATES FUSES
- DISORIENTS SMALL CALIBER WEAPONS

FIGURE 26

delayed fuse causes explosion. (See Refinement to Second Layer below). In the case of 20 mm and smaller projectiles, the arresting material would retard their velocity to such a degree that ricochet from the third layer of material would be highly probable.

Refinement to Second Layer would be beneficial if the arresting material were divided into two portions with a void space between the portions. The void space (chamber) would vent the explosion to the outside after a projectile ricochets from the third layer of protective material.

Third Layer - Reject/Deflect material would be the final external layer of protective material. It would serve to stop the projectile or to cause it to ricochet.

Optional-Inside the structure - Arresting material may be hung inside the structure on cables or draped over high cost equipment to catch projectile fragments and/or secondary projectiles.

Desired Capabilities of Materials

Materials selected for passive defense of structures must be utilized efficiently to resist the penetration and explosive forces at costs which are competitive with other methods (such as active defense) of defending against the effect of small arms, mortar, artillery and rockets. It is also desirable to understand the phenomenon resulting from the penetration of various materials having different properties and the effects associated with the explosion of conventional weapons within the structure or in its immediate proximity. For example, the contact of a steel target material by a steel projectile traveling at 3,000 feet per sound results in very high pressures (approximately 3,000,000 psi). Heat is generated adiabatically. As a consequence, very high temperatures are obtained. Pressure waves are generated in both the target material and in the projectile. The waves travel through and are reflected in both materials at characteristic velocities. The characteristic velocities are near sonic velocities. The penetration of a projectile is resisted by the target material through the application of frictional forces at the interfering surfaces, by the cohesive forces in the material and by compressive forces applied normal to the existing surface of the projectile. A successful penetration apparently proceeds in the same way for ductile or brittle materials until the stresses induced through the three methods above interact or act uniquely to fracture the target material ahead of the projectile. In the case of glass (Figure 27, "Effects of Brittle Radial Cracking on Velocity-Penetration Curve for Glass."), it may be seen that, at a point approximately half way through, the fracture ahead of the bullet is such that no further substantial resistance is offered by the target. Results of calculating the penetration of various materials assuming ductile behavior and using

EFFECTS OF BRITTLE RADIAL CRACKING ON THE VELOCITY-PENETRATION CURVE FOR GLASS

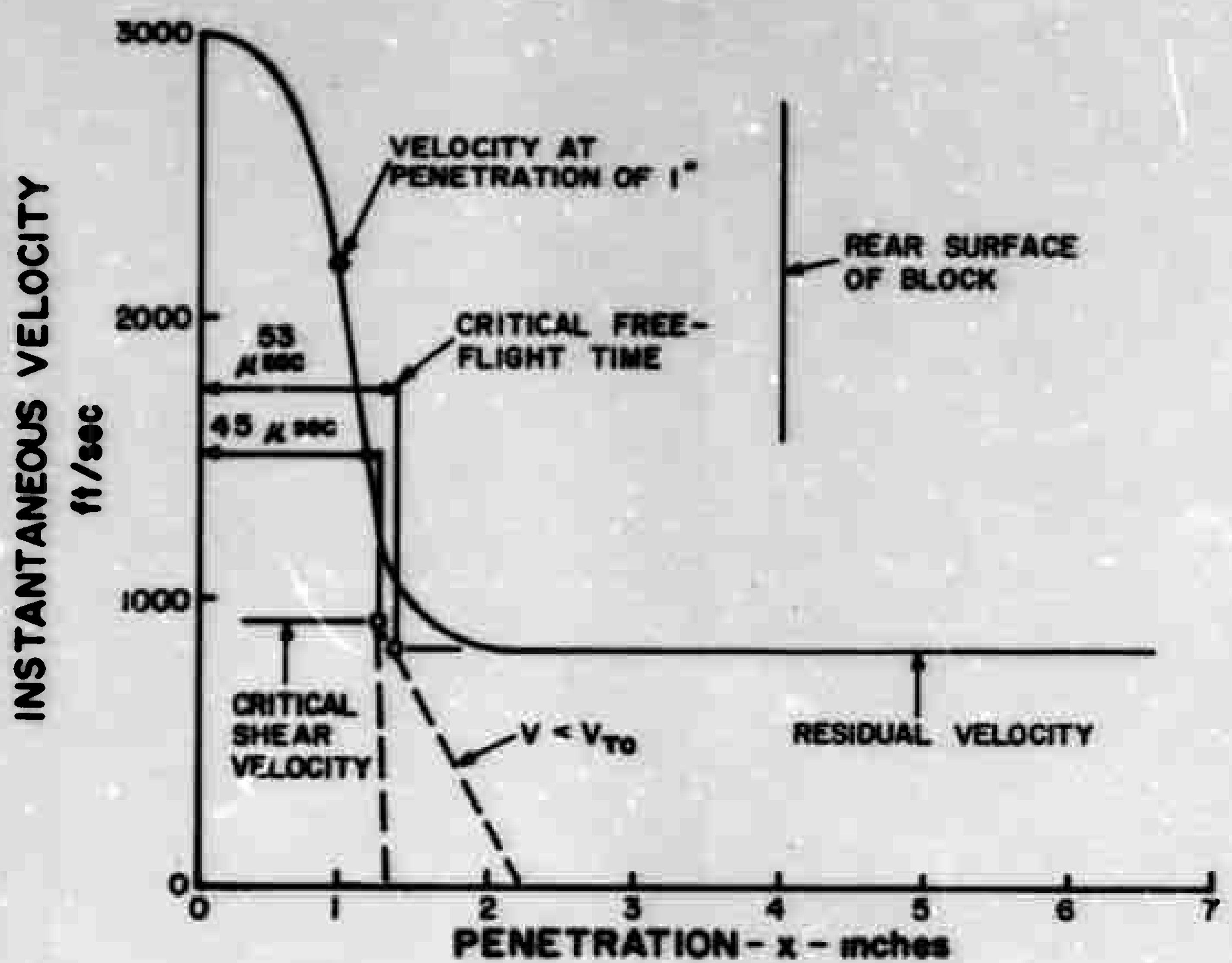


FIGURE 27

REF 37

constant static values for bulk modulus, compressive shear and coefficient of friction are shown in Figure 28, "Computed Velocity-Penetration Curves." The greater penetration resistance shown for a ceramic is due to the effect of the larger mechanical property ratios for ceramics. The difference between a ductile glass and a brittle glass can be seen by comparing the glass curve, showing instantaneous velocity at various depths of projectile penetration into materials in figures 27 and 28. It may be true that the dynamic strain forces become negative at some point which aids the projectile penetration. If either of the materials melts at the high temperatures encountered, frictional resisting forces are due to dynamic shear stresses of either the target material or the projectile material in its liquid state. High impact loads generate compression waves which are transmitted at near sonic velocities through elastic materials and are reflected in the opposite phase at the opposing surfaces of the projectile and target (Figure 29, "Wave Generation from Impact"). Thus, compression waves are reflected as rarefaction waves. Both kinds of waves interface and add and produce nodes of compression and tension. Shear is also probably produced. If the projectile overcomes the forces produced by the target material, penetration is successful. The projectile may be undeformed or it may be deformed or it may shatter in the process of penetration. Anything other than an intact projectile represents degraded successful penetration with probably less destructive momentum after

COMPUTED VELOCITY - PENETRATION CURVES

NOTE:- CONICAL PROJECTILE ASSUMING DUCTILE BEHAVIOR OF TARGET MATERIALS
PROJECTILE WEIGHT = 0.10 LB
d = 0.50 INCHES
L = 1.00 INCHES

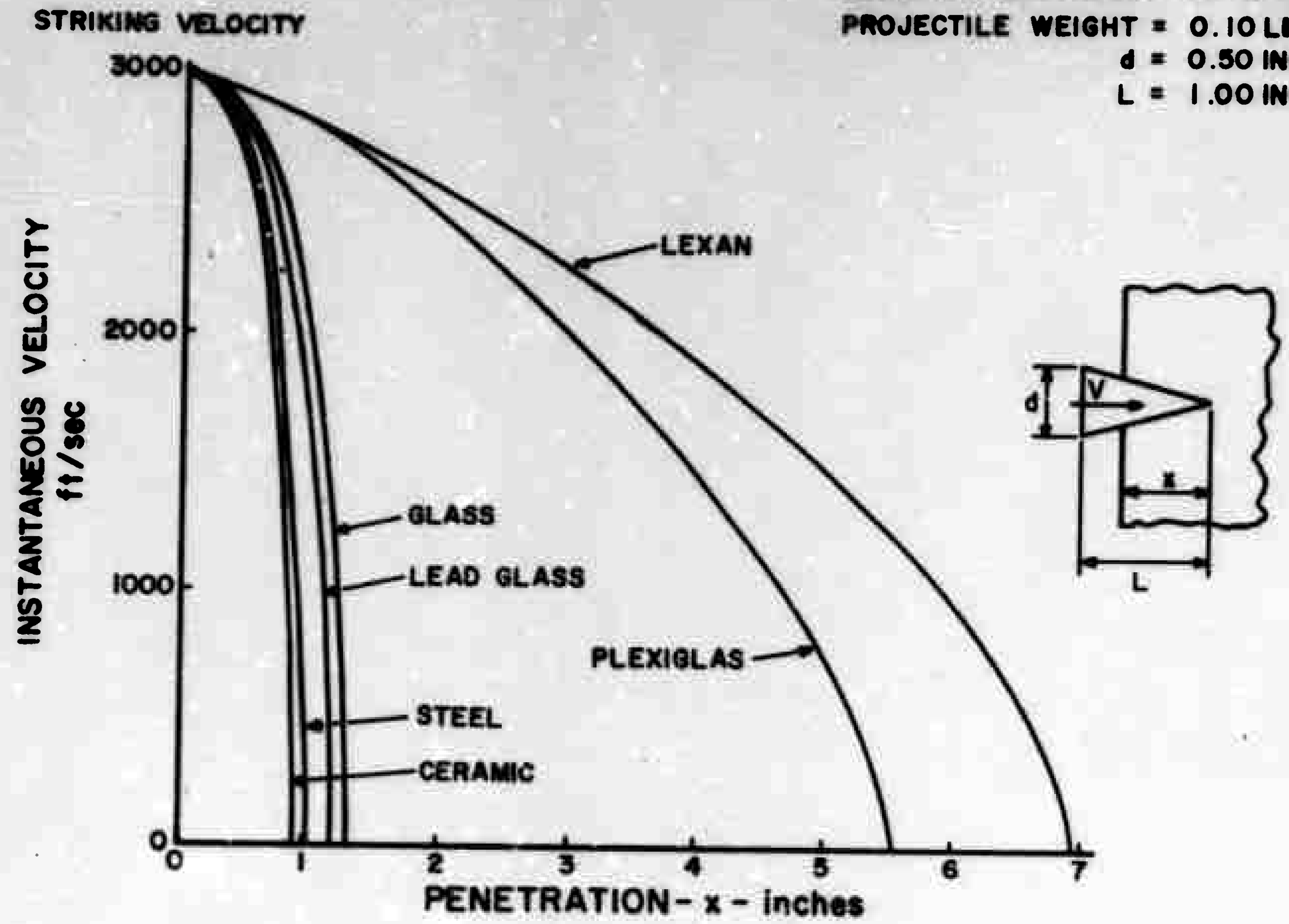


FIGURE 28

REF 37

GENERATION OF WAVES FROM IMPACT

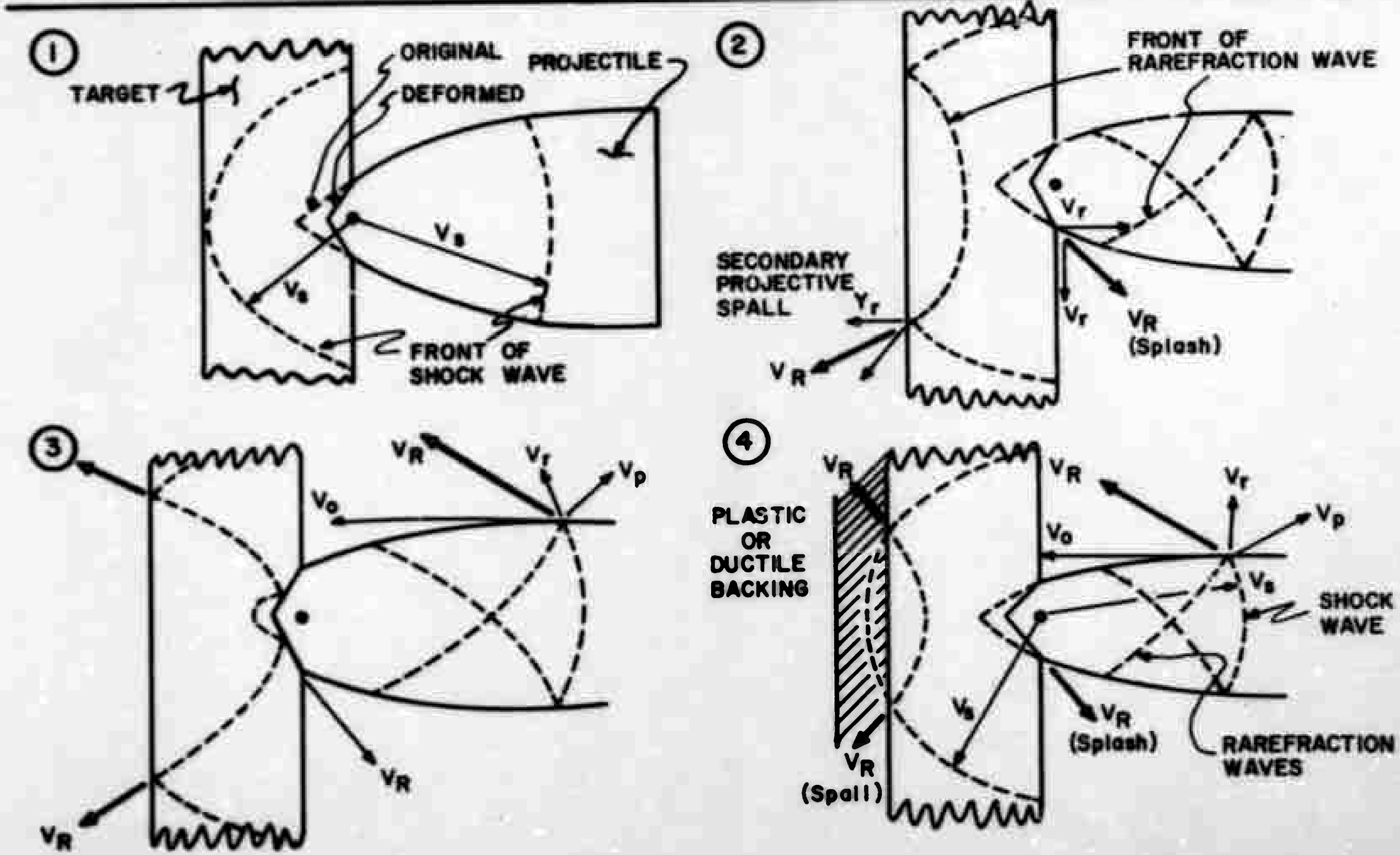


FIGURE 29

penetration. The desirable properties of materials for targets then are: High melting point, high tensile strength, high compressive strength, a high dynamic modulus. The materials for the defending target should be plastic rather than elastic. They should be heat resistant, tough, strong and plastic. No one material known provides these characteristics. In this study, combinations of materials are suggested to meet these stringent requirements.

The characteristics of various materials are tabulated in the following tables.

Table	Title
IIa (6 pages)	Specific Gravities and Weights
IIb	Mechanical Properties of Representative Plastics
IIc	Sound in Solids
IId	Physical Properties of Metals
IIe	Condensed Tabulation of Mechanical Properties, Alloys of Steel.
IIf	Mechanical Properties of Aluminum Alloys
IIg	Mechanical Properties of Magnesium Alloys
IIh	Changes in Mechanical Properties of Plastics with Decreasing Temperatures

d. Terrestrial Environment of Structures (Figure 30)

The terrestrial environment, more than any other factor, influences the configuration of the facility, its cost and its performance. Because of the importance associated with placing the facility in the environment which enhances its performance, it is necessary at this juncture, to discuss the advantages and disadvantages of above ground and buried

TABLE II A

SPECIFIC GRAVITIES AND WEIGHTS

Substance			Specific Gravity	Weight, Lb/cu ft.
METAL OR COMPOSITION				
Aluminum			2.70	168.5
Antimony			6.52	413.0
Barium			3.78	235.9
Beryllium			1.85	115.5
Bismuth			9.63	610.3
Boron			2.53	158.2
Brass:	80C.,	20Z	8.6	536.6
	70C.,	30Z	8.44	526.7
	60C.,	40Z	8.35	521.7
	50C.,	50Z	8.19	511.7
Bronze:	90C.,	10T	8.77	547.9
Cadmium			8.64	539.6
Calcium			1.54	96.1
Chromium			6.92	432.4
Cobalt			8.70	543.5
Copper			8.89	554.7
Gold			19.28	1204.3
Iridium			22.4	1399.0
Iron, cast			7.02 - 7.73	438.7 -- 482.4
Iron, wrought			7.8 - 7.9	486.7 -- 493.0
Lead			11.32	707.7
Magnesium			1.74	108.6
Manganese			7.30	455.5
Mercury (68° F)			13.54	845.3
Molybdenum			10.20	636.5
Nickel			8.80	549.1
Platinum			21.33	1333.5
Potassium			0.87	54.3
Silver			10.40 - 10.52	650.2 -- 657.1
Sodium			0.97	60.6
Steel, Carbon			7.83 - 7.86	489.0 -- 490.8
Tantalum			16.60	1035.8
Tellurium			6.25	390.0
Tin			7.29	454.9
Titanium			4.49	280.1
Tungsten			18.60 - 19.10	1161 -- 1192
Uranium			18.69	1166.9
Vanadium			6.32	394.4
Zinc			7.04 - 7.15	439.3 -- 446.8
Zirconium			6.49	405

Substance	Specific Gravity	Weight Lb/cu ft.
*GASES,	Density relative to air:	
Air, 0°C, 760 mm	1.0	0.08071
Ammonia	0.5920	0.0478
Carbon dioxide	1.5291	0.1234
Carbon monoxide	0.9673	0.0781
Gas, illuminating	0.35 - 0.45	0.028 - 0.036
Gas, natural	0.47 - 0.48	0.038 - 0.039
Helium	0.137	0.0105
Hydrogen	0.0693	0.00559
Nitrogen	0.9714	0.0784
Oxygen	1.1056	0.0892
ASHLAR MASONRY		
Granite, syenite, gneiss	2.3 - 3.0	165
Limestone, marble	2.3 - 2.8	160
Sandstone, bluestone	2.1 - 2.4	140
MORTAR RUBBLE MASONRY		
Granite, syenite, gneiss	2.2 - 2.8	155
Limestone marble	2.2 - 2.6	150
Sandstone, bluestone	2.0 - 2.2	130
DRY RUBBLE MASONRY		
Granite, syenite, gneiss	1.9 - 2.3	130
Limestone, marble	1.9 - 2.1	125
Sandstone, bluestone	1.8 - 1.9	110
BRICK MASONRY		
Pressed brick	2.2 - 2.3	140
Common brick	1.8 - 2.0	120
Soft brick	1.5 - 1.7	100
CONCRETE MASONRY		
Cement, stone, sand	2.2 - 2.4	144
Cement, slag, etc	1.9 - 2.3	130
Cement, cinder, etc	1.5 - 1.7	100
VARIOUS BUILDING MATERIAL		
Ashes, cinders	—	40 - 45
Cement, portland, loose	—	90
Cement, portland, set	2.7 - 3.2	183
Lime, gypsum, loose	—	53 - 64
Mortar, set	1.4 - 1.9	103

* For gases specific gravity is relative to air instead of water

SPECIFIC GRAVITIES AND WEIGHTS (cont.)

Substance	Specific Gravity	Weight, Lb/cu ft.
Greenstone, trap	2.8 - 3.2	187
Gypsum, alabaster	2.3 - 2.8	159
Hornblende	3.0	187
Limestone, marble	2.5 - 2.8	165
Magnesite	3.0	187
Phosphate rock, apatite	3.2	200
Porphyry	2.6 - 2.9	172
Pumice, natural	0.37 - 0.90	40
Quartz, flint	2.5 - 2.8	165
Sandstone, bluestone	2.2 - 2.5	147
Shale, slate	2.7 - 2.9	175
Soapstone, talc	2.6 - 2.8	169
STONE, QUARRIED, PILED		
Basalt, granite, gneiss	–	96
Limestone, marble, quartz	–	95
Sandstone	–	82
Shale	–	92
Greenstone, hornblende	–	107
BITUMINOUS SUBSTANCES		
Asphaltum	1.1 - 1.5	81
Coal, anthracite	1.4 - 1.7	97
Coal, bituminous	1.2 - 1.5	84
Coal, lignite	1.1 - 1.4	78
Coal, peat, turf, dry	0.65 - 0.85	47
Coal, charcoal, pine	0.28 - 0.44	23
Coal, charcoal, oak	0.47 - 0.57	33
Coal, coke	1.0 - 1.4	75
Graphite	1.9 - 2.3	131
Paraffine	0.87 - 0.91	56
Petroleum	0.87	54
Petroleum, refined	0.79 - 0.82	50
Petroleum, benzine	0.73 - 0.75	46
Petroleum, gasoline	0.66 - 0.69	42
Pitch	1.07 - 1.15	69
Tar, bituminous	1.20	75

Substance	Specific Gravity	Weight Lb/cu ft.
Slags, bank slag	–	67 - 72
Slags, bank screenings	–	98 - 117
Slags, machine slag	–	96
Slags, slag sand	–	49 - 55
EARTH, ETC., EXCAVATED		
Clay, dry	–	63
Clay, damp, plastic	–	110
Clay and gravel, dry	–	100
Earth, dry, loose	–	76
Earth, dry, packed	–	95
Earth, moist, loose	–	78
Earth, moist, packed	–	96
Earth, mud, flowing	–	108
Earth, mud, packed	–	115
Riprap, limestone	–	80 - 85
Riprap, sandstone	–	90
Riprap, shale	–	105
Sand, gravel, dry, loose	–	90 - 105
Sand, gravel, dry, packed	–	100 - 120
Sand, gravel, dry, wet	–	118 - 120
EXCAVATION IN WATER		
Sand or gravel	–	60
Sand or gravel and clay	–	65
Clay	–	80
River mud	–	90
Soil	–	70
Stone riprap	–	65
MINERALS		
Asbestos	2.1 - 2.8	153
Barytes	4.50	281
Basalt	2.7 - 3.2	184
Bauxite	2.55	159
Borax	1.7 - 1.8	109
Chalk	1.8 - 2.6	137
Clay, marl	1.8 - 2.6	137
Dolomite	2.9	181
MINERALS (Continued)		
Feldspar, orthoclase	2.5 - 2.6	159
Gneiss, serpentine	2.4 - 2.7	159
Granite, syenite	2.5 - 3.1	175

Substance	Specific Gravity	Weight Lb/cu ft.
VARIOUS SOLIDS		
Cork	–	14 -- 16
Carbon, Graphite	–	140
Rubber, Hard	–	74
Commercial	–	69
Gum	–	57 -- 58
Glass, flint	–	180 -- 370
Glass, common	2.40 - 2.60	156
Glass, plate or crown	2.45 - 2.72	161
Glass, crystal	2.90 - 3.00	184
Leather	0.86 - 1.02	59
Paper	0.70 - 1.15	58
Rubber, caoutchouc	0.92 - 0,96	59
Rubber goods	1.0 - 2.0	94
Sulphur	1.93 - 2.07	125
TIMBER, U. S. SEASONED		
Balsa	0.11 - 0.14	7 - 9
Ash, white-red	0.62 - 0.65	40
Cedar, white-red	0.32 - 0.38	22
Chestnut	0.66	41
Cypress	0.48	30
Fir, Douglas spruce	0.51	32
Fir, eastern	0.40	25
Elm	0.72	45
Hemlock	0.42 - 0.52	29
Hickory	0.74 - 0.84	49
Locust	0.73	46
Maple, hard	0.68	43
Maple, white	0.53	33
Oak, chestnut	0.86	54
Oak, live	0.95	59
Oak, red, black	0.65	41
Oak, white	0.74	46
Pine, Oregon	0.51	32
Pine, red	0.48	30
Pine, white	0.41	26
Pine, yellow, long-leaf	0.70	44
Pine, yellow, short-leaf	0.61	38
Poplar	0.48	30

Substance	Specific Gravity	Weight Lb/cu ft.
TIMBER, U. S. SEASONED (Continued)		
Redwood, California	0.42	26
Spruce, white, black	0.40 - 0.46	27
Walnut, black	0.61	38
Walnut, white	0.41	26
[Moisture Contents: Seasoned timber 15 to 20% Green timber up to 50%]		
CERAMICS		
Elec. Porcelain	2.5	156
Hi Alumina	3.8	237
Sintered Alumina	4.0	249
Cemented Carbide	13.5	842
Thorium Oxide	10	624
VARIOUS LIQUIDS		
Alcohol, 100%	0.79	49
Acids, nitric 91%	1.50	94
Acids, sulphuric 87%	1.80	112
Oils, mineral, lubricants	0.90 - 0.93	57
Water, 4°C, max. density	1.0	62.426
Water, 100° C	0.9584	59.830
Water, ice	0.88 - 0.92	56
Water, snow, fresh fallen	0.125	8
Water, sea water	1.02 - 1.03	64
Liquid Oxygen 184° F		71.4
Liquid Nitrogen 195° F		50.5
Acetone 20°C		49.4
Alcohol (methyl) 0°C	Refer to water density at proper temperature	50.5
Benzene 0° C		56.1
Carbon Tetrachloride 20° C		99.6
Gasoline		41.0 - 43.0
Glycerin 0° C		78.6
Kerosene		51.2
Mercury		849.0
Turpentine		54.3
Water 0° C		62.422
Water (SP. GR. = 1.0000) 4° C		62.43
Water 20° C		62.319

TABLE II B

MECHANICAL PROPERTIES OF REPRESENTATIVE PLASTICS

	Tensile Strength, psi	Compressive Strength, psi	Flexural Strength, psi	Impact Strength Izod, ft lbs/in. notch	Specific Gravity	Heat Distortion (264 psi), deg F	Modulus of Elasticity, psi x 10^6	Coefficient of Thermal Expansion, per C x 10^{-5}
UNCOMPOUNDED PLASTICS								
Epoxy	12,000	17,000	20,000	0.5	1.2	210	4.5	—
Nylon	10,500	—	13,800	1.0	1.14	360	2.0 - 4.0	10 - 15
Melamine	9,000	40,000	13,000	0.4	1.5	—	—	—
Polyvinyl chloride (rigid)	8,000	10,000	13,000	0.7	1.4	165	5.6	5 - 6
Modified styrene copolymers	8,000	—	15,000	0.5	1.05	190	4 - 6	3.5 - 12
Phenolic	7,500	15,000	15,000	0.3	1.3	—	7 - 10	2.5 - 6
Urea	7,500	30,000	14,000	0.3	1.5	—	15	2.5 - 3.0
Vinyl chloride acetate (rigid)	7,000	10,000	13,000	0.6	1.4	145	3.5	7 - 17
Methyl methacrylate (acrylic)	7,000	12,000	13,000	0.5	1.2	170	4.5	9
Polystyrene	7,000	16,000	11,000	0.35	1.05	185	4 - 6	7
Polyester	6,000	20,000	12,000	0.3	1.3	—	3 - 6.5	5.5
Cellulose acetate	6,000	20,000	—	2.0	1.3	145	2.5 - 3.0	8 - 16
Styrene-rubber blends	5,000	7,000	9,000	8.0	1.05	175	1.8 - 4.0	6 - 13
Silicone	4,000	9,000	8,000	8.0	1.7	550	—	2.0
Alkyd	3,500	19,000	9,000	0.3	2.2	375	—	—
Polytetrafluoroethylene	1,800	—	—	3.0	2.2	270	0.5 - 0.6	10
Polyethylene (general purpose)	1,300	—	—	—	0.92	175	0.25 - 0.50	17
Polyethylene (high density)	3,200	—	—	2.5	0.93	250	—	—
GLASS FABRIC REINFORCED PLASTICS								
Polyester	40-50,000	30-60,000	50-63,000	19 - 35	1.6 - 2.0	300/400	1 - 2.8	
Epoxy	33-46,000	50-90,000	45-80,000	6 - 16	1.7 - 1.9	300/360	2.5 - 3.5	
Melamine	20-50,000	30-65,000	28-55,000	5 - 15	1.82 - 1.98	300	—	
Phenolic	11.5-40,000	42-60,000	20-40,000	3 - 16	1.5 - 2.1	290	1.0 - 2.0	
GLASS-FILLED PREMIX MOLDING COMPOUNDS								
Polyester	4-10,000	20-26,000	5-25,000	3 - 6	1.7 - 2.0	300	1.6 - 2.0	
Melamine	6-10,000	10-25,000	9-20,000	8 - 12	1.9 - 2.0	300	—	
Phenolic	7-10,000	17-26,000	18,000	12 - 50	1.75 - 1.95	350/450	3.3	
Polystyrene	10,500	14,500	12,000	2	1.3	—	1.28	

TABLE II C

SOUND IN SOLIDS

The velocity of sound in solids is determined by the shape and size of the bounded medium as compared with the wavelength of the excitation. For rods or square bars with unconstrained sides, the velocity of propagation varies with the ratio of thickness to wavelength, being, for a wavelength in diameter, about 0.66 times the zero-diameter-to-wavelength ratio.

Material	Velocity	
	cm/sec x 10^5	ft/sec
Aluminum	5.24	17180
Antimony	3.40	11150
Beryllium	16.53	42000
Bismuth	1.79	5870
Brass	3.42	11220
Cadmium	2.40	7870
Constantan	4.30	14100
Copper	3.58	11740
German Silver	3.58	11740
Gold	2.03	6660
Iridium	4.79	15710
Iron	5.17	16950
Lead	1.25	4100
Magnesium	4.90	16060
Manganese	3.83	12560
Nickel	4.76	15610
Platinum	2.80	9180
Silver	2.64	8655
Steel	5.05	16560
Tantalum	3.35	10980
Tin	2.73	8950
Tungsten	4.31	14140
Zinc	3.81	12480
Cork	0.50	1640
Crystals		
Quartz X-cut	5.44	17840
Ammonium di-hydrogen phosphate (NH H PO)		
45° Z-cut	3.28	10760
Rochelle salt (sodium potassium tartrate)		

Material	Velocity	
	cm/sec x 10^5	ft/sec
Crystals, (cont.)		
KNaC H O . 4H O		
45° Y-cut	2.47	8100
45° X-cut	2.47	8100
Calcium fluoride (CaF fluorite)		
X-cut	6.74	22100
Sodium chloride (NaCl, rock salt)		
X-cut	4.51	14780
Sodium bromide (NaBr)		
X-cut	2.79	9145
Potassium chloride (KCl, sylvite)		
X-cut	4.14	13570
Potassium bromide (KBr)		
X-cut	3.38	11080
Glasses		
Heavy flint	3.49	11440
Extra-light flint	4.55	14920
Crown	5.30	17380
Heaviest crown	4.71	15440
Quartz	5.37	17600
Granite	3.95	12950
Ivory	3.01	9865
Marble	3.81	12480
Slate	4.51	14790
Wood		
Elm	1.01	3310
Oak	4.10	13440

TABLE II D

PHYSICAL PROPERTIES OF METALS

	Melting Point, deg F	Boiling Point, deg F	Specific Gravity	Density, lb/ cu in.
Aluminum	1217	3272	2.67	0.09 - 0.1
Antimony	1166	2624	6.76	0.24
Beryllium	2345	5032	1.85	.066
Brass	1650	—	(7.8) (8.6)	.28 .31
Bronze	1650	—	(8.52) (8.96)	.30 .32
Cadmium	609	1409	8.65	.313
Cesium	83	1275	1.9	.069
Cobalt	2723	5250	8.55	.32
Copper	1981.4	5050	8.85	.319
German Silver	1850	—	(8.5)	.307
Gold	1945.5	3992	19.258	.695
Iridium	4280 - 313	3789	22.38	.808
Iron	2786	4442	7.9	.28
Iron, Cast	(1900) (2200)	—	7.22	.26
Iron, Wrought	2700 - 29[illegible]	—	7.70	.278
Lead	621.3	(2900) (3600)	11.38	.411
Lithium	354	2403	0.53	.019
Magnesium	1204	2048	1.75	.063
Manganese	2246	3452	8.0	.289
Mercury	-37.97	680	13.58	.490
Molybdenium	4760	8670	10.2	.368
Nickel	2642	—	8.8	.317
Niobium	4380	—	8.57	.31
Palladium	2822	7200	12.0	.433
Platinum	3191	7970	21.5	.776
Silver	1760.9	3550	10.51	.379
Sodium	208	1620	0.97	.035
Steel	2550	—	7.9	.28
Sulfur	239	833	2.07	.075
Tantalum	5250	—	14.1 - 16.1	.6
Tin	449.4	4118	7.35	.264
Titanium	3260	—	3.54	.16
Tungsten	6152	10700	18.8	.697
Zinc	786.9	1663	7.14	.258
Zirconium	3355	—	6.57	.23

REF 52

TABLE II D (Cont.)

PHYSICAL PROPERTIES OF METALS...

Specific Heat	Atomic Weight	Heat Conductivity, Silver = 100	Electrical Conductivity, Silver = 100	Cubical Expansion by Heat from 130°F to 212°F	Typical Tensile Strength, psi
0.215	27.1	48	53.0	0.0070	18,000
.050	120.2	4.2	3.5	0.027 - 0.050	1,000
—	—	—	10	—	30-90,000
.092	—	(15)	23	0.0057	9,000
—	—	(30)	17	.0064	40,000
.086	—	—	—	(.0051)	3,000
—	—	—	—	(.0057)	25,000
.055	112.4	22.2	—	—	--
.052	132.9	—	—	—	—
.099	58.97	—	19.9	.0037	34,400
.093	63.57	89	99.5	.0051	30,000
.095	—	8	10 - 32	.0055	—
.032	197.2	53.2	76.7	.0044	14,000
.032	193.1	34	30	.0020	—
.113	55.84	11 - 18	9.9 - 17.0	.0036	39,500
.1298	—	11.9	(2.8) (1.4)	.0033	—
.1138	—	—	17	.0035	50,000
.031	207.20	8.2	7.6	.0088	(1,600) (2,400)
.79	6.94	—	—	—	—
.025	24.32	37.6	35.8	.0083	20,000
.115	54.93	—	—	—	—
.033	200.6	1.8	1.7	.0182	—
.061	95.95	34.6	34	—	54-100,000
.109	58.68	14	(14.5) (9.9)	.0038	(50,000) (100,000)
.065	92.9	—	—	—	—
.058	106.7	17	15	.0036	50,000
.032	195.2	17	(20) (10)	.0027	(30,000) (50,000)
.057	107.88	100	100	.0058	36,000
.295	22.99	—	—	—	—
.117	—	(6)	16	.0041	50,000
		(14)	3	.0030	20,000
.175	32.07	—	—	—	—
.036	181.5	—	9.9	.0024	—
.056	118.7	15.2	11.3	.0069	5,000
.130	48.1	—	13.7	—	—
.033	184.0	—	23.	—	500,000
.096	65.37	28.1	26	.0088	9,000 - 24,000
.069	91.22	—	4.3	—	—

REF 52

TABLE II E

CONDENSED TABULATION OF MECHANICAL PROPERTIES OF ALLOY STEELS

Commercial Designation	Form	Condition	Tensile Strength (psi)	Yield Strength 0.2% Offset (psi)	Elongation (% in 2 in.)	Hardness (Brinell)	Miscellaneous Information
SAE-4130	Sheet, plate, tube, bar & rod	$t < 0.188''$	95,000	75,000	25.5	197	Elongation & hardness is for 1" rd.
SAE-4130	Plate and bar	Annealed $t < 1.50''$	65,000	45,000	28.2	156	Elongation & hardness is for 1" rd.
SAE-4130	Sheet, plate, tube & rod	Heat-treated	150,000	135,000	16	306	
SAE-4340	Sheet	Heat-treated	236,000	212,000	10		Red. area—35%
18-8	Sheet and strip	Annealed	75,000	30,000			
18-8	Sheet and strip	Cold-rolled ½ hard	150,000	110,000			
18-8	Sheet and strip	Cold-rolled & heat-treated ½ hard	150,000	120,000			
18-8 (Type 304)	Sheet	Annealed	85,000	30,000	55-63	160	
18-8 (Type 304)	Sheet	Cold-rolled	185,000	160,000	8	400	Sample sheet
18-8 (Type 316)	Sheet	Annealed	90/100,000	35/45,000	50-60	170/200	
Inconel X	Sheet and strip (Gauges 0.025" to 0.250")	Annealed	100/140,000	40/80,000	35-60	140/241	
Inconel X	Sheet and strip (Gauges 0.025" to 0.250")	Annealed & aged	150/175,000	100/130,000	20-30	293/372	
Inconel X	Sheet	Annealed	120,000	55,000	50	175	Sample sheet
Inconel X	Sheet	Hot-rolled	188,000	130,000	23	355	Sample sheet

REF 52

TABLE II F

CONDENSED TABULATION OF MECHANICAL PROPERTIES OF ALUMINUM ALLOYS

Commercial Designation	Form	Condition	Tensile Strength (psi)	Yield Strength 0.2% Offset (psi)	Elongation (% in 2 in.)	Hardness (Brinell)	Miscellaneous Information
2024-T3 (24S-T3)	Sheet and plate	Heat-treated 0.250"	65,000	48,000	15	—	
2024-T4 (24S-T4)	Rolled bar, rod and shapes	Heat-treated 3.0"	62,000	40,000	16	—	
2024-T3 (24S-T3)	Tubing	Heat-treated	64,000	42,000	12	—	
2024-T81 (24S-T81)	Tubing	Heat-treated, cold worked and aged	68,000	60,000	—	—	
2024-T4 (24S-T4)	Extruded shapes	Heat-treated 0.250"	57,000	42,000	12	—	
2024-T81 (24S-T81)	Extruded shapes	Heat-treated, cold worked and aged	64,000	56,000	—	—	
2024-T36 (24S-T36)	Sheet	Wrought	72,000	57,000	14	130	
2024-T36 (24S-T36)	Alclad	Heat-treated & rolled	67,000	53,000	11	—	
2024-T86 (24S-T86)	Alclad	Artificially aged	70,000	66,000	6	—	
7075-T6 (75S-T6)	Sheet and plate	Heat-treated and aged 0.040-0.249"	77,000	67,000	8	—	
7075-T6 (75S-T6)	Rolled bar, rod & shapes	Heat-treated and aged—3.0"	77,000	66,000	7	—	
7075-T6 (75S-T6)	Extruded bar rod & shapes	Heat-treated and aged. Up to 0.249"	78,000	70,000	7	—	
7075-T6 (75S-T6)	Hand-forged stock	Cross section area —16 sq in.	75,000	64,000	9	—	
7075-T6 (75S-T6)	Die forgings	Thickness—4"	75,000	65,000	10	135	
7075-T6 (75S-T6)	Sheet	Wrought	82,000	72,000	11	150	

REF 52

TABLE II G

CONDENSED TABULATION OF MECHANICAL PROPERTIES OF MAGNESIUM ALLOYS

Commercial Designation	Form	Condition	Tensile Strength (psi)	Yield Strength 0.2% Offset (psi)	Compression Yield (psi)	Elongation (% in 2-in.)	Hardness (Brinell)	Miscellaneous Information
FS-1	Sheet	H 24	42/39,000	32/29,000	27/25,000	16-4	73	Dow desig.
FS-1	Sheet	O/F	37/32,000	22/18,000	16/12,000	21-12	56	
MH	Sheet	—	37/32,000	29/22,000		8-4	56	
AZ31B	Extruded rods, bars & solids	F	37,000	26,000	15,000	12	49	
	Sheet and plate	O	37,000	22,000	16,000	21	56	
		H 24	42,000	32,000	27,000	16	73	
O-1	Extrusion	—T 5	52/48,000	36/30,000	28/24,000	5-4	82	
ZK 60A	Extrusion	F	49/43,000	38/31,000		12-5	75	
		—T 5	51,000	42,000	30,000	10	82	
AZ63A	Casting	F	23,000	14,000	14,000	6	50	
		—T 6	40,000	19,000	19,000	5	73	
EK 30A	Casting	—T 6	20,000	15,000		3		High-temp. alloy
		@ 400 °F	17,000	10,000		15		
HK31XA	Casting	—T 2	37,000	18,000		8		High-temp. alloy
		@ 400 °F	26,000	14,000		17		
		@ 600 °F	20,000	12,000		22		
AZ91A	Die casting	F	33,000	22,000	20,000	3	60	
HM21XA	Extrusion	—T 5	38,000	30,000	24,000	7		
		@ 400 °F	21,000	19,000				
		@ 600 °F	15,000	13,000.				

O = annealed
H 24 = hard rolled
F = as fabricated

—T 5 = aged
—T 2 = as cast and stabilized
—T 6 = solution heat treated and aged

REF 52

TABLE II H

CHANGE OF MECHANICAL PROPERTIES OF PLASTICS WITH DECREASING TEMPERATURE

i - Increases with decreasing temperature

n - No change with decreasing temperature

d - Decreases with decreasing temperature

Material Group	Approximate Room Temp. Values and Behavior with Decreasing Temperature				
	Ultimate Tensile Strength, 1000 psi	Elongation, %	Mod. of Elasticity, 10^6 psi	Work to Produce Failure, Ft lb/in.^{3}	Izod Impact, Ft lb/in. of notch
Thermosetting, laminated, glass fabric base*	30. i	1.5 i	2. n	25. i	10. i
Thermosetting, laminated paper base	20. i	1.5 d	1.5 i	20. d	1. d
Thermosetting, laminated cotton base	12. i	4. d	1. i	30. d	2. d
Thermosetting, molded, phenolics	5. i	1. d	1.5 i	2. d	2. d
Thermosetting, molded, miscellaneous	5. n	.4 d	2. i	2. d	.3 n
Thermosetting, cast, miscellaneous	6. i	1.5 d	.5 i	5. d	.3 n
Thermo plastic, cellulose acetates	4. i	12. d	.3 i	30. d	3. d
Thermo plastic, cellulose acet. butyrates	5. i	15. d	.3 i	60. d	3. d
Thermo plastic, cellulose propionate	6. i	13. d	.3 i	60. d	3. d
Thermo plastic, ethyl cellulose	5. i	6. d	.2 i	20. d	3. d
Thermo plastic, cellulose nitrate	9. i	15. d	.2 i	100. d	2.5 d
Thermo plastic, polystyrene	6. i	5. d	.4 i	20. d	.5 d
Thermo plastic, polymethyl methacrylate	10. i	6. d	.4 i	37. d	.4 n

*Stronger and stiffer laminates are available. Ex.: 91-LD phenolic resin-fiberglass laminate, 181-114 cloth. $F_{t_u} \sim 60$, $E \sim 4$.

REF 52

ENVIRONMENT OF STRUCTURES

- ENTIRELY ABOVE GROUND
- ABOVE GROUND AND REVETTED/COVERED
- PARTLY BURIED
- PARTLY BURIED AND REVETTED
- PARTLY BURIED AND COVERED
- TOTALLY UNDERGROUND

FIGURE 30

structures (and combinations thereof) with respect to their use. Table III, "Terrestrial Environment of Structures" summarizes the cogent features associated with placing different types of structures in the various terrestrial environments. From the table, it is initially concluded that aircraft shelters should be placed in an above ground environment and covered with protective materials. Protection of stored POL is enhanced by placing it entirely underground. Barracks and Command, Control and Communications (C^3) facilities should be initially placed in a partly buried environment. If the intensity of conflict increases, the partly buried structure should be covered with protective materials. It should be configured so that it can accept the loads imposed by the addition of these materials.

e. Degree of Acceptable Risk

The risk a commander takes by not providing adequate passive protection for aircraft, personnel and equipment will vary in each specific battle situation. It is possible, however, to show the cost effect of providing shelters relative to the threat. From Figure 12 "Cost of Shelters for Aircraft," it can be seen that the cost of providing 70 arch-type shelters having three sides is $4,250,000. (Approximately $60,000 each). Without shelters, the U.S. would sustain a loss of about $5,200,000 in aircraft, facilities and equipment after a total of approximately 17 cumulative rounds of 122 mm rockets (assume delay fusing on 8 of the rockets) and 17 cumulative mortars are directed against the ramp area of a tactical air base. It

TABLE III A

TERRESTRIAL ENVIRONMENT OF STRUCTURES

	AIRCRAFT SHELTER	POL STORAGE	BARRACKS	(C[3]) COMMAND CONTROL & COMMUNICATION
ABOVE GROUND	Advantages: • Easy Entrance and Exit • Inexpensive • Good Ventilation • Easy Maintenance • Operationally Preferred Disadvantages: • Minimum Protection	Advantages: • Same as above Ground - less Maintenance • Provides limited protection • Mobile Disadvantages: • Protection is function of strength/thickness of materials used in cover • More expensive	Advantages: • Pleasant Human Factor Conditions • Quick Erection • Good Ventilation • Inexpensive • Easy Access for Maintenance Disadvantages: • Vulnerable	Generally the same advantages and disadvantages as for barracks
ABOVE GROUND AND REVETTED (including covered with earth)	Advantages: • Same as above ground • Gives Protection Disadvantages: • Protection given is limited to strength of revet and/or cover and strength of structure • Added cost	Advantages: • Same as above ground - less maintenance • Provides limited protection • Mobile Disadvantages: • Protection is function of strength/thickness of materials used in cover • More expensive	Advantages: • Provides more protection than above ground and partle burried and reveted Disadvantages: • Ventilation • Added Expense • Heavier structure • Maintenance Difficult	As above

TABLE III B

TERRESTRIAL ENVIRONMENT OF STRUCTURES

	AIRCRAFT SHELTER	POL STORAGE	BARRACKS	(C^3) COMMAND CONTROL AND COMMUNICATION
PARTLY BURRIED	Advantages: • Protects lower vulnerable portions of A/C Disadvantages: • Ramp required • Added cost • H_2O Intrusion via Ramp • Increased maintenance costs • Entrapment of volatile materials	Advantages: • Protects tower portion of tanks or bladders Disadvantages: • Not totally protected • Relatively expensive • Immobile	Advantages: • Protective bottom floor if multi-storied • Good against initial threat • Ventilation better than above ground and revetted • cover • Protection against larger threat • Capable of expansion Disadvantages: • Leaves upper level and top unprotected	Generally the same advantages and disadvantages as for barracks
PARTLY BURRIED AND REVETTED	Advantages: • Protects entire A/C from hit except direct from overhead Disadvantages: • Same as for Partly buried • Maintenance may become more difficult • Top of facility is unprotected	Advantages: • Protects sides of tanks and/or bladders Disadvantages: • Top is unprotected • Drainage system is necessary • Expensive • Immobile	Advantages: • Protects entire sides Disadvantages: • Top remains unprotected • Cost is high • Ventilation	As above

TABLE III C

TERRESTRIAL ENVIRONMENT OF STRUCTURES

	AIRCRAFT SHELTER	PCL STORAGE	BARRACKS	(C^3) COMMAND CONTROL AND COMMUNICATION
PARTLY BURIED AND COVERED WITH EARTH	Advantages: • Protects A/C from all angels of attack but level of protection is only slightly better than above ground and covered Disadvantages: • Expensive • Structure must be stressed to take surcharge	Advantages: • Provides almost same overall protection as totally buried • Comparable cost with partly buried and revetted Disadvantages: • Maintenance Difficulty • High cost • Immobile	Advantages: • Protects entire structure Disadvantages: • Walls and roof inaccessable for maintenance and repair • Poor ventilation and access • Cost is high	Generally the same advantages and disadvantages as for barracks
TOTALLY BURIED	Advantages: • Provides best protection of all options Disadvantages: • Longer and/or steeper ramp • Most expensive option • All other disadvantages same as partly buried	Advantages: • Almost complete protection Disadvantages: • Immobile • Difficult to maintain • Very Expensive	Advantages: • Provides total protection at the outset Disadvantages: • Takes most time to build • Most expensive • Maintenance and Repair difficulty	Same as above

would be advisable to provide shelters of three sides so that they will be in place by the time the "break-even" point of a combination of 34 cumulative rounds is expected to be reached. By the same token, shelters with closures should be deployed by the time approximately 42 cumulative hostile rounds are expected because the cost of the protection afforded by the shelters with their closure will be amortized at that point. It is interesting to note that the cost of equipping shelters with closures vs. continuing with shelters with no protective doors is not amortized until about the 130th cumulative round. If the threat is changed so that the enemy uses only rockets with delayed fuses, he must now switch from area targets to "point" targets. The change to this tactic complicates the passive defense problem because the defender must now increase the level of protection by "thickening" the protective materials with an attendant increase in the cost for each structure. The attacker, on the other hand, must improve his CEP, commit more weapons, or a combination of the two. This is also a costly course of action. Under the "all delayed fuse threat" the defender can affort to do without shelters until the cumulative number of rockets reaches 72. When that point is reached, the defender should have shelters in place whose three sides are capable of repelling or at least containing the delayed fused rocket. By the time approximately 105 cumulative delayed fuse rockets are expected, the three-sided shelter should be provided with doors. In this discussion, the cost used for shelters in both the instantaneous and delayed fuse environments were assumed to be the same.

It is concluded, therefore, from a cost standpoint, that the degree of acceptable risk is a function of the cumulative number of rounds and the cost to defend against them. It should appear to be in the best interest of the defender to have shelters for aircraft constructed and in operation at least by the time the "break-even" points discussed above are reached.

Other factors, such as the "utile" value of the aircraft vis-a-vis the tactical situation may dictate that shelters be provided at an earlier time.

f. Desired Capabilities for Form of Facilities

The features of concepts which are desirable (in some cases undesirable) are discussed in the following paragraphs. (Figure 31, "Desired Capabilities"). These features were used as selection criteria for arriving at the preferred concept.

(1) Design

For the purpose of evaluating the various concepts with respect to design, the following subsets of design are used:

- Simplicity
- Reliability
- Redundancy
- Adaptability

DESIRED CAPABILITIES
(SELECTION CRITERIA)

FACILITY SHOULD:

- RESIST BATTLE DAMAGE AND FIRE (PROTECT AGAINST THREAT)
- BE SIMPLE DESIGN
- HAVE AN EARLY IOC
- BE AIR TRANSPORTABLE
- BE STORABLE OUTSIDE
- SIMPLE TO FABRICATE
- SIMPLE TO ERECT AND MAINTAIN
- BE SIZED TO ACCEPT BARE BASE MODULES, IF REQUIRED
- ENHANCE OPERATIONS
- EASILY REPAIRABLE FROM BATTLE DAMAGE
- BE CAPABLE OF ACCEPTING ADDITIONAL PROTECTIVE MATERIALS
- USE MATERIALS EFFICIENTLY (INDIGENOUS WHERE PRACTICAL)
- CONFORM TO FOREIGN POLICY
- HAVE LOW TOTAL COST

FIGURE 31

- Growth potential

- Ability of conversion to other uses

- Substitution of structural components within a single structure and other structures

- Low cost

The above facets become important with the realization that:

- The structures are to be erected by field forces

- It is difficult to predict the variation of battle situations

- The uses of facilities may change as conflict intensifies decreases and

- Manpower efforts devoted to resolving logistic problems in time of war often equal or exceed those devoted to operational tasks.

(a.) <u>Simplicity</u>

Simplicity of design is a relative term. A measure of simplicity is the repeatability of identical modules of simple detail throughout the structure and their basic application to other facilities.

(b.) <u>Reliability</u>

Reliability refers to those features and methods of design that have a proven history of successful and reliable application. New unproven techniques, worthy of possible development, should be explored for reliability. Concepts possessing only enough reliability for the task performed are preferred from a cost standpoint.

(c.) Redundancy

Redundancy is that feature of design which, in case of failure of one part, enables other parts of the structure to accept the load safely. Redundancy, within reasonable cost, is a desirable feature.

(d.) Adaptability

Adaptability of design is that attribute which permits the structure to be used for more than one function or purpose. Adaptability also refers to the ability of the structure to be placed in terrestrial environments other than above ground. A scheme that has a high degree of adaptability is preferable to concepts with little or no adaptability.

(e.) Growth

Growth characteristics permit the structure to be changed to accept escalation in the threat. Inherent in growth is the ability of the structure to be enlarged to accept objects of changed dimensions over which it was originally designed. Concepts with a good growth potential are desirable.

(f.) Conversion

Conversion is the ability to change the function of the building from one purpose to another with minimum modifications. Another facet of conversion is the capability to use components or whole sections of the structure for another complete function (e.g., Using structural system originally designed for an aircraft shelter for a warehouse or barracks).

(g.) Substitution

Substitution is the ability of various components within the structure to be interchanged.

(h.) Low Cost

Cost is a function of all the other attributes discussed heretofore with respect to design.

(2) Manufacturing

The term manufacturing as used in this effort refers to the making of components of the structure from raw materials. There is a fine line of distinction to be drawn between manufacturing and fabrication. For the definition of fabrication, see paragraph (5) below. Some of the attributes of manufacturing that will be discussed are: Simplicity, productivity, tooling and low cost.

(a.) Simplicity

Simplicity of manufacturing is the degree of component repetition and ease which a plant encounters in the manufacturing process. Simplicity is also measured by the presence of product stability and the absence of close tolerances.

(b.) Productivity

Productivity refers to the ability to utilize mass production tools and techniques in producing the manufactured components.

(c.) Tooling

Some designs may require special tooling in the manufacturing process. Special tooling is normally required when complex shapes or components are specified or a new method or material is utilized. Tooling also influences productivity, complexity and cost.

(d.) Low Cost

Cost is the absolute number of dollars associated with manufacturing and is influenced by the manufacturing processes above. A high cost of manufacturing is not necessarily deleterious because of the trade-off opportunities between manufacturing costs and fabrication and erection costs.

(3) Shipping

The transfer of a structure from the place of manufacture and/or fabrication to the geographical location of use is "shipping." Modes of shipping chosen for this study are by aircraft, ship and trucks and railroads as representative. Shipping is measured by packageability of the product, freight, handling and the ability of the shipment to be diverted to another location during transit.

(a.) Packageability

The efficiency with which components of a structure can be stacked in standardized shipping containers (of all categories) is packageability.

(b.) Freight

Freight is the cost of placing the fabricated structure on the carrier, transporting it to its destination and then unloading it on the site.

(c.) Handling

Handling refers to the degree of ease with which the packaged structures are transferred from one method of transportation to another.

(d.) Diversion

Diversion is the ability of a packaged structure to be sent to a different location once it is en-route to an initial destination. Diversion relates to the mode of shipping.

(4) Storing

Storing is the act of placing the packaged structure at a site in an enclosed structure or in an open area. Some of the effects of storing are: Deterioration due to weather, age, and/or corrosion. There is also a cost associated with storage and its related effects.

(a.) <u>Minimum Deterioration by Weather</u>

Deterioration by weather is the degree to which exposure to the elements has caused the stored structure to decay. It is related to the material that the structure is made of as well as the manner in which it is packaged.

(b.) <u>Minimum Deterioration due to Age</u>

Some materials, whether in use or in storage, tend to deteriorate faster than others. This parameter, then, is a measure of the ability of the packaged structure to resist the effects of inactivity while it is in the storage state.

(c.) <u>Low Cost</u>

Cost of storage is the absolute dollar value, not only of storing packaged structural components, but also the cost of periodically inspecting, maintaining and repairing them.

(5) <u>Fabrication</u>

Fabrication is the act of assembling and packaging the manufactured components into identifiable entities for shipment and subsequent erection. Fabrication includes the physical erection of the structure on the designated site. Some things influencing fabrication are skill levels, tool complexity, time and cost.

(a.) Low Skill Level

Skill level is the relative expertise required by personnel to assemble and erect the structure. Portions of fabrication may necessitate unusually high skill levels, but erection of the building parts should be simple and straightforward.

(b.) Low Tool Complexity

Tool Complexity relates to special or complicated tools required for fabrication. When special or complicated tools are required, the skill level and cost of fabrication usually become higher.

(c.) Minimum Time

Time for fabrication is the calendar days necessary to assemble (including erection) the structure. It is measured from the date the manufactured components are delivered to the fabricator to the date of initial operational capability (IOC).

(d.) Low Cost

Cost of fabrication is the dollar amount required to perform the fabrication task.

(6) Maintenance

Maintenance is the effort necessary to keep a structure available for combat or support operations. As in the case of "storing," some of the things related to maintenance and repair. The terrestrial environment (underground and/or above ground) in which the structure is situated will influence the complexity of the maintenance task. Maintenance, as used here, is independent of the combat environment (whether or not the structure is hit by projectiles) which determines the amount of time a facility will be out of commission awaiting the repair/replacement of damaged areas. This is covered under paragraph (8) entitled "Repair."

(a.) Corrosion

Corrosion is the natural combination of materials in the structure with unwanted substances such as oxygen. This process will degrade the quality and strength of the structure. The requirement for abnormal corrosion prevention measures in a structure is undesirable.

(b.) Weathering

Weathering is the deterioration of the structure due to light, moisture cycling and other factors associated with weather. Resistance to weathering is desirable.

(c.) Aging

Aging is the deterioration of the structure as a result of slow chemical processes within the structural materials and the long term effects of stress and temperature change. Resistance to aging is desirable.

(d.) Maintenance Repair

Maintenance repair is the action taken to reverse or correct the effects of corrosion, weathering and aging. Low cost in labor, materials and time is desirable.

(e.) Low Cost

Cost is the dollar amount estimated for keeping the facility in an adequate state of repair and available for its intended use.

(7) Operation

Operation refers to the actions necessary to keep a well maintained and "in commission" facility available under all conditions. The procedures and action required to operate the closure and the environmental controls as examples of operationa. Keeping a facility in operation has an effect on the operational efficiency of the organization occupying the facility.

(a.) Ease of Operation of Closure

Ease of operation of closure is the degree of absence in the complexity and amount of time necessary to either open or close the doors and/or openings of the facility.

(b.) Simple and Reliable Operation of Environmental Controls

Operation of environmental controls relates to the effort and complexity of operating the machinery and other devices necessary to keep the structure under the specified conditions of temperature, humidity and ventilation. It includes, but is not limited to, the operation of air conditioning, heating, water removel (sump pumps), dust and refuse removal and detection equipment.

(c.) High Organizational Efficiency

Organizational efficiency is engendered when a facility is operated efficiently. Sometimes poor performance of an organization is directly related to an undesirable facility environment. Quantification of this parameter amounts to a value judgment on how efficiently (reliably) the components of the structure and equipment operate.

(8) Repair

Repair is the act of replacing structural components and/or equipment of a facility because the components and/or equipment were damaged in battle. This type of repair is unrelated to the maintenance repair stated under "Maintenance," which refers to repairing the facility due to normal wear and tear. The quickness of repair due to battle damage is related to the complexity and skill level required to affect the necessary restoration.

(a.) Low Complexity

Complexity is related to the degree of difficulty or ease of operations necessary to affect restoration of the damaged structure. It is influenced by the simplicity and/or complexity of the basic design and the repair kits, materials andprocedures associated with such restoration.

(b.) Low Skill Level

Skill level is the degree of dexterity required of the personnel performing the repair function.

(c.) Low Cost

Cost of repair is the estimated dollar amount required to restore the structure to at least its original condition. For the purpose of evaluation, a direct hit by a 122 mm rocket was assumed.

(9) Damage Resistance

Damage resistance is the ability of a structure to overcome the effects of attacking weapons. This can be accomplished by the selection of the proper materials and configuration for the facility. Damage resistance can be increased by inducing triggering of the fuse of attacking projectiles, by encouraging rocochet of whole projectiles and/or their fragments, by resisting penetration of hostile missiles, by overcoming the effects of external and internal pressure gradients by increasing the facility resistance to fire and reducing the production of secondary fragments.

(a.) Trigger Inducing

Trigger inducing is a characteristic which causes an attacking projectile to explode prior to substantive impact. By triggering the fuse of an incoming projectile at the proper distance from a facility, the full force of the attack is negated and defense becomes a matter of repelling, arresting or deflecting the fragments of the projectile. The effectiveness of the triggering device is measured by: its ability to cause the projectile to burst, its distance from the target and the relative difficulty or ease, as the case may be, of incorporating the triggering method or device into the facility.

(b.) Ricochet Inducing

Richchet inducing is the characteristic produced by configuring the facility so that there is a high probability that a hit will not occur at the critical angle. This parameter is measured by examining the shape of the facility and assessing the areas which encourage ricochet with respect to the total external area of the structure.

(c.) <u>High Degree of Penetration Resistance</u>

Penetration resistance is measured by the inverse of the distance a given projectile will enter a material.

(d.) <u>Resistance (Internal Pressure Gradients)</u>

Once a projectile with a delayed fuse obtains penetration into a structure, and the explosion occurs, differential pressures are involved. This feature is measured by examining how well the pressure is handled either through containment, venting or absorption.

(e.) <u>Resistance (External Pressure Gradients)</u>

An air burst of a weapon creates pressures on the outside of structures which tend to crush and/or topple the building. Structures designed for passive protection must resist this impulse. This parameter is measured by examining the provisions of the concept which mitigate against accepting damage from over-pressures.

(f.) <u>High Resistance to Fire</u>

Often fire follows the impact of a projectile or bomb on or near a facility. It is important to minimize this hazard; therefore, an assessment of how well fire resistant materials and equipment are incorporated into the concept is in order.

(g.) Reduction of Secondary Fragment

Once a missile has impacted on an element of a structure, its energy is transmitted into the material. This energy transfer is often so strong that it produces fragments of its own which are damaging to the contents in the structure. In some cases the secondary fragments do more damage than the basic weapon. It is therefore desirable that the internal liner of the building be composed of a material which will not spall or which will negate the effects of secondary fragments from the succeeding course of protective material. This term is quantified by assessing the properties of the last two courses of protective material.

(10) Materials

Materials play a most important role in the performance of a structure in the protective construction arena. They must possess those properties that resist damage as discussed above. However, there may be materials with superior attributes that are not available at reasonable cost or are not available in sufficient quantity to be applied. Generally, materials of high density and strength are preferable when employed in the rejecting and deflecting modes. More pliable materials have good application in the arresting role.

Using certain materials in the proximity of electronic facilities may have a deleterious effect on the proper functioning of the electronic equipment. These types of things are examined and quantified under the general heading of "Materials."

(a.) <u>High Degree of Availability</u>

Availability is measured by the lack of delay in obtaining materials for manufacturing and subsequent incorporation into the structure at a reasonable cost.

(b.) <u>Density</u>

Density as used for evaluation of materials refers to areal density.

(c.) <u>Strength</u>

A high strength/weight ration is desirable from the standpoint of efficiency without consideration of damage. However, residual strength must be obtainable in the structural materials through workability, redundancy or understressing.

(d.) <u>Electro-Magnetic Compatibility</u>

The structure should present minimum absorbtion to radiant energy and should have desirable reflecting characteristics. Interference with placement of antennas should be negligible.

(e.) Low Cost

Cost is the dollar value of the materials incorporated into the structure.

(11) Good Foreign Relations Impact

The structures should be adaptable to the current policy of the governments involved. A permanent structure may be objectionable during a stated "temporary" occupation period.

(12) Low Cost Per Square Foot

(a.) Low cost per square foot is the total dollar cost of the structure divided by its usable area in square feet.

Total cost (C_T) is composed of the following:

$$C_T = C_S + C_D + C_L + C_C + C_{MO_5} + C_R$$

Where:

C_S = Cost of Studies Relating to the Structure

C_D = Cost of Design

C_L = Cost of Real Estate (Land)

C_C = Cost of Construction (Includes Manufacturing, Fabrication and Erection)

C_{MO_5} = Cost of Maintenance and Operation of the Facility for 5 Years

C_R = Cost of Repair of the Structure given a Single Direct Hit by a 122 mm Rocket

(b.) In some cases it may be desirable to determine the annual cost of a facility when it is anticipated that up-grading of the facility to keep pace with the threat is desirable. In this case the following formula would be useful.

$$C = \overline{CRF}_n \left[A+D+E_1\overline{PWF}_{n_1} + E_2\overline{PWF}_{n_1} - (1-\frac{Y}{X})(E_1 \text{ or } E_2)PWF_n \right] +M+O+K$$

where:

C = Complete Annual Cost

$\overline{CRF}$ = Capital Recovery Factor = $\frac{r(1+r)^n}{(1+r)^n-1}$

$\overline{PWF}$ = Present Worth Factor = $\frac{1}{(1+r)^n 1}$

r = Interest Rate on Government Bonds

n = The analysis period (years

n_1 = Estimated number of years or fraction of a year that upgrading of protection is to be performed (n_1 will have different values in the same analysis depending on whether it is used with E_1 or E_2)

A = Total cost of construction of basic core

E_1 = Cost of first escalation

E_2 = Cost of second escalation

Y = Time (fraction of years between last escalation and end of analysis period

X = Estimated service life of facility in last escalation

M = Annual maintenance cost per year

K = Annual administration and overhead

D = Design cost

EXAMPLE

ELEMENTS	VALUE
Analysis period, n	4 years
Interest rate, r	6 per cent (assumed)
Initial cost, A	\$70,710
Cost of first escalation, E	\$11,705
Estimated service life of last escalation increment	2 years
Capital recovery factor, $\overline{CRF}_n$ - 4 years	$\frac{r(1+r)^n}{(1+r)^n-1} = \frac{.06(1+.06)^4}{(1+.06)^4-1} = \frac{.0756}{(1.26)-1} = .29$
Present worth factor, $\overline{PWF}_n$ - 4 years	$\frac{1}{(1+r)^n} = \frac{1}{(1+.06)^4} = \frac{1}{1.26} = .00784$
Present worth factor, $\overline{PWF}_{n_1}$ - 2 years	$\frac{1}{(1+r)^{n_1}} = \frac{1}{(1+.06)^2} = \frac{1}{1.12} = .00893$
Annual maintenance cost, M	\$190
Time between last upgrading and end of analysis period, Y	2 years

$$C = \overline{CRF}_n \left[A + D + E_1 \overline{PWF}_{n_1} + E_2 \overline{PWF}_n - (1 - \frac{Y}{X})(E_1 \text{ or } E_2) \overline{PWF}_n \right] + M + O + K$$

$$C = .29 \left[70,710 + (11,705)(.00893) + 0 - 0 \right] + 190$$

$$C = .29 \left[70,710 + 104.52 \right] + 190$$

$C = \$19,896 \longleftarrow$ ANNUAL COST

4. THE APPLICATION OF COUNTERS TO THE THREAT TO PASSIVE PROTECTION CONCEPTS

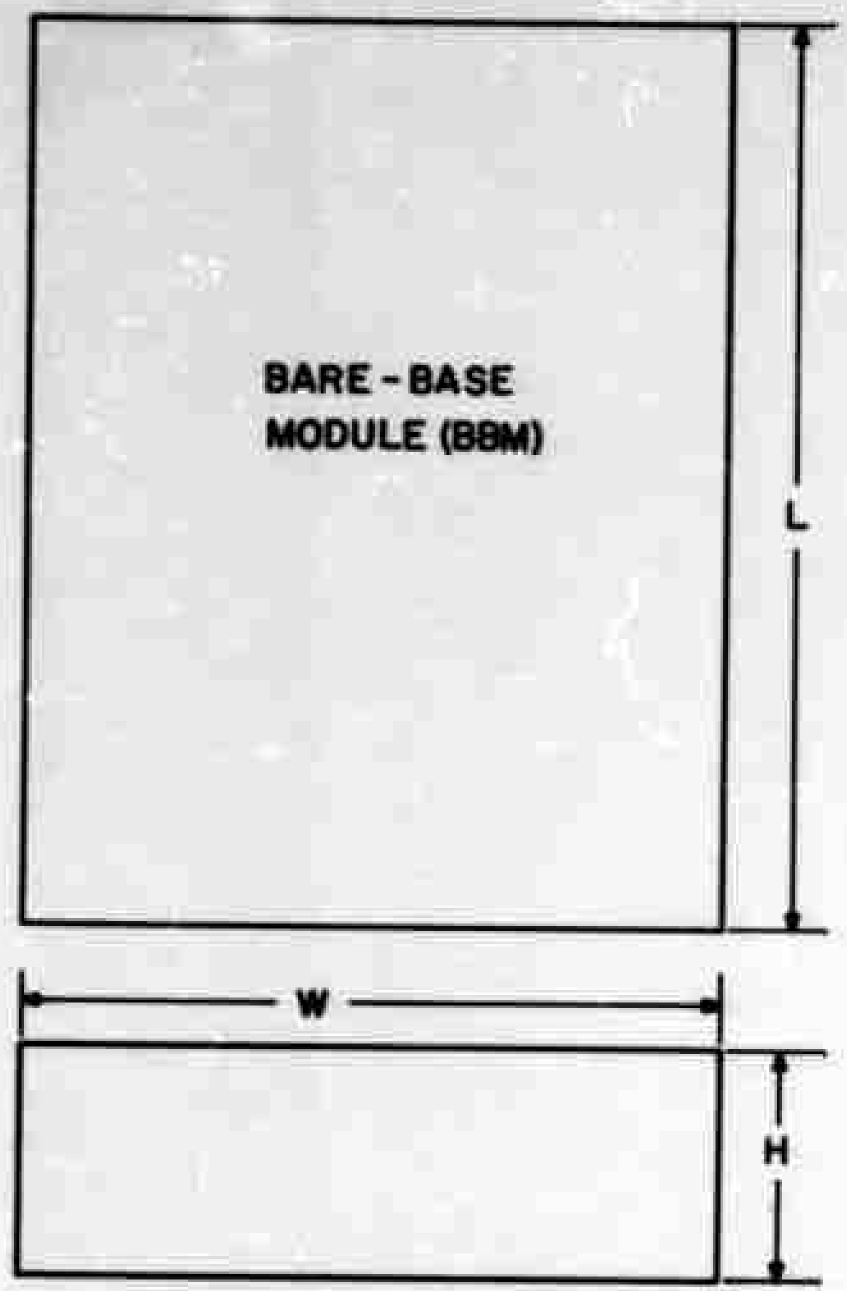
In Paragraph 3, above, the effect of target size, obliquity of facility surfaces, the strength and functions of materials, the terrestrial environments, degree of acceptable risk and the functions desired in concepts were exposed. The purpose of this section is to describe how the above parameters are used to formulate concepts for passive protection. They will be discussed in the same order as they appeared in Paragraph 3.

a. Size and Shape

The sizes of the shelters were founded on the dimensions used for the modules in the "Bare Base" Studies. (Figure 32, "Sizes of Bare Base Structures"). These sizes were validated by comparing them with the space envelopes required for aircraft, supplies and equipment being considered for the Air Force inventory by 1973.

The size designated in the bare base package (58' x 80') for aircraft was found adequate, but the clearances for wing span are somewhat tight. It is interesting to note that the 48 foot diameter semi-circular aircraft shelter now being procured (1968) will not accommodate the future F-X. Moreover, to accept the F-X, the wings must be "swung" to the high speed cruise configuration. The size of the shelter for aircraft in this report have been made slightly larger than the bare base module to provide safe wing-tip clearance.

SIZES OF BARE BASE STRUCTURES



TYPE OF FACILITY	L	W	H
GENERAL PURPOSE	40	30	AS REQ
EQUIPMENT	13	9	8
PERSONNEL	27	13	8
AIRCRAFT SHELTER	80	58	AS REQ
UNSPECIFIED FUTURE	35	16	10

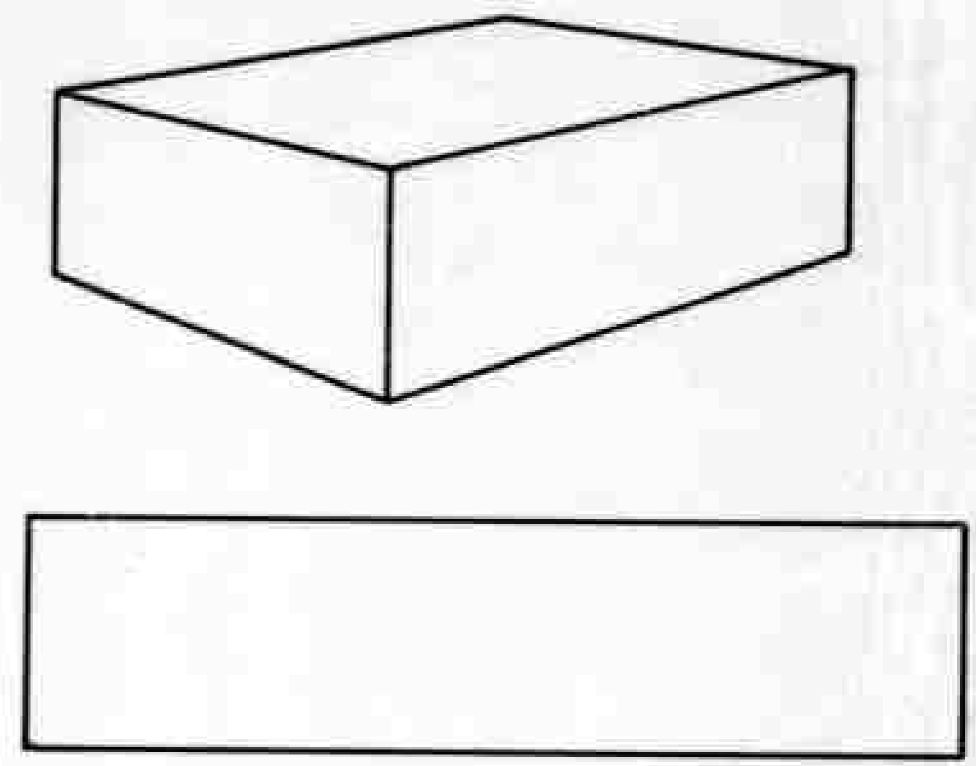


FIGURE 32

The sizes of other bare base modules were used directly because adequate clearances are provided. Therefore, the sizes of shelters used in this effort will accommodate the bare base modules (BBM) if it is decided to deploy them in areas where passive protection is needed. The sizes of shelters are:

Type	BBM	Inside Dimensions of Shelter
General Purpose	40' x 30' x "H"	43' x 33' x "H" + 2'
Equipment	13' x 9' x 8'	16' x 12' x 12'
Personnel	27' x 13' x 8'	30' x 16' x 12'
Aircraft	80' x 58' x "H"	86' x 64' x 25'
Unspecified	35' x 16' x 10'	38' x 19' x 12'

(1) Alternative Configurations for Facilities

The facilities for Personnel, Aircraft Shelters, POL and Command, Control and Communications (C^3) can take many forms and shapes. With the exception of POL facilities, many of the shapes can be used for all facilities with only their dimensions changed to suit the function assigned. The materials applicable to all shapes are discussed in Paragraph 4c "Materials for Application to Concepts". The terrestrial environment in which the facilities could be placed were described in Paragraph 3d "Terrestrial Environments of Structures". To identify the alternative configurations, the form of the sides, top and the plan of structures were identified. Each form, in turn, was divided into several options as follows. (See Figure 33 "Alternatives for Plan, Sides and Top")

Form	Number of Options
• The Plan	Seven (7) Options
• The Sides (Walls)	Seven (7) Options
• The Top (Roof)	Seven (7) Options

By combining these options, 343 different configurations evolved. (See Figure 34 "Combinations of Sides and Top"). To bound the problem, however, only those configurations which exhibited the outstanding characteristics alluded to in Paragraph 3 above were considered. In arriving at the "candidate" configurations, the options within each form were examined, the best options were then combined to make the concept candidates for further consideration.

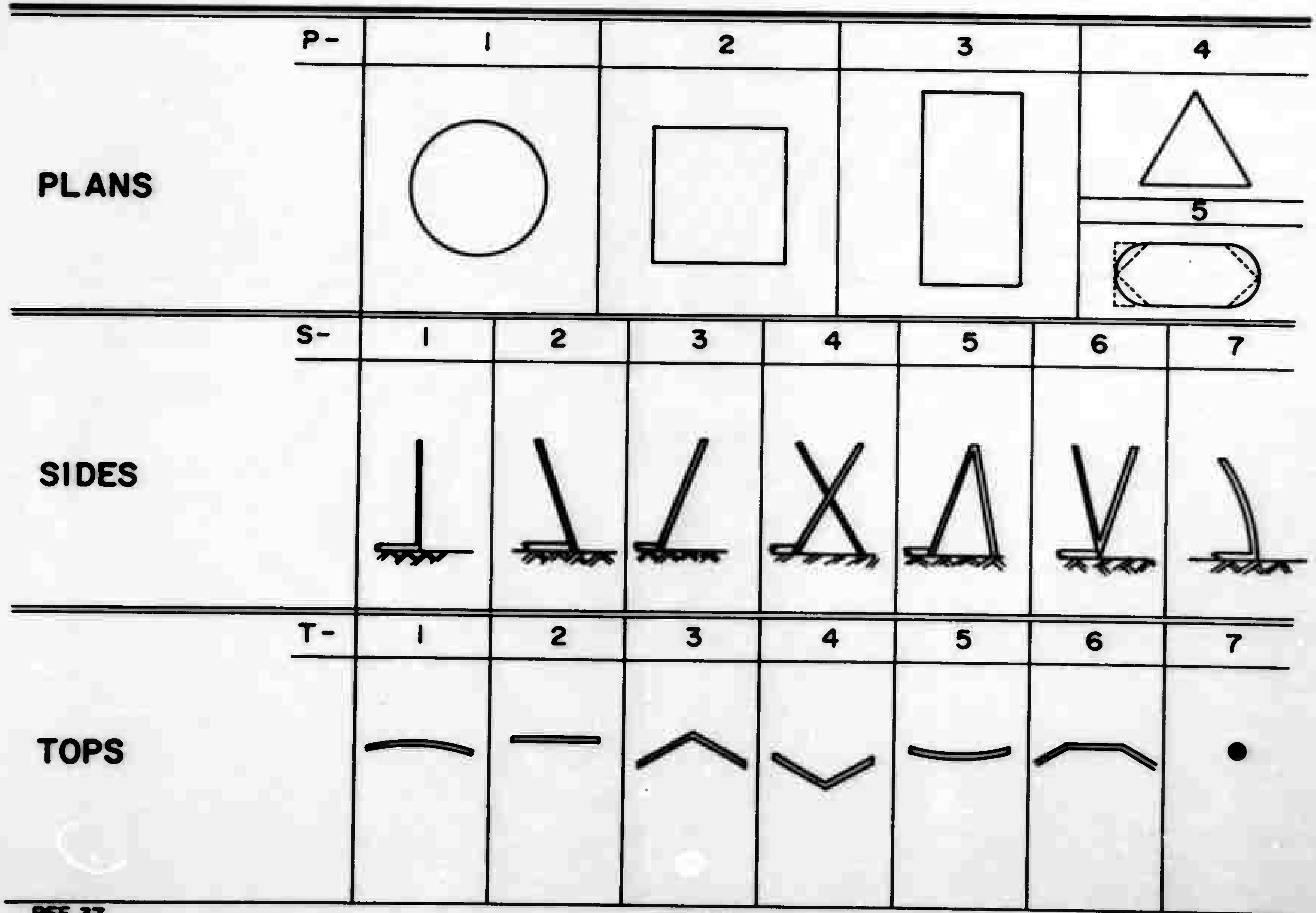
(a) <u>The Plan</u>

The options are:

- Circular
- Square
- Rectangular
- Triangular
- Elliptical
  - Hexagonal
  - Combination - Rectangle and Triangle

Selection of the desired plan form for the facility involved the consideration of seven factors with their attendant "importance weights". (The higher the weighting number, the more important the factor.)

ALTERNATIVES FOR PLANS, SIDES & TOPS



REF 37

FIGURE 33

<u>Importance Weight</u>	<u>Factor</u>
6	• Flexibility for adaptation to all functions.
3	• Economy of manufacture, fabrication and erection.
4	• Ease and rapidity of erection by field forces.
7	• Encouragement of ricochet.
5	• Simple design.
2	• Adaptable to a variety of materials.
1	• Provides most area for minimum parameter.

The following table shows the evaluation of the options with respect to the above factors. The numbers used in this and subsequent evaluations are based on value judgments, experience and the application of quantified data relating to the option and the evaluation parameter.

FACTOR & WEIGHT IMPORTANCE

LEGEND: Basic Score High-3 / Weighted Value High-21

OPTION	Flexibility (6)	Economy (3)	Erection Ease & Rapidity (4)	Encourages Ricochet (7)	Simple Design (5)	Adaptability to Materials (2)	Large Area for small [illegible] (1)	WEIGHTED TOTAL
1. Circular	1 / 6	1 / 3	2 / 8	3 / 21	1 / 5	1 / 2	3 / 3	48
2. Square	1 / 6	3 / 9	3 / 12	1 / 7	2 / 10	3 / 6	2 / 2	52
3. Rectangular	3 / 18	3 / 9	3 / 12	1 / 7	3 / 15	3 / 6	1 / 1	68
4. Triangular	1 / 6	3 / 9	3 / 12	2 / 14	1 / 5	3 / 6	1 / 1	53
5. Elliptical	2 / 12	1 / 3	1 / 4	1.5 / 11	1 / 5	2 / 4	1.5 / 2	41
6. Hexagon	3 / 18	4 / 12	3 / 12	25 / 20	2 / 10	3 / 6	2 / 2	80
7. Rectangle/ Triangle	3 / 18	3 / 9	4 / 16	2 / 14	3 / 15	3 / 6	2 / 2	80

On the basis of the above evaluation, the rectangular, the hexagon and the rectangular/triangular plan forms are selected for applying the best side and top options.

(b) <u>The Sides (Walls)</u>

The options for this feature are: (See Figure 33, "Alternatives for Plan, Sides and Tops").

- Straight with no slope
- Sloping Inward (straight)
- Sloping Outward (straight)
- Crossed (one wall sloping out and one in)
- Inverted "V"
- Curved

Using approximately the same criteria as delineated for "The Plan", Paragraph 4(1)(a) above, the following analysis is presented:

FACTOR AND WEIGHT

OPTION	Flexibility (6)	Economy (3)	Erection Ease (4)	Encourages Ricochet (7)	Simple Design (5)	Adaptability to Materials (2)	Large Vol. for sm. surf. (1)	WEIGHTED TOTAL
Straight	3 / 18	3 / 9	3 / 12	2 / 14	3 / 15	3 / 15	2 / 2	85
Slope Inward	2 / 12	2 / 6	2 / 8	1 / 7	2 / 10	2 / 10	1 / 1	54
Slope Outward	2 / 12	2 / 6	2 / 8	3 / 21	2 / 10	2 / 10	1 / 1	58
Crossed	1 / 6	1 / 3	1 / 4	3 / 21	1 / 5	2 / 10	1 / 1	50
Inverted "V"	3 / 18	1 / 3	2 / 8	3 / 21	1 / 5	2 / 10	1 / 1	66
"V"	2 / 12	1 / 3	2 / 8	3 / 21	1 / 5	2 / 10	1 / 1	60
Curved	3 / 18	3 / 9	3 / 12	2 / 14	2 / 10	2 / 10	3 / 3	76

COMBINATIONS OF SIDES & TOPS

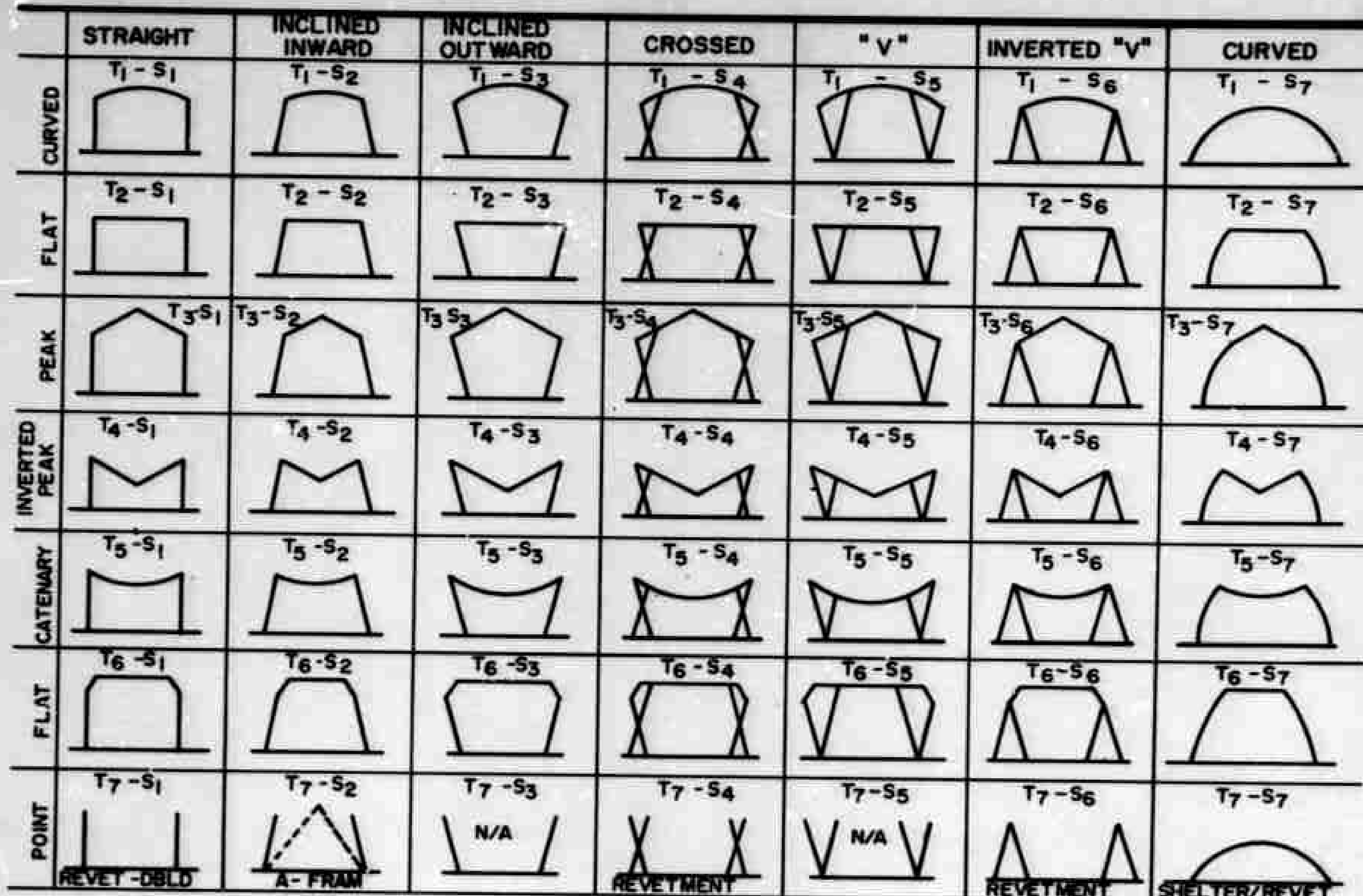


FIGURE 34

Based on the above evaluation, 5 wall options will be considered for application to the plan forms previously selected. The wall options are:

- Straight
- Sloping Outward
- Sloping Inward
- Curved
- Inverted "V"

(c) The Top (Roof)

The following are options for the roof of the structure:

- Curved (Convex)
- Flat
- Hip
- Inverted Hip
- Curved (Concave)
- Point (No roof-walls to meet to form the shelter)

The table, below, indicates the relative values placed on each option so that the choice of the best configuration for the top of the shelter can be made.

EVALUATION — FACTORS AND WEIGHTS

OPTION	Flexibility (6)	Economy (3)	Erection Ease (4)	Encourages Richochet (7)	Simple Design (5)	Adaptability to Materials (2)	Strength of Span (1)	TOTAL WEIGHT
Convex (Arch)	3 / 18	3 / 9	2 / 8	2 / 14	3 / 15	2 / 4	3 / 3	71
Flat	3 / 18	2 / 6	2 / 8	3 / 21	2 / 10	3 / 6	1 / 1	70
Hip	1 / 3	1 / 3	2 / 8	1 / 7	1 / 5	2 / 4	2 / 2	32
Inverted Hip	1 / 3	1 / 3	2 / 8	1 / 7	1 / 5	2 / 4	1 / 1	31
Concave (Cable)	3 / 18	2 / 6	3 / 12	2 / 14	3 / 15	2 / 4	3 / 3	72
Point (Line)	N/R* / -	N/R / -	N/R / -	N/R / -	N/R / -	N/R / -	N/R / -	N/R

* N/R = not rated

From the above evaluation, three forms for the roof of the structure should be considered for further analysis. They are: • the curve convex • the flat and • the curved concave.

(d) First Configurations

The preliminary investigations just conducted reduced the 343 original configurations to 36 or derivitives thereof. These 36 are the product of the following:

PLAN	SIDES	TOP
• Rectangular	• Straight Perpendicular	• Curved Convex
	• Sloping Outward	• Flat
• Hexagon	• Sloping Inward	• Curved Concave
• Rectangular/ Triangular	• Curved	

Some of the above combinations proved to be impractical or duplicative to some degree. These were eliminated a-priori.

Ten successful candidate shelter configurations finally evolved. They were examined, as one parameter of many, for the area each presents to incomming projectiles. The probability of a single shot hit on the various configurations was determined. Figure 35 through 37 "Trade-off Data on Size and Shape" display the sketches of each candidate and

TRADE-OFF DATA ON SIZE & SHAPE

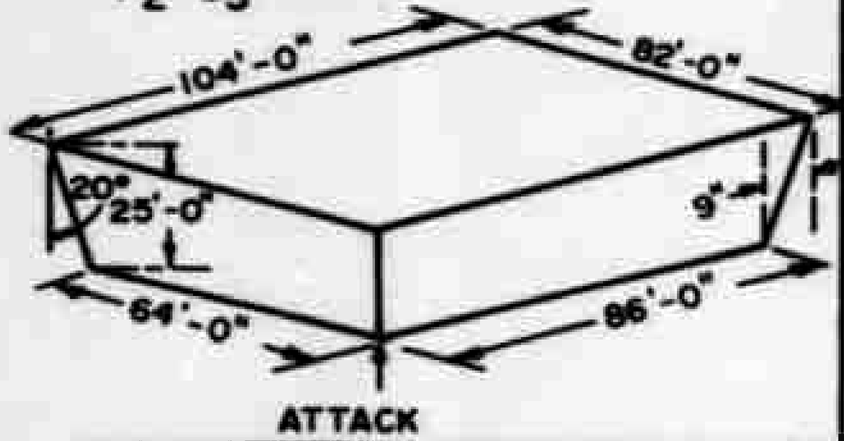
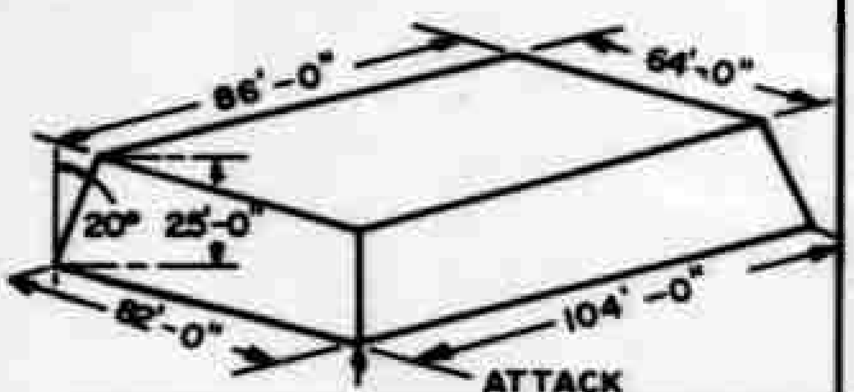
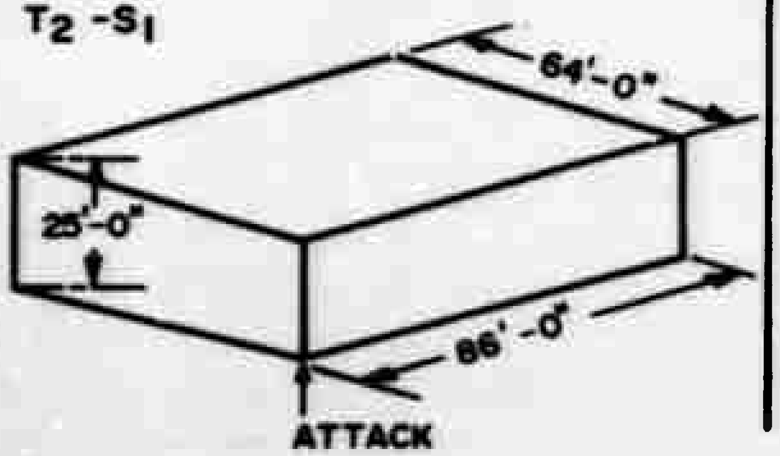
SHAPE	PRESENTED AREA				PROB. OF HIT (SINGLE SHOT)				SHOTS REQD FOR 90% Ph
	APPROACH OF PROJECTILE	APPROXIMATE AREAS SIDE/TOP	END	TOTAL	PRESENTED AREAS	P_h WHEN CEP = 50'	200'	500'	
T_2-S_3 	30°	4,260#	2,155#	6,415#	6,415#	.39	.033	.0055	
	45°	6,040	1,375	7,415	7,415	.43	.035	.0060	
	60°	7,400	479	7,879	7,879	.46	.038	.0065	
T_2-S_2 	30°	2,750#	3,175#	5,925#	5,925#	.38	.032	.0050	
	45°	3,885	2,935	6,820	6,820	.42	.036	.0058	
	60°	4,760	2,455	7,215	7,215	.45	.038	.0060	
T_2-S_1 	30°	2,750#	2,335#	5,085#	5,085#	.35	.027	.0045	
	45°	3,890	1,910	5,800	5,800	.38	.031	.0049	
	60°	4,760	1,271	6,031	6,031	.39	.032	.0052	

FIGURE 35

TRADE-OFF DATA ON SIZE & SHAPE

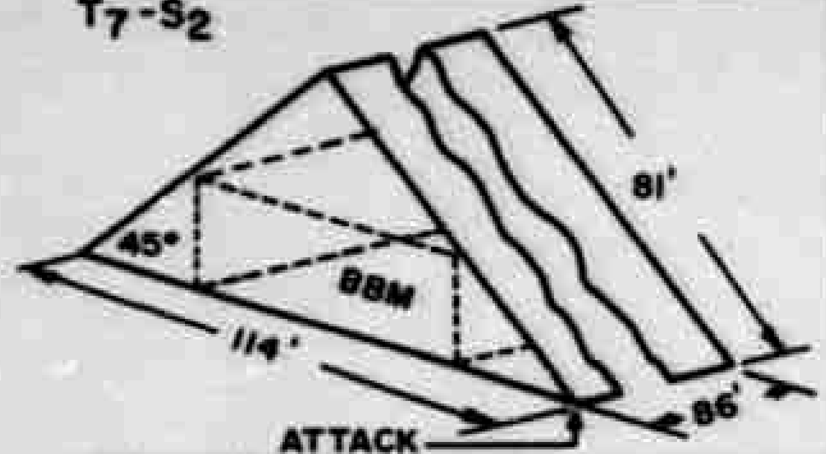
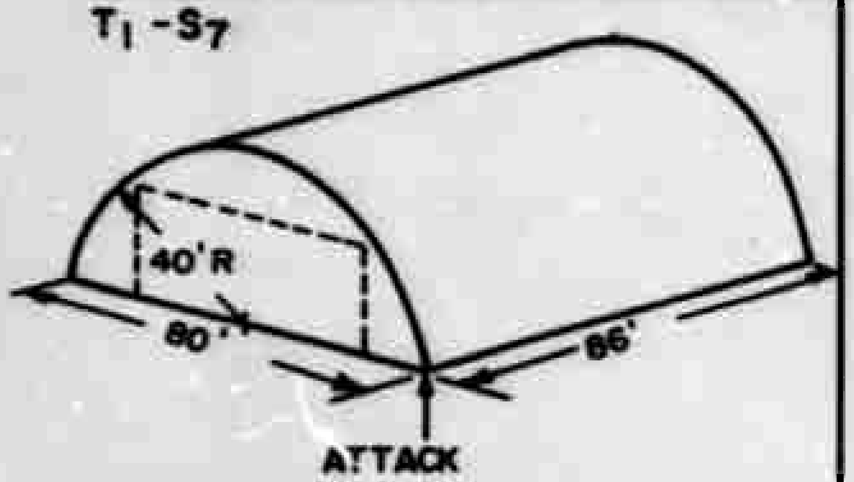
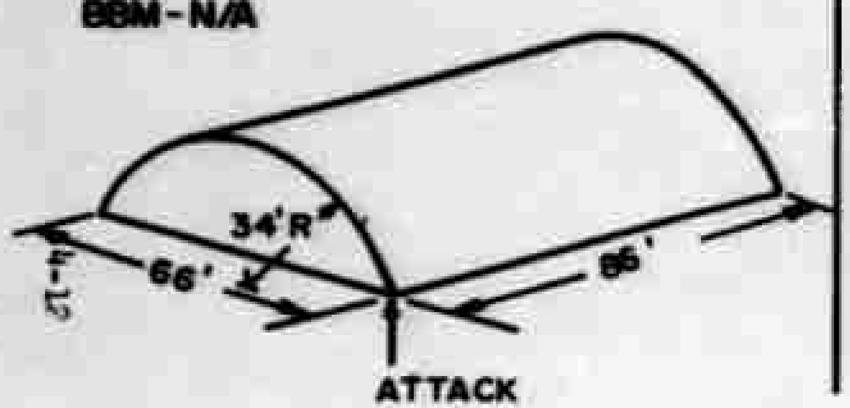
SHAPE	PRESENTED AREA				PROB. OF HIT (SINGLE SHOT)				SHOTS REQD FOR 90% P_h
	APPROACH OF PROJECTILE	APPROXIMATE AREAS SIDE/TOP	END	TOTAL	PRESENTED AREAS	P_h WHEN CEP = 50'	200'	500'	
T_7-S_2 	30°	4,740Φ	1,990Φ	6,730Φ	6,730Φ	.41	.034	.0055	
	45°	4,930	1,620	6,550	6,550	.40	.033	.0054	
	60°	5,950	1,148	7,098	7,098	.43	.037	.0059	
T_1-S_7 	30°	3,640Φ	3,090Φ	6,730Φ	6,730Φ	.41	.034	.0055	
	45°	4,160	2,520	6,780	6,780	.42	.036	.0057	
	60°	4,560	1,780	6,340	6,340	.39	.033	.0052	
T_7-S_7 BBM-N/A 	30°	2,735Φ	1,940Φ	4,675Φ	4,675Φ	.32	.026	.0042	
	45°	3,220	1,582	4,802	4,802	.33	.027	.0043	
	60°	3,640	1,120	4,760	4,760	.33	.027	.0043	

FIGURE 36

TRADE-OFF DATA ON SIZE & SHAPE

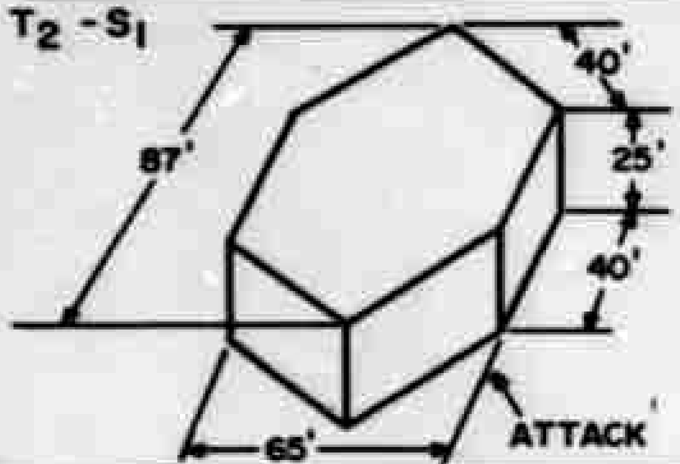
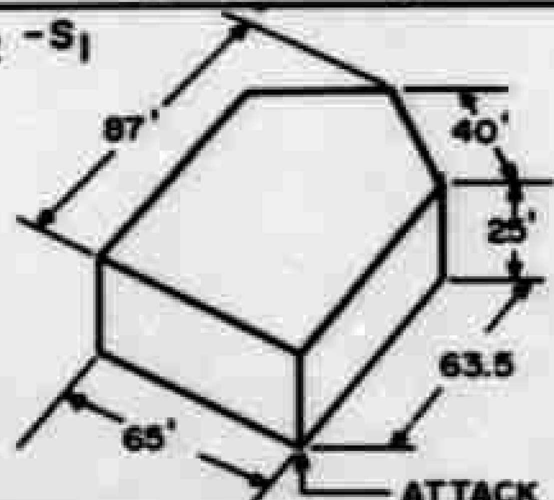
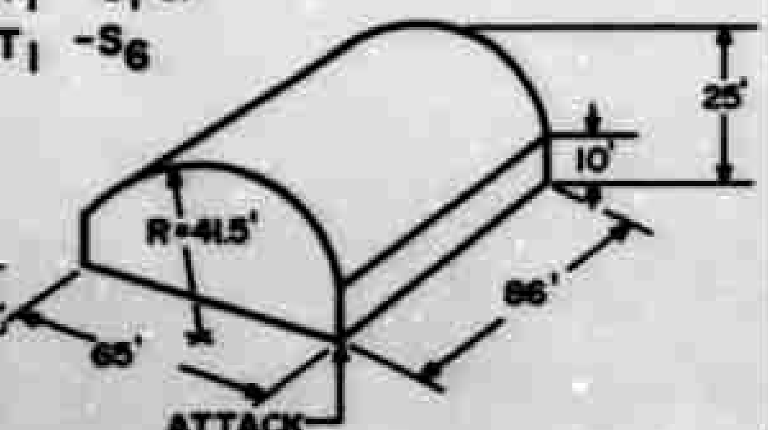
SHAPE	PRESENTED AREA				PROB. OF HIT (SINGLE SHOT)				SHOTS REQD FOR 90% Ph
	APPROACH OF PROJECTILE	APPROXIMATE AREAS SIDE/TOP	END	TOTAL	PRESENTED AREAS	Ph WHEN CEP= 50'	200'	500'	
$T_2 - S_1$ 	30°	2,060*	1,650*	3,710*	3,710*	.28	.021	.0034	
	45°	2,920	1,350	4,270	4,270	.32	.025	.0038	
	60°	3,580	900	4,480	4,480	.33	.026	.0040	
$T_2 - S_1$ 	30°	2,440*	2,120*	4,560*	4,560*	.33	.026	.0040	
	45°	3,450	1,657	5,107	5,107	.35	.028	.0045	
	60°	4,230	1,150	5,380	5,380	.37	.029	.0047	
$T_1 - S_1$ or $T_1 - S_6$ 	30°	2,680*	932*	3,612*	3,612*	.27	.021	.0033	
	45°	3,222	759	4,081	4,081	.30	.024	.0038	
	60°	3,710	536	4,246	4,246	.31	.025	.0039	

FIGURE 37

SIZE & SHAPE SUMMARY

IDENT. NUMBER	DESCRIPTION PLAN	TOP	SIDE	AVERAGE PRESENTED AREA (SQ. FT.)	* AVERAGE PROBABILITY OF HIT (P_h)
$P_3 - T_2 - S_3$	RECTANGULAR	FLAT	INCLINED OUT	7,250	.038
$P_3 - T_2 - S_2$	RECTANGULAR	FLAT	INCLINED IN	6,667	.035
$P_3 - T_2 - S_1$	RECTANGULAR	FLAT	STRAIGHT	5,650	.030
$P_3 - T_1 - S_2$	RECTANGULAR	POINT	SLANTED IN	6,690	.035
$P_3 - T_1 - S_7$	RECTANGULAR	CURVED	CURVED	6,620	.035
$P_3 - T_7 - S_7$	RECTANGULAR	POINT	CURVED	4,750	.027
$P_5 - T_2 - S_1$	HEXAGON	FLAT	STRAIGHT	4,080	.024
$P_5 - T_7 - S_1$	RECTANGULAR/ TRIANGULAR	FLAT	STRAIGHT	5,000	.028
$P_3 - T_1 - S_6$	RECTANGULAR	CURVED	STRAIGHT OR INVERTED 'V'	3,979	.022

* CEP = 200' USE IN OBTAINING THIS PARAMETER.

FIGURE 38

COMPOSITE AIRCRAFT

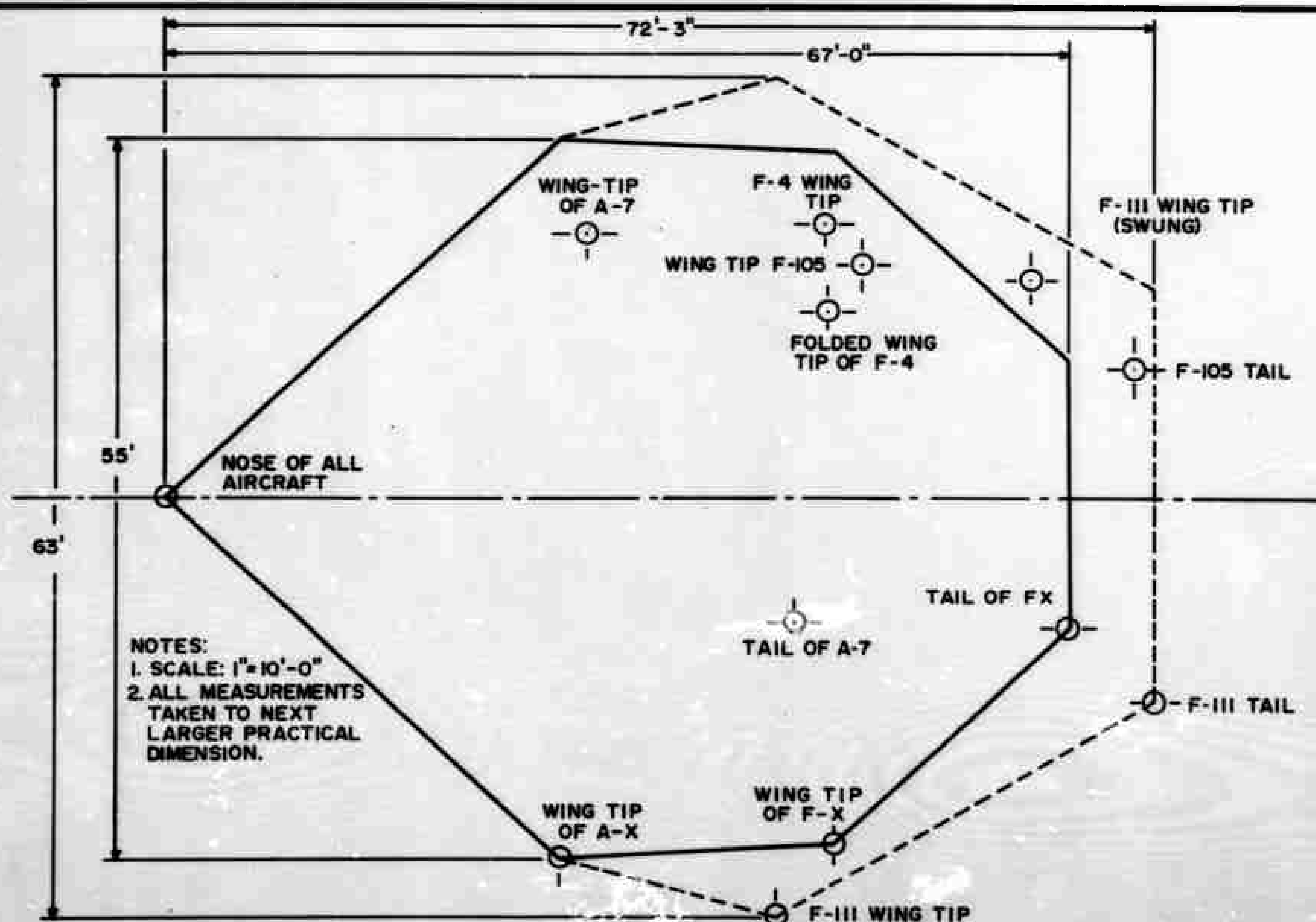
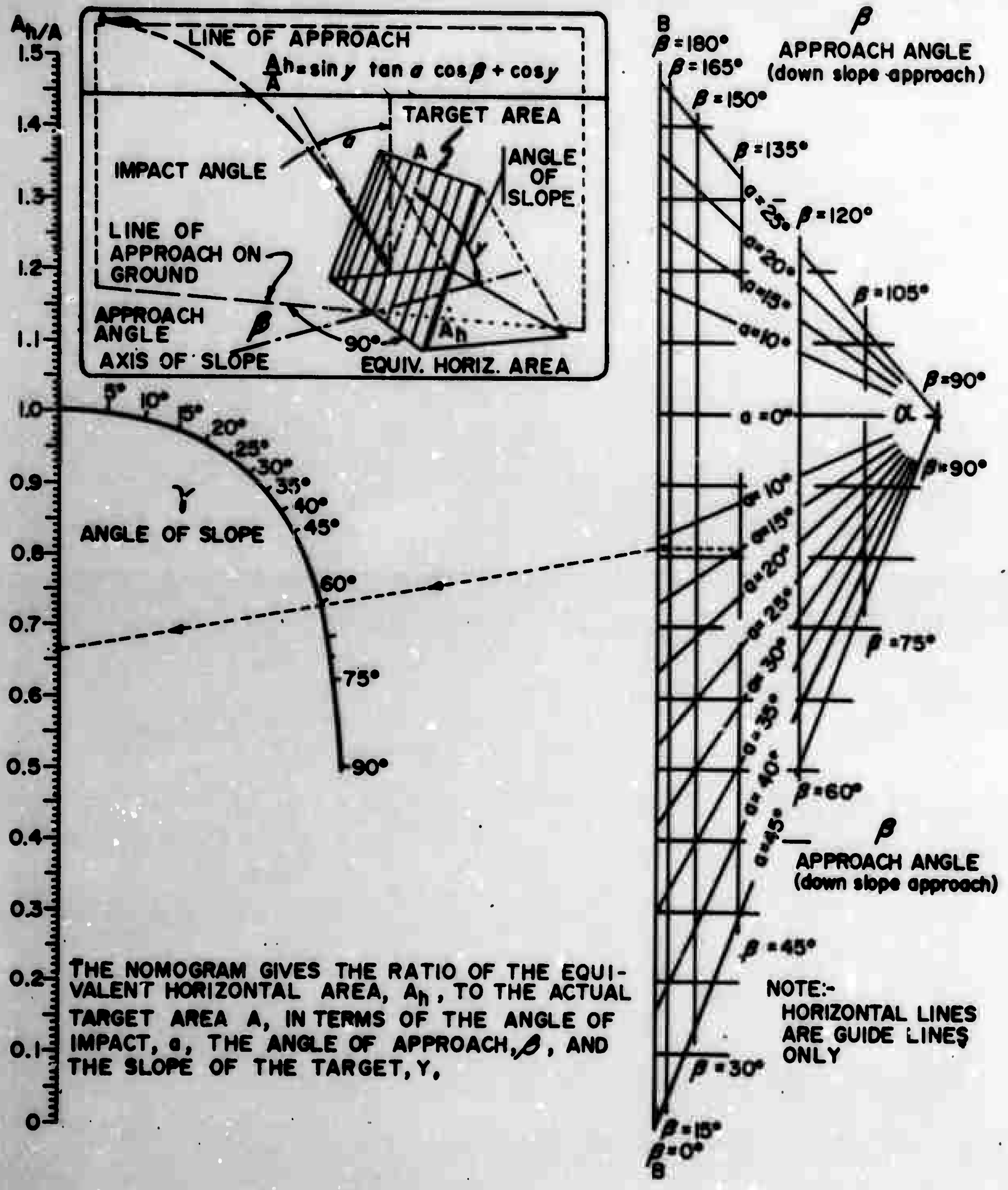


FIGURE 39

EQUIVALENT HORIZONTAL AREA FOR A SLOPING TARGET



THE NOMOGRAM GIVES THE RATIO OF THE EQUIVALENT HORIZONTAL AREA, A_h, TO THE ACTUAL TARGET AREA A, IN TERMS OF THE ANGLE OF IMPACT, α, THE ANGLE OF APPROACH, β, AND THE SLOPE OF THE TARGET, γ,

FIGURE 40

REF 44

give information relating to presented areas and probabilities of hit. Figure 38 presents a tabular summary of size and shape parameters. Figure 39 "Composite Aircraft" delineates the space envelop required to accommodate present and future aircraft. Figure 40, "Nomogram of Impact Angle" can be used for determining presented areas for targets with inclined walls and roofs.

b. Application of Obliquity Theory to Shelter Concepts

Oblique surfaces presented to impacts of projectiles are advantageous to the defender because yaw and ricochet are introduced into the flight of the projectiles. The penetration capability of projectiles is reduced when breakup of the projectiles occurs since the resulting fragments have greater ratios of mass to impact area. A successful penetration of an oblique surface must occur at higher velocities by the factor sec θ where θ is the angle of obliquity. Weight savings can also be achieved.

(1) Introduction of Yaw

Projectiles are usually stable in yaw but when they strike a target at an angle, yaw is introduced. (Figure 42, "Change in Direction during Perforation at Ballistic Limit Velocity"). The yaw is introduced because the projectile is spin stabilized, hence gyroscopic, and exhibits gyrating motion subsequent to the application of a force system where the resultant does not pass through the mass center of the projectile. During oblique perforation of a plate, the unbalanced force system introduces such motion. Even during normal perforation of a material, yaw of the projectile and stripping of its jacket can result in force imbalances and subsequent projectile gyration. At short ranges, before the projectile stabilizes from the imbalanced forces as it passes through the barrel of the weapon, there is a high probability that the projectile will arrive at the target with some degree of obliquity. Building oblique surfaces into a structure will maintain or increase this probability at longer ranges. Figure 43, "Change in Direction of an Armor-Piercing Projectile During Plate Perforation" shows the yaw that is introduced as a function of obliquities and striking velocities. Projectiles increase in yaw as they perforate successive layers of plate materials. Therefore, layers of materials should be employed in the construction of shelters.

These data reveal that a 30 caliber AP, after perforating a 0.075 inch mild steel plate at low to moderate obliquities (5° - 25°), will gyrate 20° for each foot of travel after exit from the plate. At 60°, this rate will increase to 25° per foot. Penetrations of a 0.25 inch mild steel plate, however, will result in 30° per foot if the plate is inclined at 15° to the flight path of the projectile. Consequently, in addition to "layering" of

CHANGE IN DIRECTION DURING PERFORATION AT THE BALLISTIC LIMIT VELOCITY

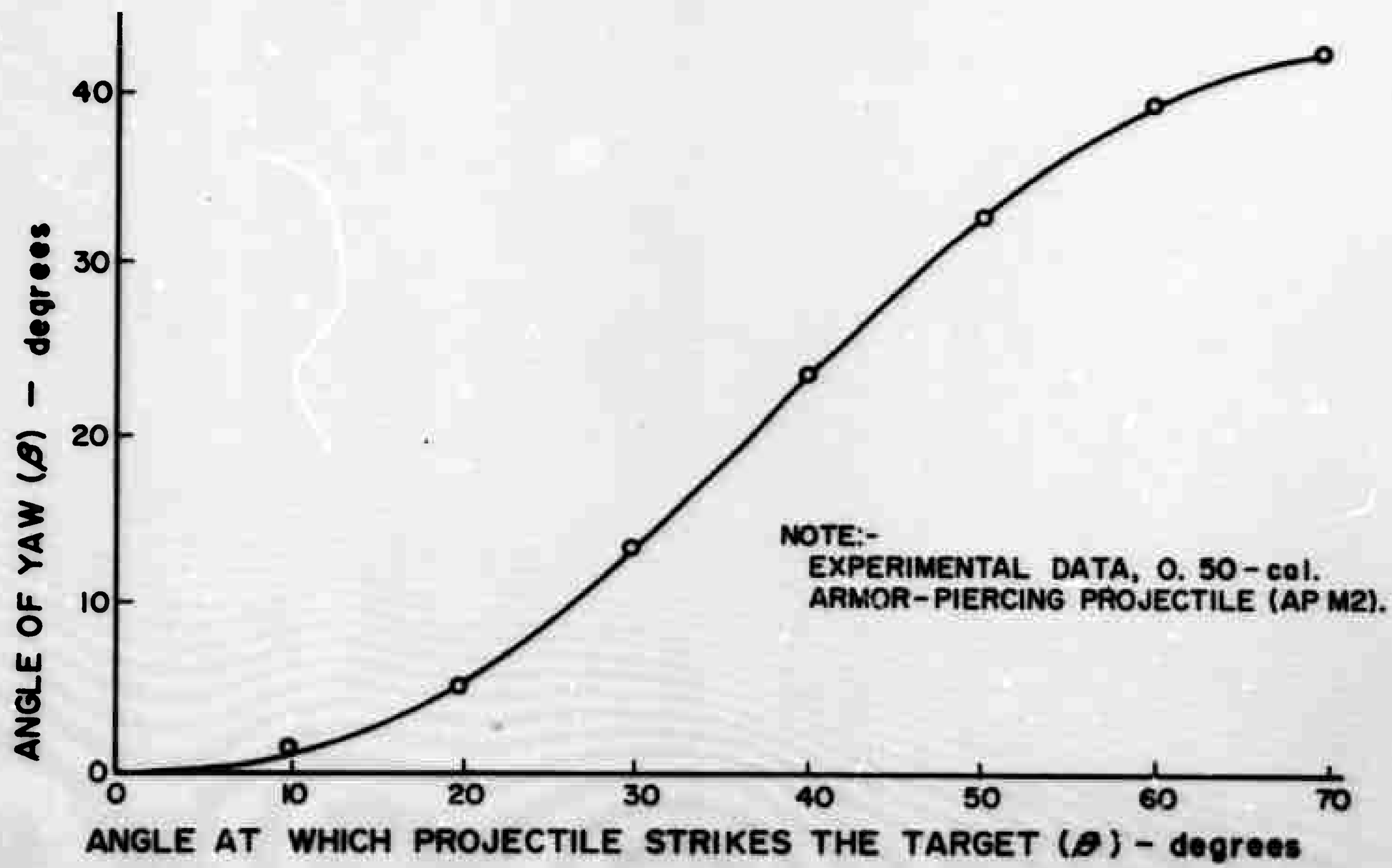


FIGURE 42

REF 37

CHANGE IN DIRECTION OF AN ARMOR-PIERCING PROJECTILE DURING PLATE PERFORATION

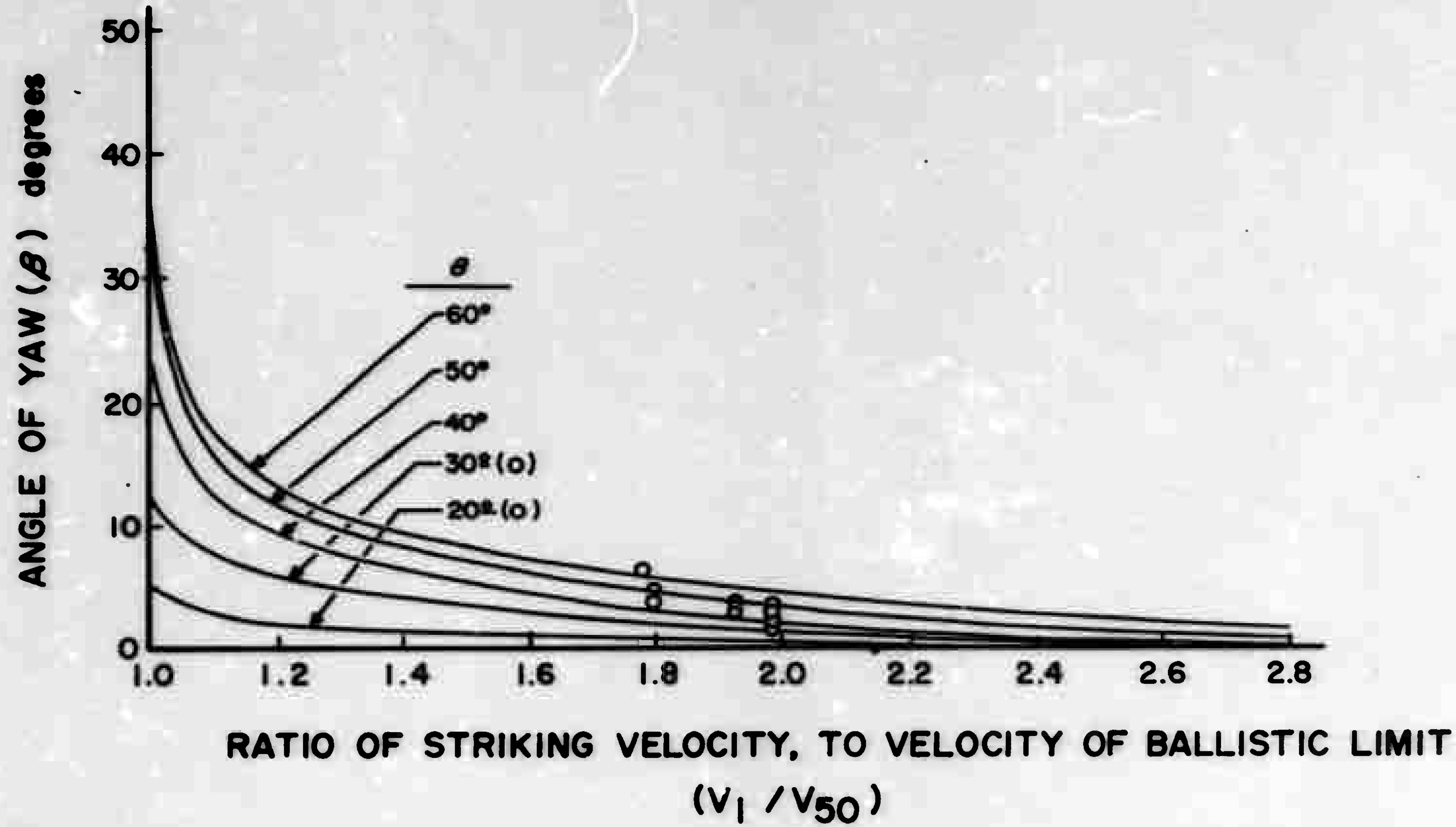


FIGURE 43

REF 37

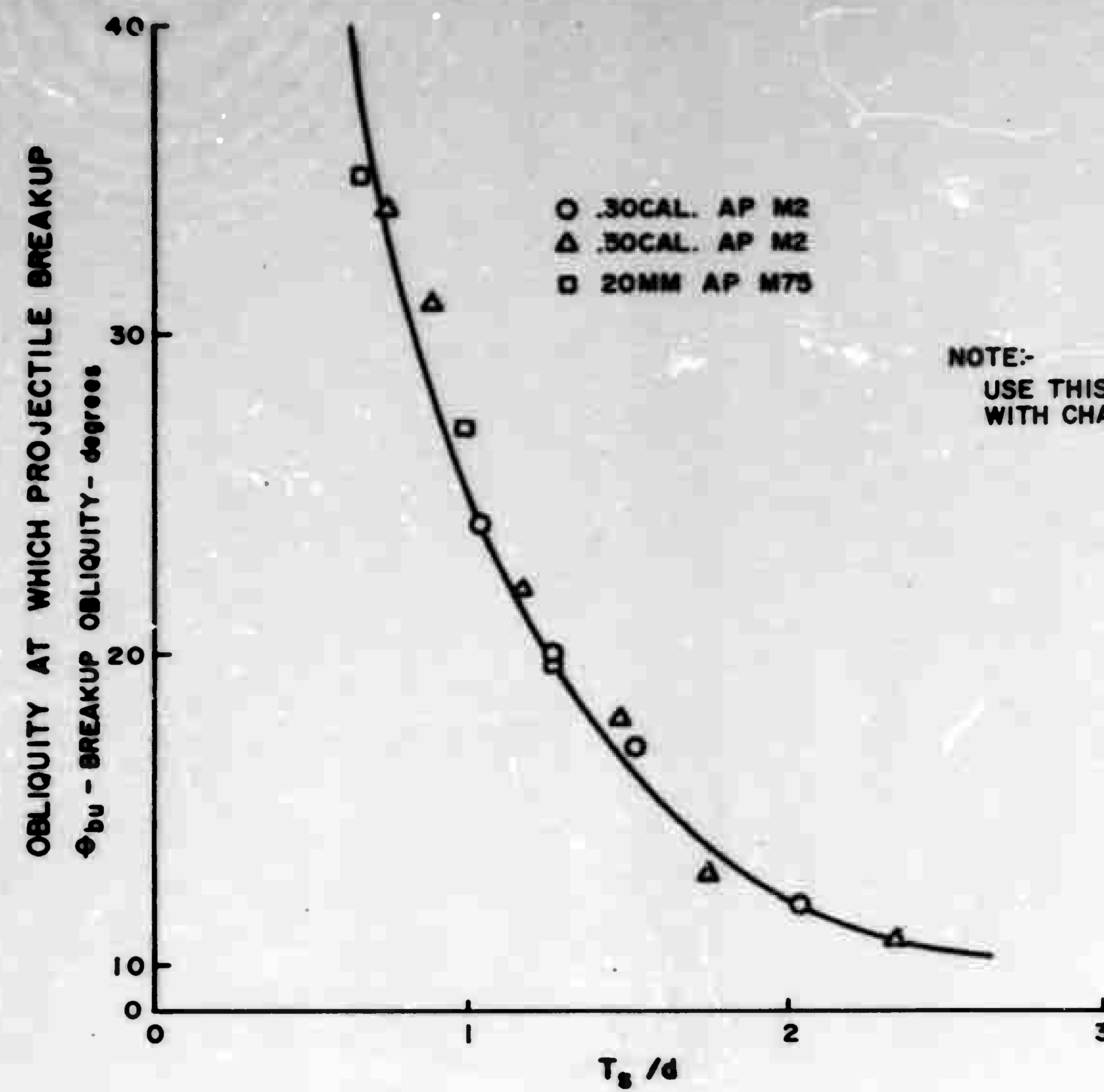
protective materials, these same materials should also be inclined to the most probable final increment of trajectory of the projectile.

(2) Prediction of Break-Up

(a) Break-up Model

Normal penetration of an isotropic plate develops resisting pressures which act symmetrically and with the resultant force along the longitudinal axis of the projectile. Oblique impact produces assymetry and the resultant resisting force produces a moment about the centroid which induces bending stresses and acts to flatten the projectile against the plate. If the moment continues to act in this way, the projectile will ricochet. If the plate is thick and the surface is soft, or the projectile is moving at high speed, the amount the projectile will turn before the centroid disappears below the surface is not great. As the centroid continues below the surface, the moment will decrease. If the plate is relatively thin, the pressure below the projectile will suddenly decrease as the release wave reflects from the rear surface; thus the moment which was initially acting to flatten the projectile will reverse - acting to reorient it toward normal. Projectile cores break primarily as

BREAKUP PREDICTION RICOCHET MODEL



NOTE:-
USE THIS CHART IN CONJUNCTION WITH CHART 45

REF 37

FIGURE 44

the result of bending stresses endured by moments of the type just described. Figure 44, "Break-up Prediction, Ricochet Model", gives the break-up angles for various projectiles at different obliquities.

(b) <u>Formula for Determining Break-up of Projectiles at Zero Yaw</u>

If the projectile arrives at the target with zero yaw, the following formula can be used to determine the obliquity angle(s) at which projectiles will break up.

$$\sin^2\theta \ \cos\theta = \frac{(C_p)(C_{bu})(V_1)}{(V_{50})_n^{\ 3}}$$

where:

$(V_{50})_n$	=	Normal Protection ballistic limit velocity, ft/sec
V_1	=	Striking velocity
C_{bu}	=	Constant related to material properties and proportionality difference between the ricochet model and perforation behavior (to account for plate hardness and penetration)
θ	=	Angle of Obliquity at which projectiles will break up
C_p	=	$\frac{\pi L_p r^3 \tau}{4 \bar{x} M_p}$ = 2.65×10^5 for 30 caliber, 50 cal. and 20 mm

where:

L_p	=	Length of projectile
τ	=	Tensile strength of the core
M_p	=	Mass of projectile
r	=	Radius of projectile
$\bar{x}$	=	Axial distance to centroid

If yaw is in the plane of obliquity, the break-up angle for 30 caliber, 50 caliber and 20 mm projectiles is given by:

$$(\sin^2\theta \cos\theta) + \frac{(C_{bu})(V_1)(L_p)(\sin\phi)}{2\,(V_{50})_n(T_s)(\cos\theta)} = \frac{(C_p)(C_{bu})(V_1)}{(V_{50})_n^{\,3}}$$

where:

ϕ	=	Angle of yaw
T_s	=	Thickness of plate

The foregoing equations are good for predicting the break-up angle of projectiles where the ratio of the thickness of the plate (T_s) to the diameter of the projectile (d) is less than $T_s/d = 1.5$. At higher values of $(V_{50})_n$ which increase with greater thickness of plate (T_s), the equations are not valid*. Projectiles impacting relatively thick plates at high ballistic limit velocities enter the surface at high velocity, quickly escaping the effects of the impact obliquity on the bending moment and thereafter tend to maintain a straight trajectory. However, break-up on the thicker plates is caused by the penetration process. This phenomena is illustrated by referring to Figure 45, "Obliquity Angle Associated with Projectile Break-up at Army Ballistic Limit," where it can be seen that (even for materials of various quality) as far as obliquity is concerned T_s/d values over 1.5 add little or no better ricochet performance than those where $T_s/d < 1.5$.

*The equation is based on ricochet from a rigid surface and does not account for plate hardness or penetration which causes the break-up curve to reverse at values of T_s/d of 1.5 or above.

(c) <u>Ricochet from Plates</u>

At low velocities, the component of impact velocity parallel to the surface undergoes little change, since sliding friction is the only force opposing the energy associated with this velocity. Rebound velocity normal to the surface is much smaller than the striking velocity normal to the surface because a greater proportion of the normal energy to the surface is absorbed by the target material. Thus the resultant ricochet velocity is only slightly less than the parallel component of the initial velocity. As velocities increase, the rebound normal to the surface decreases as the impact becomes less elastic and the projectile, or its fragments, tends to slide along the surface of the target material. Also at higher velocities penetration begins and the motion parallel to the surface is resisted by the target material. The projectile is forced to rise out of the cavity it has formed in the material (scooping action). As this happens, the ratio $(\frac{V_r}{V_0})$ of ricochet velocity (V_r) to impact velocity (V_0) begins to decrease and the rebound normal to the surface begins to increase because of the "scooping action." In general, curves of ricochet velocity V_r are linear functions until surface deformation is achieved. As the minimum perforation velocity (or ballistic limit velocity) is approached in a plate, the curve deviates from linear relationship (Figure 45, "Obliquity Angle Associated with

OBLIQUITY ANGLE ASSOCIATED WITH PROJECTILE BREAKUP AT THE ARMY BALLISTIC LIMIT

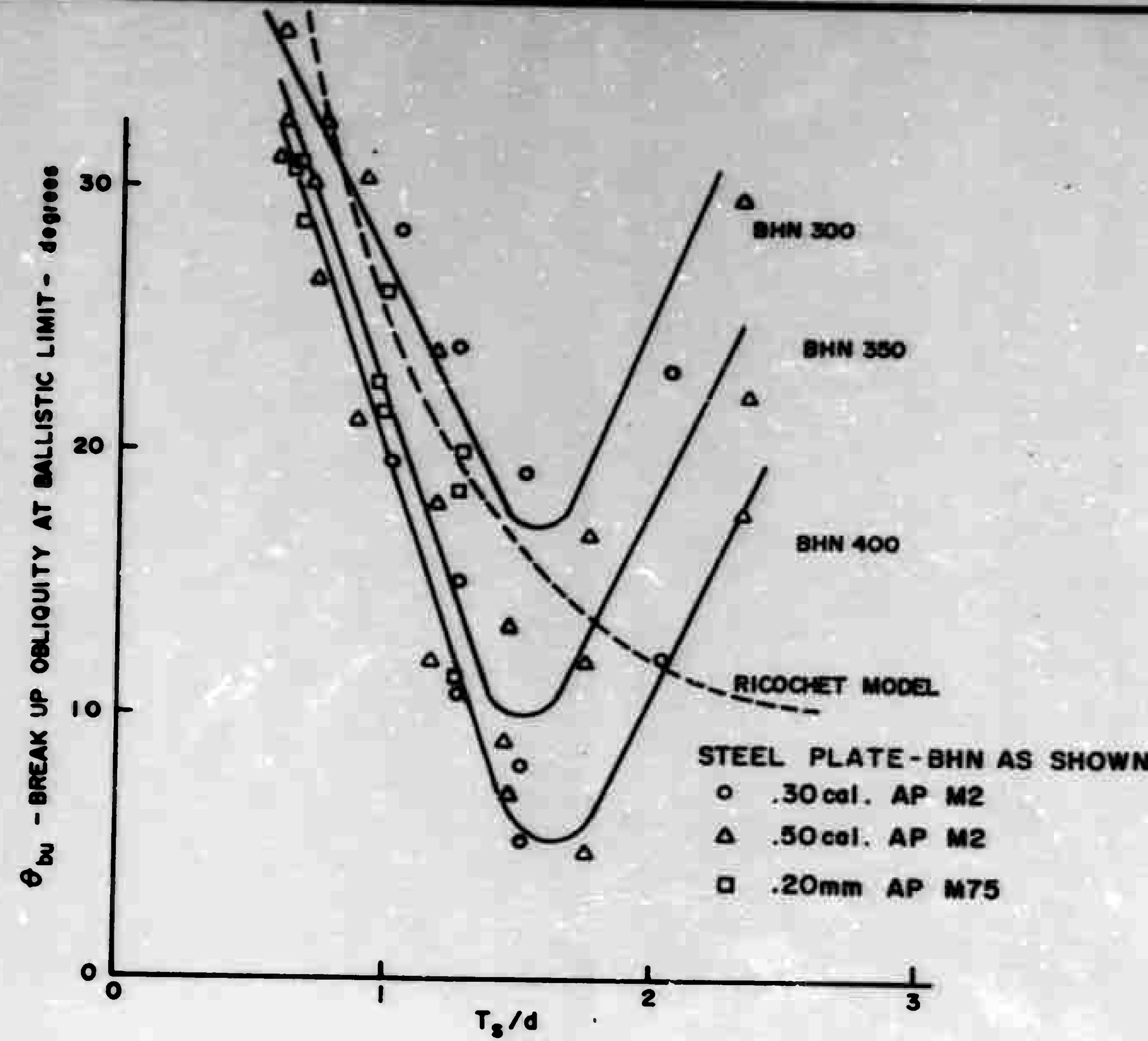


FIGURE 45

REF 37

Projectile Break-up at V_{50}"). Curves of rebound obliquity measured from the normal to the plate, exhibit a maximum due to the conflicting contributions of increasing inelasticity and plate scooping; the rebound obliquity increases as the impact becomes less elastic until scooping is capable of reversing the trend. For example, Aluminum, being soft, yields to penetration at very low velocities. Projectiles inbed readily. Aluminum is an excellent energy absorber, the projectile enters the surface easily, loses energy and, for this reason, has a difficult time getting out.

(d) Ricochet from Soils, Sand and Water

As might be expected for soft materials, ricochet from soils, sand and water occur at much larger angles of obliquity than for armor plates. The resistance to penetration of soils is primarily a function of density while for hard materials such as steel and concrete it is a function of all mechanical strengths. For materials such as soft rock, both strength and density may be of comparable importance. For striking obliquities of 65 degrees or more, measured from the normal to the surface, the underground trajectory of a projectile is likely to have a short underground length and the projectile is more likely to ricochet. Ricochet of artillery projectiles in soil is dependent on velocity and angle of impact.

Figure 46, "Ricochet from Water, Soil and Concrete" shows these relationships quantitatively. In the velocity range of howitzers (700 to 1800 fps) ricochet may be expected when the angle of fall of the projectile is less than 20 degrees at the lower part of this velocity range and less than 12 degrees at the higher portions. The condition of ricochet is favored when the projectile is fired with a propellant charge that is greater than that required to obtain the required range. At maximum range or near maximum range for a given charge for a projectile, ricochet is not a likely condition because the angle of fall will exceed the angles given above.

Projectiles fired from large caliber guns have a higher velocity range (900 to 3,000). Ricochet may be expected with the same fall angles as for howitzers but will occur at greater ranges than howitzers because of the greater muzzle velocity. The capability of the artilleryman to adjust angle of fall by variation of the propellant charge for a given range is not as extensive with rockets. Therefore, it may be easier to slope the exterior surfaces of a structure to obtain the ricochet of rockets with a higher probability of success. Since the path of projectiles in soils curves upward as the velocity decreases, a hard surface beneath the soil such as concrete

RICOCHET FROM WATER, SOIL AND CONCRETE

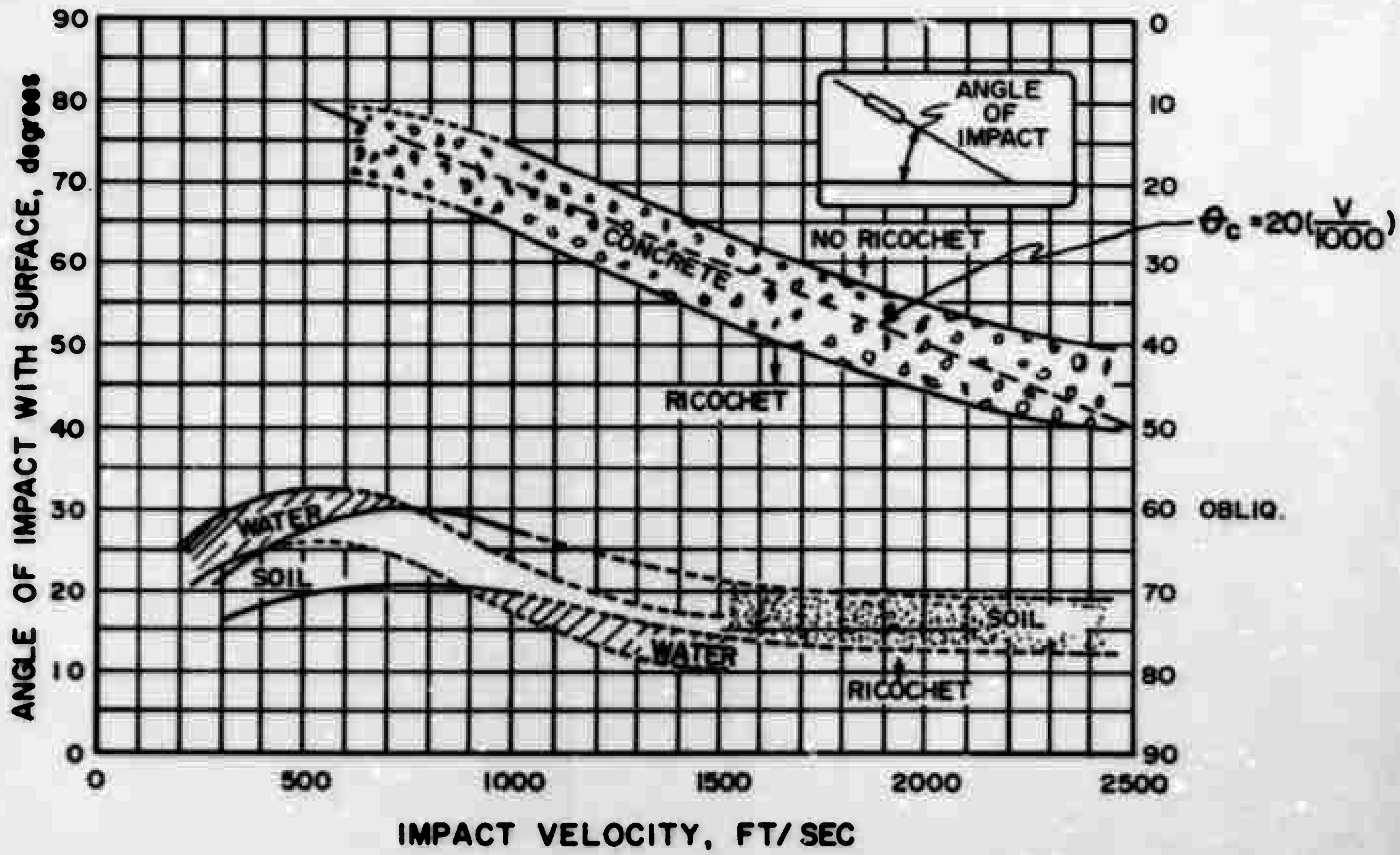


FIGURE 46

REF 44

or armor plate may achieve ricochet where the soil alone would not.

(e) Ricochet from Concrete

At striking velocities up to about 1,000 feet/second, a normally incident projectile does not penetrate beyond the crater which it forms (the face spall) and the deepest point of nose penetration appears roughly as the apex of the sloping crater sides. At higher velocities a nondeforming projectile begins to form a cylindrical penetration hole beyond the crater, provided the target is "massive". A massive concrete target is one which is so thick that when struck by a single projectile scabbing does not occur. This is a conditional thickness which is a function of the static and dynamic characteristics of a projectile and its impact. The distinction is important because a less than massive target is subject to destruction by the effects of the pressure wave impingment on the back face of the target and its reflection as a rarefaction wave which breaks up the target ahead of the projectile penetration (Figure 27). Thickness of concrete which is sufficient to prevent this phenomena is more efficient in stopping projectiles for the amount of materials used. Beginning at the scab limit, penetration increases more rapidly with striking velocity in thin slabs than in massive concrete, the excess being largest just before perforation is attained.

Hence the perforation limit is found to be markedly lower than the velocity required to penetrate a distance equal to the slab thickness in massive concrete of the same characteristics. The pressure wave phenomena or Hugoniot characteristics may be related to the fact that the perforation thickness of 5,000 psi concrete for 50 caliber projectiles at 2,000 feet/second may be 9 to 12 calibers and as high as 16 to 18 calibers for 16 inch projectiles. (Reference 44). Ricochet will occur for a given striking velocity when the obliquity becomes great enough. Figure 46, "Ricochet from Water, Soil and Concrete", shows this relationship for massive concrete. Ricochet greatly handicaps a projectile with respect to the target and thereby enhances the protection afforded by the slab while decreasing the relative effectiveness of the projectile. This applies particularly to explosive projectiles when the fuse setting is such that the detonation takes place when the projectile is no longer in contact with the target. The lateral and turning forces exerted on the projectile during ricochet also pose difficult problems for a fuse designer.

(3) Analysis of Wall and Roof Slopes

Since small caliber projectiles break up at angles of obliquity of 20 degrees, then it appears that the slope of a building surface most likely to be attacked by small arms should be slanted at that angle from the most likely angle of of fall of the projectile at its effective range interval. If a wall is chosen as the most likely surface then a choice must be made as to whether it should slant toward the attack or away from it. If the wall slants away from the attack, then the angle of obliquity will decrease as the range increases because the angle of fall also increases with range unless the propellant charge is increased. If the wall is slanted toward the attack at an angle of 20 degrees, then sufficient obliquity for small caliber is presented at the minimum effective range. The obliquity presented to the attack will increase as the range and angle of fall increases. Thus, it appears that for defense against smaller caliber weapons that the walls should slant outward at least 20 degrees for this range of threat. An added advantage of this slope is that the ricochet will be directed toward the ground and close to the surface of the wall. Backfill placed near the base of the wall can absorb and capture the projectiles or fragments.

The use of skirting plates may be an alternative to slanting the building walls toward an attack. Skirting plates are small lightweight movable plates which are deflected around their point of attachment by the impact of a projectile. As the plate edge comes in contact with the supporting surface, the plate resists the flight of the trajectory and tends to induce deflection breakup and ricochet. The disadvantages of this method as compared to a slanting wall are that the projectile may ricochet in any direction depending on its point of contact with the plate and its subsequent orientation. The projectile will also ricochet into the adjoining plates and may damage their function unless carefully designed. Additionally, the complexity of the arrangement with its associated increase in cost should be understood. Also skirting plates do not have the added advantage of weather proofing which is inherent in other wall formations.

Slanting the wall toward the attack will result in a saving of material weight in the case of steel even though the area of the wall is greater than if it were vertical. This occurs because the effect of obliquity is greater than the effect of increase of area, (Paragraph 4a). By reference to Figure 45, "Obliquity Angle Associated with Projectile Break-Up of Army Ballistic Limit", it can be seen that the most favorable conditions for ricochet are achieved when the thickness of steel plate is 0.45", 0.75" and 1.8" for 30 and 50 caliber and 20 mm projectiles respectively. If oblique striking can be assured, these thicknesses can be decreased accordingly. Striking velocities are at the ballistic limits of increasing plate thicknesses at 0° obliquity and thicknesses of mild steel required to defeat 30 and 50 caliber and 20 mm at 100 yards are .43 inches, 1.15 inches, and 2.06 inches respectively. This corresponds to 2560, 2800 and 3460 ft/sec and these velocities fall within the range of ballistic limit velocities given in Figure 45, "Obliquity Angle Associated with Projectile Break-up at Army Ballistic Limit". By slanting the walls toward the attack a further reduction can be made in the wall thickness and reasonable assurance of ricochet will still be obtained. It does not appear practical to use steel thickness in excess of 2" for field erection for walls for passive protection. Other materials more adaptable to field handling should be utilized to increase the degree of protection if required. Concrete combined with steel plate seems the best candidate for increased protection at the present time. This is primarily because of its cost, availability and logistic facility. Projectiles ricochet from concrete at 10° obliquity at striking velocities of less than 500 ft/sec. As the velocities increase the obliquity angle at which the ricochet occurs increases. At 1000 ft/sec, the angle of obliquity for ricochet increases to 20°; at 1500 ft/sec and 2000 ft/sec the corresponding angles are approximately 27° and 33° respectively.

Nose shape effects penetration of concrete and also effects ricochet. The angles given above are those where ricochet starts and cannot, therefore, be utilized as design criteria without some margin for individual projectile variation and difference in nose shape.

(4) Howitzers and Guns

The angle of fall of howitzers varies from approximately 75° to 20° depending on range. At ranges at which the weapon is used the most the angles of fall group around 30° (60° obliquity) so that a horizontal roof of concrete should induce ricochet for these ranges. At ranges less than 8000 yards, where the angle of fall becomes less than 24°, a horizontal roof should in all cases provide a good ricochet surface. Striking velocities at ranges in excess of 7000 yards of 90 mm weapons are less than 1300 ft/sec and even less for larger caliber shells at larger ranges (Reference 5). This velocity/obliquity profile falls well within the ricochet ranges of Figure 46, "Ricochet from Water, Soil and Concrete." At the maximum range of howitzers the angle of fall is greater. For example, the 152 mm howitzer has an angle of fall of 73° at 14,960 yards, and a striking velocity of 1100 ft/sec (Reference 5). This projectile will penetrate close to 1.8 inches of concrete prior to explosion (Reference 44). Sand at this velocity range will reduce the velocity of the shell nearly 150 ft/sec per foot of sand. Three feet of sand would reduce the striking velocity to 650 ft/sec. The probability of ricochet would be high at this velocity when the projectile strikes the concrete. Results of using equation AA, on Page 4-66, show that this projectile striking concrete at 0° obliquity at this velocity would penetrate 2.2 calibers prior to explosion. Assuming the projectile approaching at 17° obliquity does not yaw in its penetration through the sand, it would still penetrate about 2.2 calibers, however, the shell would probably ricochet and explode some distance down from the crater which had been formed by its impact on the concrete and, therefore, against the full thickness of the concrete slab. This situation robs the projectile of the benefit of its prior penetration of the slab before explosion. The effect of the explosion as the shell lies against the concrete should be examined. The explosive charge of a 152 mm Howitzer approximates 15 lb. Investigations of explosions backed by earth placed in contact with concrete walls were conducted at the end of World War II. It was found that the scabbing limit of reinforced concrete, or thickness at which scabbing barely occurs, in case of a contact earth backed explosion, is given by:

$$T = 1.4W^{1/3}$$

where:

T = Thickness of concrete in feet.

W = Weight of explosive charge in lb.

Utilizing the 15 lb. charge in this formula, the results are T = 1.4 x 2.466 = 3.44 feet. Pressures on the face of the concrete roof derived from Table 4-1 from Reference 30 will fall in a range of 7,000 PSI to 3000 PSI assuming the shell, when it explodes, is 3" to 9" from the concrete respectively. Unfortunately, the layer of sand which was used to reduce the velocity of the shell will have the effect of confining the shell explosion and the pressures will be much higher (something on the order of 15,000 to 25,000 PSI). It appears from this that it would be beneficial to construct two layers of sand. One of 12" lying on the concrete and one of two foot thickness separated from the first layer by an airspace nominally of one foot. The benefit derived from this arrangement is that the total thickness would still affect the same velocity reduction but when the shell ricocheted it would have a tendency to slide up on the thin layer and explode close to the airspace between the layers. Thus the explosion would be partially vented and the pressure effect on the roof would be considerably reduced as a result of the venting. Additionally any sand between the shell and roof would attenuate the pressure effect of the explosion. Attenuation of the blast is considerably improved if the sand density is below 85 lb/ ft^3. This effect may be accomplished by mixing the sand with small pellets of expanded polystyene or similar material which would allow greater movement of the sand and, therefore, better blast absorption.

A further reduction in the effects of the blast may be accomplished by incorporating a flexible beam design after the methods described in Reference 30 so that the impulse loading is transmitted throughout the structure. Such a design will reduce the compressive pressure on the concrete upper surface and will reduce spalling. It may be eliminated in some cases. This will also reduce the thickness of concrete required to minimize the scabbing on the opposite surface.

(5) Rockets

The terminal velocities of rockets appear to vary inversely with range. The angle of incidence increases as the range increases. at approximately 11,000 yards, the terminal velocity of the 140 mm rocket is about 870 ft/sec and its angle of obliquity, 38°.

It is suggested that the rationale applied to the example of a 152 howitzer would be useful in the defeat of this shell and the 122 mm rocket. All this, of course, falls in the area of theory until tested by actual firings. It is suggested that in this case, it would be worthwhile to do so.

(6) Evaluation of Shapes for Desired Obliquities

From the foregoing discussion, it appears that roofs should be horizontal, walls should be slanted outward, or toward the attack, by about 20° to obtain the best ricochet probability from attack in any direction. Additional materials or layers in various combinations should be placeable on the structure when the conditions for ricochet are marginal. Easily penetratable materials should be placed at the base of walls to absorb ricochet fragments.

Of the sides presented for obliquity analysis, they rank as follows: (Refer to Figure 33, "Alternatives for Plans, Sides, and Tops") S-5, Inverted "V"; S-3, Slanted outward; and S-7, Curved. Side-five (S-5) is attractive because of the possibility of making a thick outer wall which may be penetrated but introduce tumbling. Subsequently, as the projectile proceeds, a high probability of ricochet at lower velocity against the inner wall would result. Side-five also has the best structural stability. The tops rank: T-2, Flat; T-1, Convex curved; T-5, Concave curved. These tops most closely approach the horizontal flat roof which appears best for ricochet. The most advantageous plan from the standpoint of obliquity is P-4, triangular, because of its angularity. Rectangles and squares such as P-2 and P-3 respectively appear to be second best and equal choices from an obliquity standpoint. Combinations of shapes employing triangles and rectangles may represent one of the better compromises between desirable characteristics of obliquity and practical consideration regarding functions. P-1 round, will present a normal surface from any azimuth of attack. The best combination of sides and tops are shown below (Refer to Figure 34, "Combinations of Sides and Tops):

TOP	SIDE
Flat	Inverted "V" Slanted outward Curved
Convex Curved	Inverted "V" Slanted outward Curved
Concave Curved	Inverted "V" Slanted outward Curved

c. Materials for Application to Concepts

The concept of a flexible response to escalation in the intensity of conflict (Paragraph 2a) necessitates that materials be identified that will form the basic core of the building. The basic core has several purposes:

First, it will provide space in which to perform an operational function. In the illustrative example that will follow below, the dimensions of the structure will be slightly larger than those specified for "Bare Base" modules (See Figure 32, "Sizes of Bare Base Structures"). The structures are sized to accept Bare Base modules and/or their equipment with about one foot or two feet clearances on all sides. In some cases, for example, aircraft shelters, space envelopes were used in sizing the facility.

Second, the basic core will be used to counter the projectiles associated initially with the lower orders of conflict. In the case which will be illustrated, the first projectile which is to be defeated is the 30 caliber. Subsequent levels of protection are treated for defeating the 50 caliber, the 20 mm, mortars, rockets and howitzers.

Third, the basic core will serve as an infra-structure upon which other materials may be added or mounted to improve the protective qualities of the structure against progressive increases in the intensities of conflict as mentioned above. Therefore, essential structural components of the building must be planned to accommodate the larger loads which might later be imposed if it becomes necessary to counter direct hits from projectiles of 160 mm or even larger.

With the above background in mind, then, to counter the 30 caliber projectile, the thickness of the first increment of the wall and roof will be a function of the material to be used and the slant of the walls and the roof with respect to the angle of attack of the projectile. The first step is to identify the materials to be used. The function of the material is to stop the projectile. The projectile can be stopped either by outright rejection, deflection, arrest or a combination of these features. The candidate materials for stopping the projectile at 0^{o} obliquity are:

MATERIAL	COST/POUND	POUNDS/SF REQUIRED FOR PROTECTION AGAINST 30 CAL AP (EST)	COST/SF FOR PROTECTION AGAINST 30 CAL AP (EST)
Steels			
Structural Steel	0.10	30.5 lb.	$ 3.05
Rolled homogeneous steel	0.60	21.0	12.50
High hardened steel	0.25	18.0	4.45
Face hardened steel	0.80	16.5	13.12
Dual hardened steel	-	-	-
Heat treated	1.50	11.5	17.25
Ausformed	4.00	10.5	42.00
Aluminum			
Aluminum 7039	0.75	19.0	14.30
Aluminum 5083	0.75	19.0	17.40
Aluminum oxide	1.26	ineffective used alone	-
Titanium 6Al-4V(EL1)	4.50	15.8	71.10
Fiberglass backed Materials			
Aluminium oxide	4.50	8.5	38.35
Boron carbide	27.00	6.5	175.50

MATERIAL	COST/POUND	POUNDS/SF REQUIRED FOR PROTECTION AGAINST 30 CAL AP (EST)	COST/SF FOR PROTECTION AGAINST 30 CAL AP (EST)
Plexiglass	1.50	27.0 lbs.	$ 40.50
Laminated glass	4.00	-	No Data
Glass plastic Laminate	8-10.00	25.0	170.00-250.00
Lexan	4.70	-	No Data
Other Manufactured			
1157 Doron Cloth	2.00	9	18.00
Ballistic Nylon Unbonded	1.24	4.16	5.15
Ballistic Nylon Bonded	1.65	4.75	7.83

The following materials are computed in place, no supporting structures included.

Concrete	\$50 yd^3	.011	55	.61
Sandy (dry)	\$4 yd^3	.0013	92	.12
Clay	\$2 yd^3	.00065	183	.12
Sandy Loam	\$2 yd^3	.00065	165	.11
Loam	\$2 yd^3	.00065	134	.09

All costs F.O.B. source except soils and concrete.

The cost of the material is based on the cost at the place of manufacture, except for native materials and materials mixed in place. Cost of transporting the material to the job site and installing it on the structure is not included. The amount (pounds per square foot) of material required to protect against the 30 caliber projectile was determined by referring to Figure 45, "Obliquity Angle Associated with Projectile Breakup." At an obliquity of 20°, the ratio of the thickness of a mild steel plate (T_s) to the caliber of the projectile (d) is equal to 1.3 T_s would equal 0.4 inches for a 30 caliber projectile. In this portion of the analysis when the term "mild steel" is used, it also refers to the equivalent of other materials to mild steel (Figure 47, "Thickness of Materials Required to Defeat Designated Projectiles"). Since the thicknesses of all materials considered (mild steel or its equivalent) will counter the projectile with varying degrees of efficiency, the choice of the material to be used is made on the basis of cost. In this case, mild steel was selected and 0.4 inches in thickness is required. The actions taken to protect primarily against 30 caliber projectiles carries with it a bonus which also protects against certain fragments from larger weapons such as the mortars, rockets and howitzers. Hence, it is necessary to install protective materials on the roof, not as a counter for the 30 caliber projectile, but as a counter to fragments from air bursts of other weapons if such weapons are employed by the

THICKNESSES OF MATERIALS REQUIRED TO DEFEAT DESIGNATED PROJECTILES

MATERIALS (THICKNESS IN INCHES)

PROJECTILE	MILD STEEL	DUAL ARMOR	SAND	CONCRETE	5083 AL	7039 AL	FACE HARDENED STEEL	STEEL (500 BHN)	TITANIUM 6Al-4V	TITANIUM 7Al-4V	B_4C-W.R.F.G.	S.C.-W.R.F.G.	85% Al_2O_3 F.G.
.30 AP	.75	.28	11	4	1.66	1.3	.44	.42	.68	.65	.29/.25	.29/.25	.37/.25
.50 AP	1.1	.63	17	5.2	3.16	2.56	.72	1.15	1.39	1.05	.62/.5	.52/.5	.62/.50
14.5 AP	2.37	1.45	20	7.1	4.34	3.64	—	1.39	1.69	1.6	2.28/.75	2.03/.75	2.25/.75
20 MM	3.72	—	26	10.6	4.56	5.60	—	2.06	—	—	—	—	—

VELOCITY	MV (F/S)	V@100 YARDS
30 AP	2760	2560 F/S
50 AP	2940	2800
14.5 MM AP	3280	3180
20 MM	3620	3460

NOTE:-
PENETRATIONS GIVEN FOR 100 YDS. RANGE

REF 16

FIGURE 47A

4-41

COMPARISON OF THE PENETRATION RESISTANCE OF VARIOUS PLASTIC MATERIALS TO COMPACT STEEL FRAGMENTS

MATERIAL	THICKNESS (INCHES) FOR PROTECTION					
	10 GRAINS		30 GRAINS		50 GRAINS	
	0°	60°	0°	60°	0°	60°
UNBONDED NYLON	1.7	.65	1.9	.75	2.1	.85
BONDED NYLON	1.3	.87	1.5	1.0	1.7	1.2
PLEXIGLAS AS CAST	1.0	.50	1.5	.70	1.7	.85
PLEXIGLAS STRETCHED	1.1	.70	1.25	.80	1.3	.85
DORON	.60	.35	.90	.45	1.0	.5

FRAGMENT WEIGHTS 10, 30, 50
FRAGMENT VELOCITY 3700 fps
0° AND 60° OBLIQUITY
lb = 7000 grains

REF 41

FIGURE 47B

THICKNESS OF PLASTIC TARGET MATERIALS vs AREAL DENSITY OF TARGET

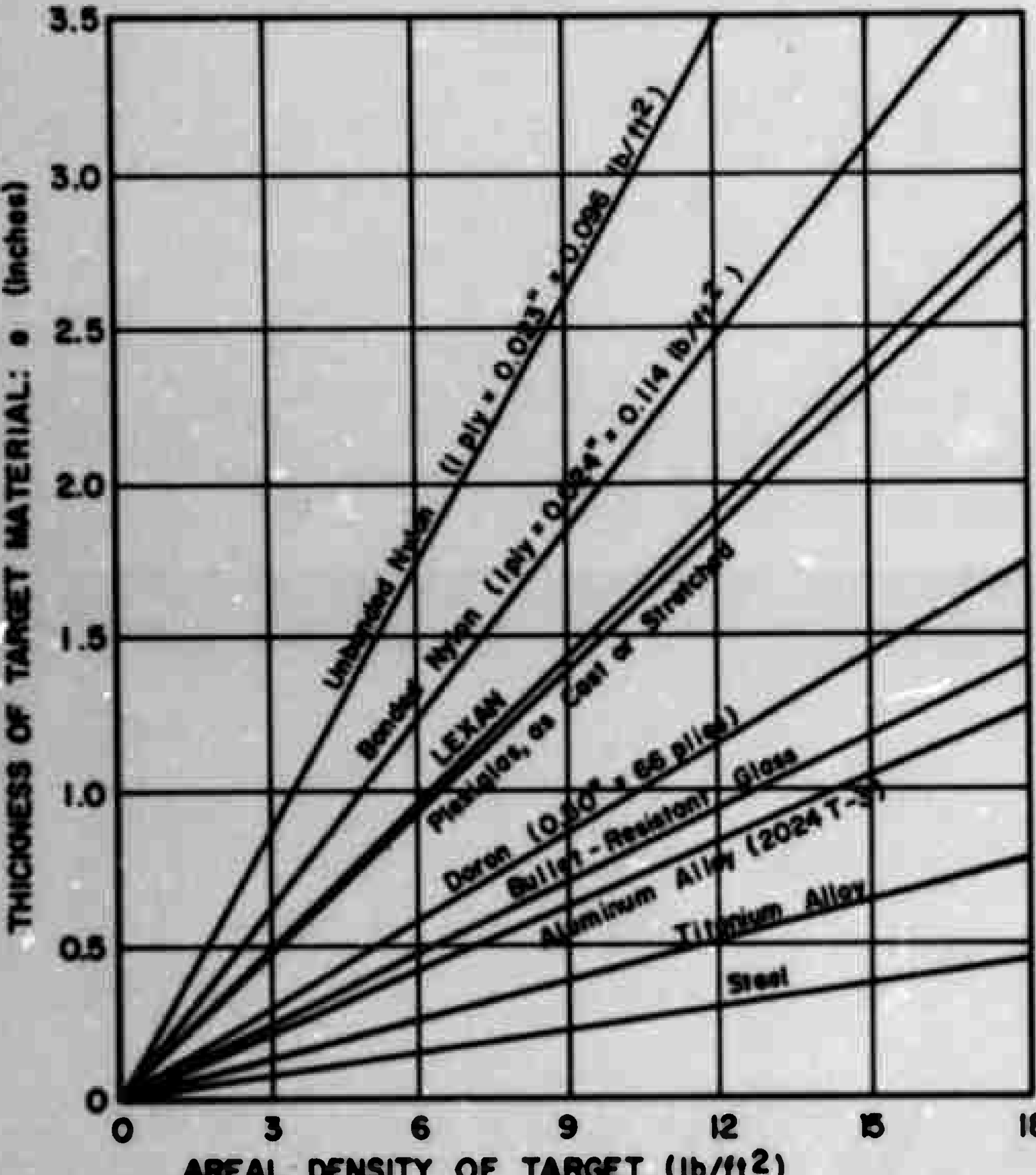


FIGURE 47C

REF 41

enemy. For example, 0.4 inches of mild steel (or the required thickness of another material) will protect against fragments from the larger weapons whose weights are less than 90 grains and whose velocities on impact do not exceed 2,000 feet per second (See Figure 48, "Thickness of Mild Steel as a Function of Random Fragments"). For comparative purposes by reference to Figure 49, "Thickness of Aluminum as a Function of Random Fragments," it can be seen that approximately 0.72 inches of aluminum alloy are required to perform the same function as 0.4 inches of mild steel.

The advantage gained by slanting the wall is also considered an important feature for countering the next higher caliber weapon contained in the threat (50 caliber). A combination of the 20 degree slant of the walls and the 0.4 inch thickness of mild steel (or equivalent of other material) is not sufficient to defeat the 50 caliber projectile. This is demonstrated by referring to Figure 44, "Breakup Prediction, Ricochet Model, AP Projectiles."

(1) The First Escalation

The basic core with its covering of protective materials provided protection against 30 caliber and fragments from large weapons whose weight and velocity did not exceed 50 grains and 2,000 feet per second respectively. The basic core did not quite protect against the 50 caliber threat.

THICKNESS OF MILD STEEL AS A FUNCTION OF MASS OF RANDOM FRAGMENTS

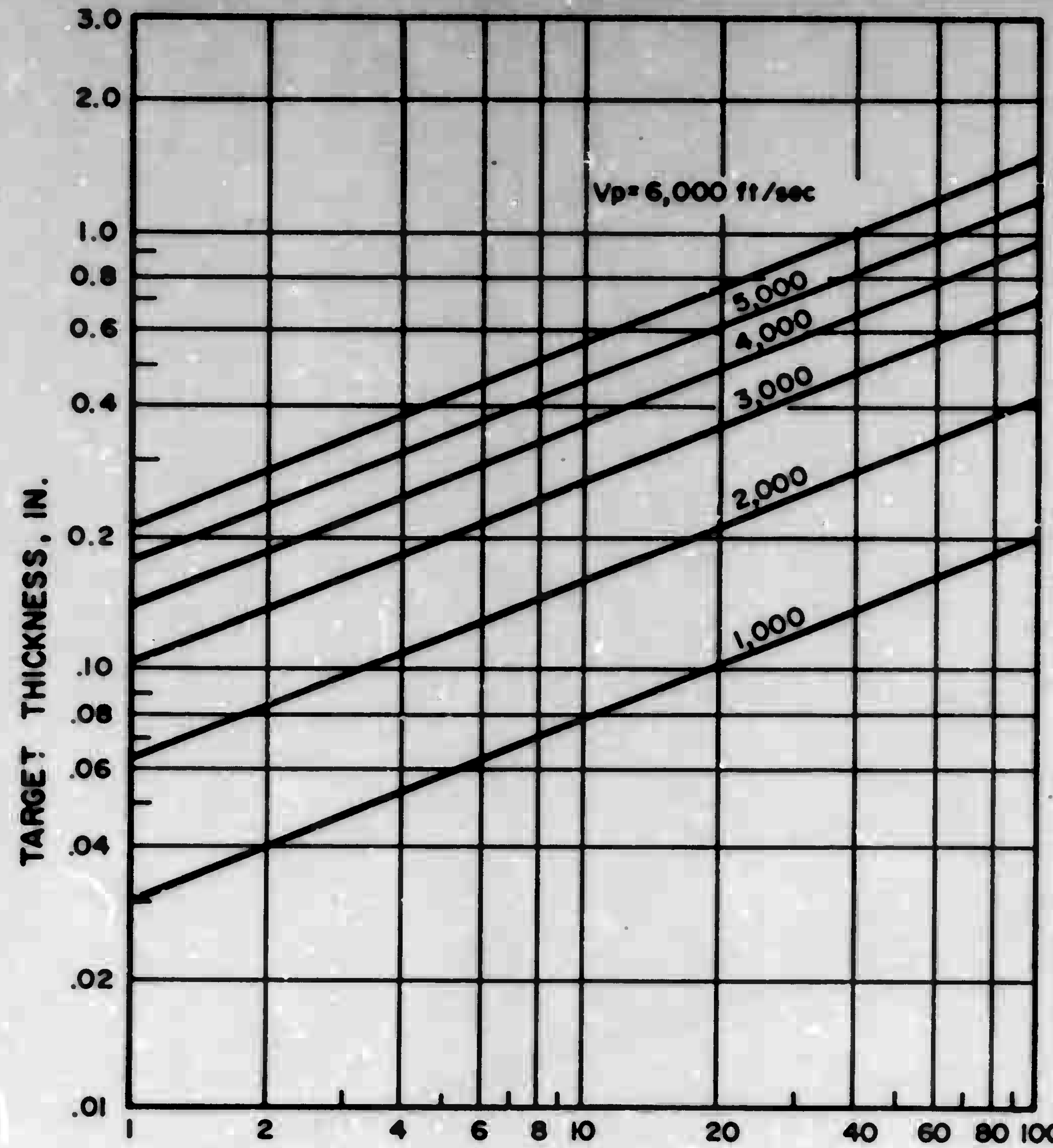
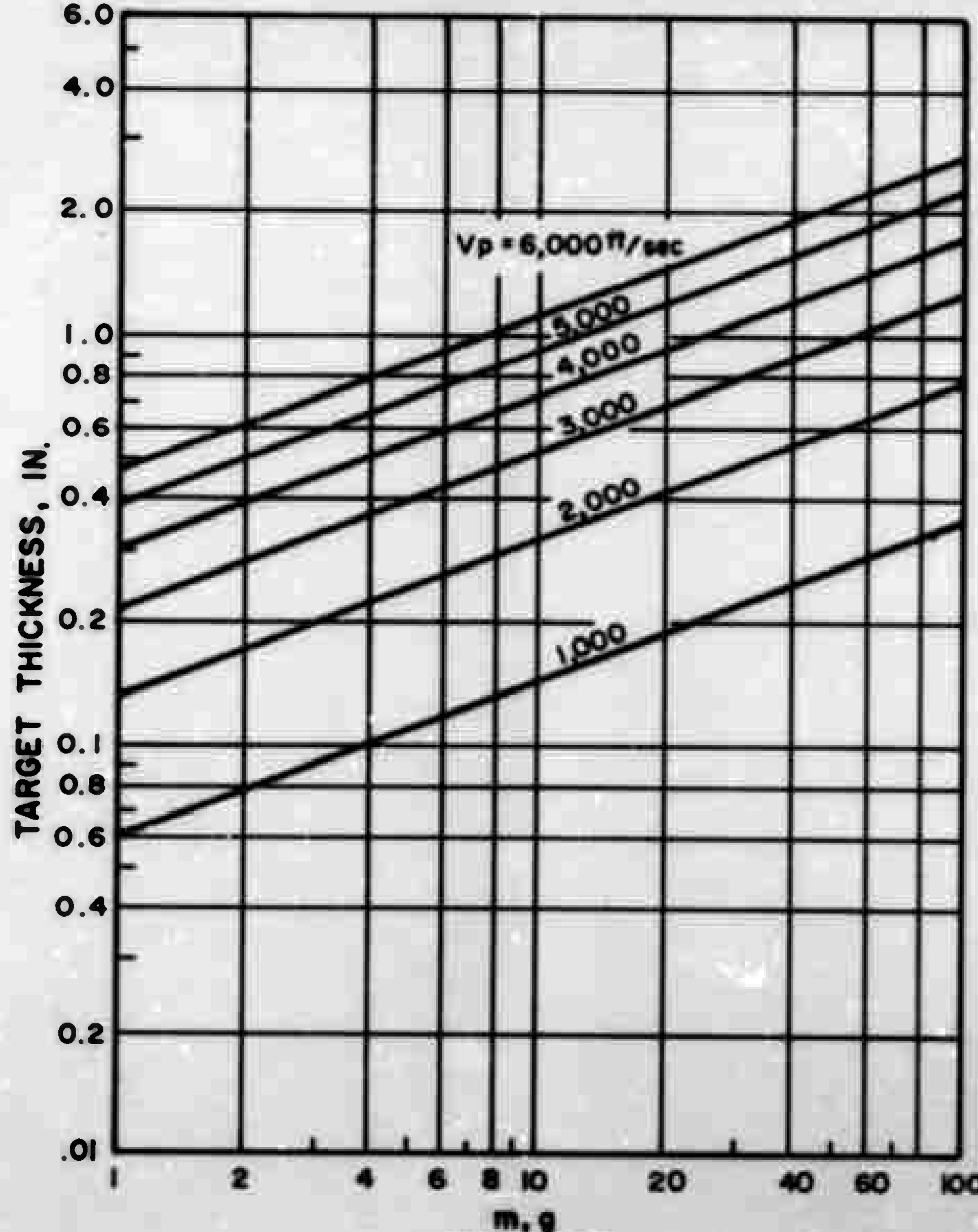


FIGURE 48

REF 25

THICKNESS OF ALUMINUM ALLOY AS A FUNCTION OF MASS OF RANDOM FRAGMENTS



NOTE:-
ALUMINUM 2024S-T USED.

FIGURE 49

REF 25

As can be seen from Figure 44, "Breakup Prediction, Ricochet Model, AP Projectiles," if the obliquity angle can be increased above the 20 degrees of the slanted wall, the same thickness of material that would stop a 30 caliber projectile at an obliquity of 20 degrees would also cause breakup of the 50 caliber projectile at about 31 degrees. Therefore, action should be taken to design a method that would cause tumbling or rotation of the 50 caliber projectile by at least 11 degrees. Materials that deflect projectiles should be placed in front of basic core plate. A screen so placed at the proper distance from the basic core structure would cause the projectile to tumble. This same screen could also be used to "trigger" projectiles equipped with instantaneous fuses and cause activation of projectiles with delayed fuses. Figure 50, "Penetration Behavior of 7.6 mm AP versus Mild Steel" shows that a substantial change in projectile orientation (tumbling) can be expected as a result of the installation of a "trigger" screen. Even at an obliquity of zero degrees, 0.037 inches of mild steel will cause a 7.62 mm AP projectile to tumble. Tests performed at Aberdeen Proving Ground indicate that an expanded metal screen weighing 1.2 pounds per square foot and placed 10 feet in front of a target defended by 4 feet of sand bags were effective in defeating the Soviet RPG-2 and RPG-7 weapons. Without a trigger screen a substantial increase

PENETRATION BEHAVIOR OF 7.62MM A. P. vs MILD STEEL

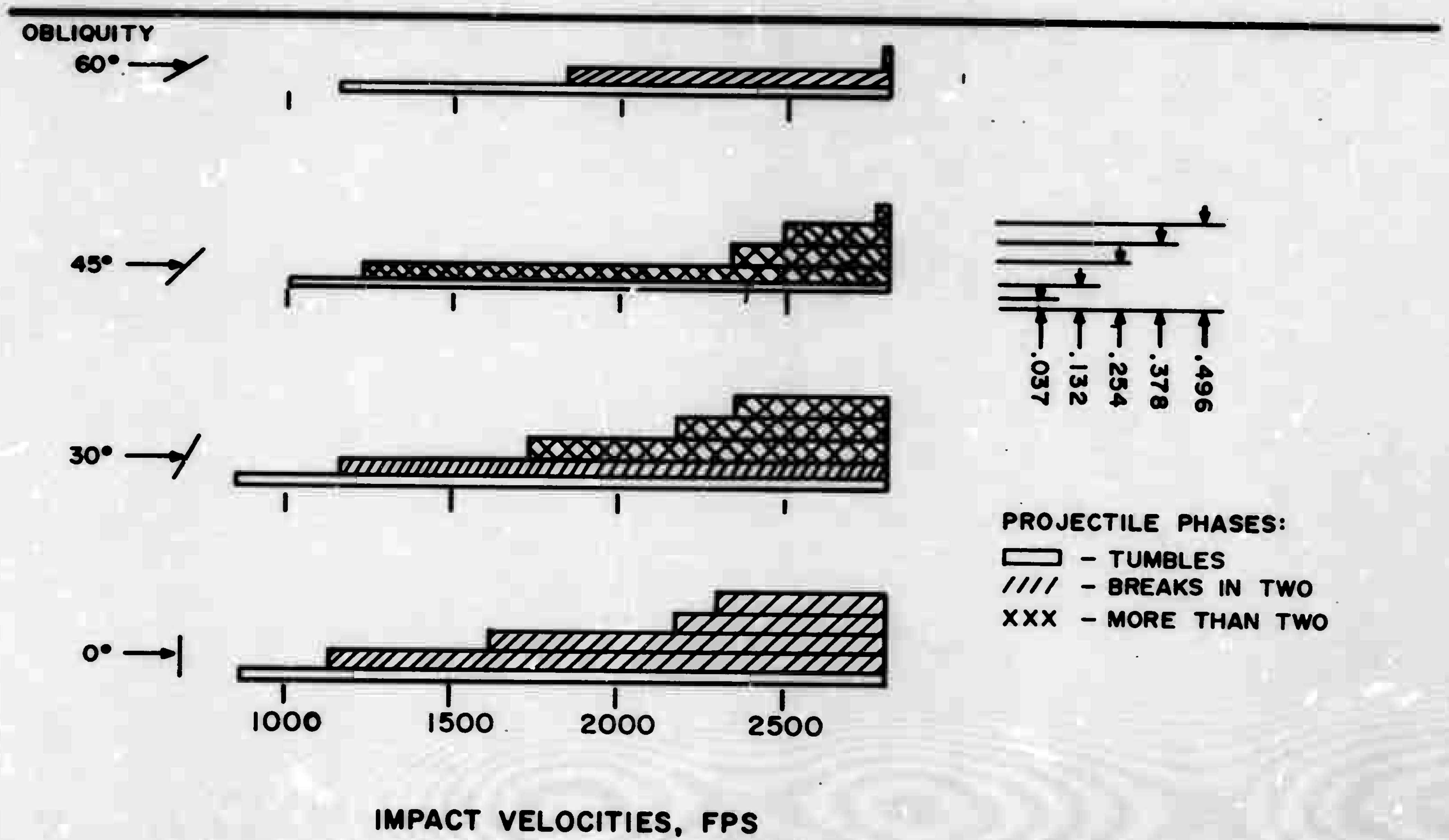


FIGURE 50

REF 1

in the thickness of sand is required to defend against these weapons. A trigger screen, therefore, is an inexpensive method of:

1. Causing projectiles of 50 caliber to tumble
2. Activating delayed fuses
3. Detonating instantaneous fuses and
4. Degrading anti-tank weapons which are being used against stationary targets.

The first modification to the basic core, then, should be the addition of a trigger screen, Figure 51a, "Structuring of the Concept." It can either be installed on rigging provided as part of the basic core or as a separate undertaking. If the "rigging" were provided as part of the basic core, it would generally be more economical and quicker to install the trigger screen when and if it is required.

(2) <u>The Second Escalation</u>

The 20 mm projectile is the next size projectile which is to be defeated. Following the same reasoning advanced for handling 50 caliber size projectiles, the 20 mm requires 1.04 inches of mild steel to defeat it at an obliquity of 20 degrees. (The trigger screen can be expected to cause some projectile rotation.) The options are to add another plate immediately against existing basic core or to add the required thickness of plate at some distance, either inside or outside, the basic core structure.

Separating the plates gives the opportunity to add yet another level of protection by placing material such as sand, concrete, asphalt, soil, metal grits or combinations between the two plate surfaces without removing protective plates and starting anew. This configuration also affords the opportunity for the projectile or its fragments to be slowed down and to change orientation prior to impacting on the basic core plate by virtue of its passing through the trigger screen, the added plate and a dead space. This broaches the questions alluded to earlier, in Paragraph 4b and on Figure 25, "Combination", on the value of layered materials for structures for protective defence.

The concept of layering and/or using composite materials for protection was advanced by Major N. M. Hopkins in 1918, but little follow-through was done on his concepts. In 1964, however, American industry developed protective materials using a combination of reinforced plastic and a ceramic. This combination has countered armor-piercing projectiles traveling 3,000 feet per second. Promising ceramic materials for use in this application are: Aluminum oxide, Silicon-carbide, and Boron-carbide. All of these materials possess outstanding hardness qualities. The least expensive of the three materials is Aluminum-oxide. The hardest and lightest is Boron-carbide. Notwithstanding the exceptional characteristics of these materials, structural steel is, by far, the material which gives the greatest protection per dollar. However, it has the disadvantage of being exceedingly heavy. The advantage of ceramics is that they exhibit high temperature resistance and hardness. They have compressive strengths of 150,000 psi in comparison with steel of 100,000 psi. However, the low resistance to impact and, therefore, fracture makes them of little value for penetration resistance when used alone. To overcome the generation of secondary fragments and to absorb the rarefaction shock wave resulting from the projectile impingement, a metal or plastic backing plate can be used. If, however, ductile behavior of the ceramic can be assumed Figure 28, "Computed Velocity-Penetration Curves for a Conical Projectile Assuming Ductile Behavior of Target Materials", shows the superior resistance of ceramic materials to penetration over other materials. These specific curves are dedicated to the particular size and shape of the projectile considered, but the principle demonstrated holds. Plastic composite structures for backing ceramics are made of woven glass roving with polyester resin urethane or epoxy as the binder. Of three backing methods (metal, plastic or composite) the composite of glass roving with a resin has the best penetration resistance, is the most readily available and the least expensive. The best performing and lightest combination of ceramic with plastic backing is Boron-Carbide and woven glass. The poorest performer and the least expensive is Aluminum-oxide with woven glass backing. These combinations of materials have application primarily to armor for personnel. Actual costs of producing armor for this application are approximately $19 per square foot for Aluminum-oxide, $56 per square foot for Silicon-carbide and $97 per square foot for Boron-carbide. By comparison, dual property steel and mild steel costs are extremely low for use in structures used in passive defense.

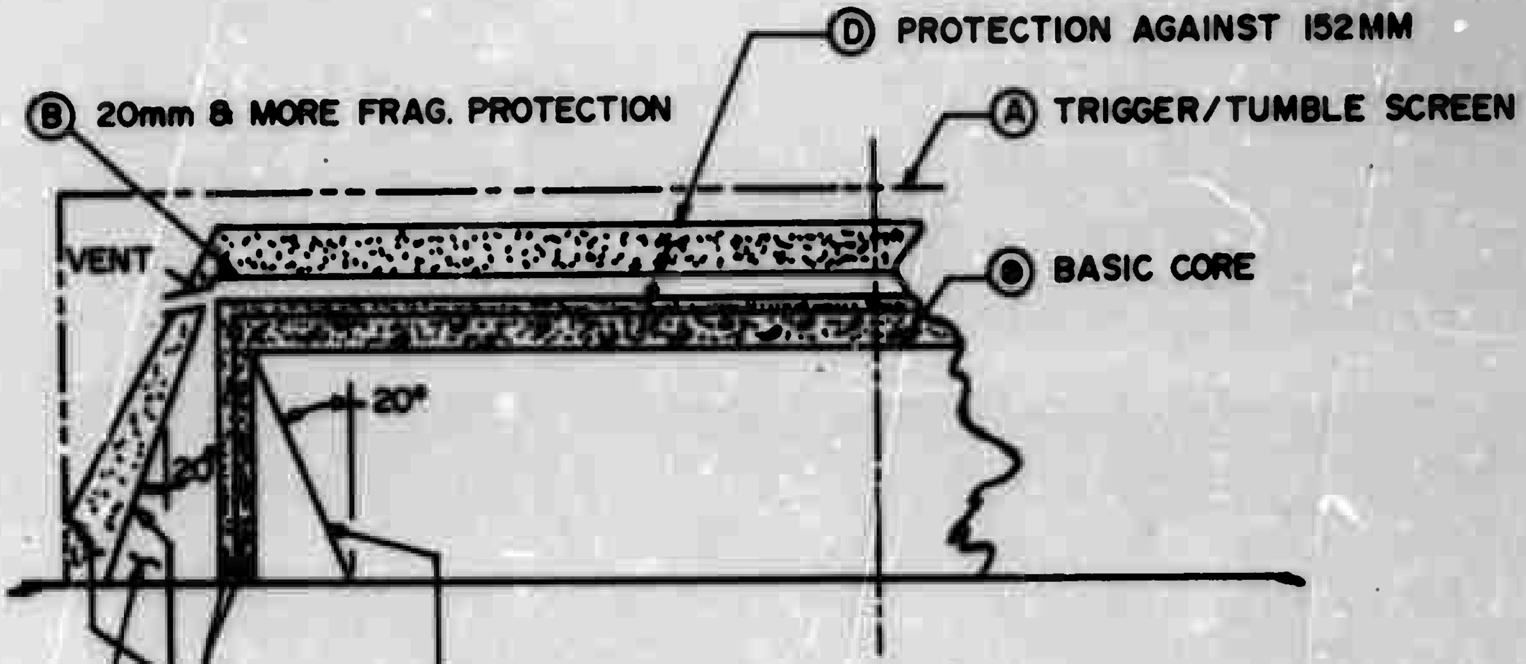
From the above discussion, to counter the 20 mm projectile and at the same time preserve the option to upgrade the structure for more severe threats, it appears that the best course of action is to create a laminar structure. The arguments presented earlier regarding ricochet would also apply. As stated earlier, a total of 1.04 inches of mild steel in a single plate is needed to defeat the 20 mm projectile at an obliquity of 20 degrees. The basic core provided a wall of 0.4 inches or the equivalent of mild steel at 20 degrees slanted outward. If, however, another plate of 0.4 inch thickness and inclined 20 degrees in the opposite direction were installed in front of the basic core plate, the 20 mm projectile would be defeated, (see Figure 51b, "Structuring of the Concept"). The projectile would first be deflected by the trigger screen. Next, the projectile, in a "yawed" posture, would "see" the 0.4 inch thick mild steel outer wall of the structure inclined 20 degrees upward. Depending on the amount of yaw, the 20 mm projectile wou . perforate this layer of material only to "see" another plate of the same thickness inclined 20 degrees downward. During the penetrations of the trigger screen and initial steel plate, the projectile would lose energy and suffer disorientation to such a degree that the final layer of steel would counter the weapon.

Providing a second mild steel plate around the structure was primarily intended to counter the 20 mm projectile; however, the combined layers of material will defeat many of the fragments from larger weapons. Fragments whose size and velocity do not exceed 60 grains and 3,000 feet per second respectively will be defeated. This group of fragmentation is roughly the equivalent to fragments from the 122 mm and the 160 mm projectiles and rockets.

(3) Final Responses to Escalation

The basic core of the structure provided the structural system for the final configuration. It also gave protection against the 30 caliber projectile and fragments from the 82 mm mortar. The first escalation of the facility provided a trigger screen. The combination of the trigger screen and the basic core countered the 50 caliber and fragments from the 60 mm mortar and RPG-2 and RPG-7 anti-tank weapons. The second escalation added another layer of protective material to defeat the 20 mm projectile and fragments from 122 mm and 160 mm projectiles. Voids now exist in two places. First, between the basic core wall and the outer wall, and second, between the outer wall

STRUCTURING THE CONCEPT



(●) 0.4" MILD STEEL INCLINED 20° WILL STOP 30 CALIBER & 90 GRAIN FRAGMENTS @ 2000 fps (82mm mortar).

(A) 1.2 #/▯ SCREEN WILL CAUSE 50 CALIBER TO YAW 11°. TRIGGERS FUSES. HELPS TO COUNTER RPG 2,7 & 57mm MORTAR FRAGS.

(B) 0.4" MILD STEEL INCLINED 20° WILL SLOW & DISORIENT THE 20mm TO EXTENT THAT IT WILL BE STOPPED BY BASIC CORE.

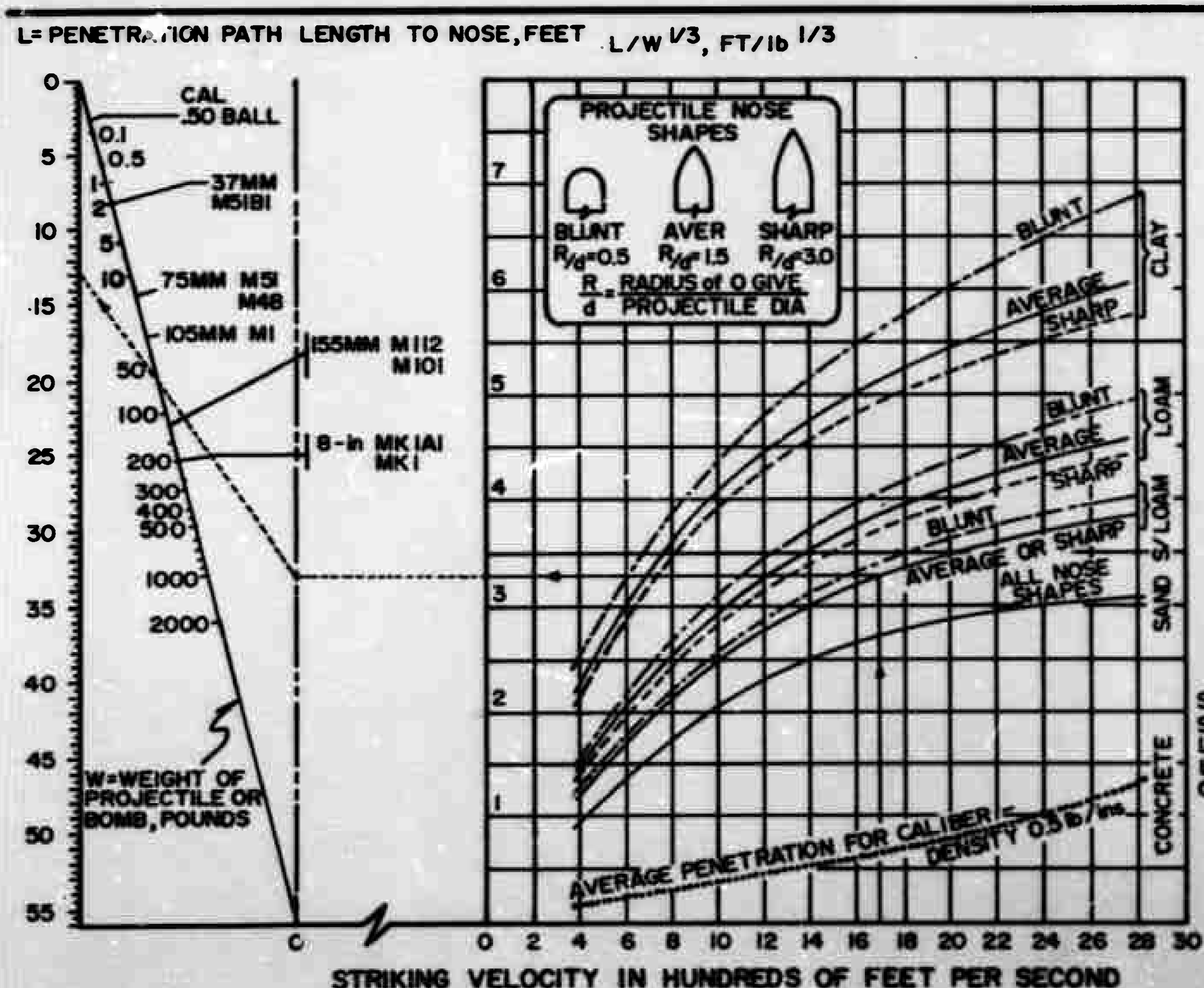
(C) VOIDS

(D) FILL VOIDS WITH CONCRETE & SAND. LEAVE VENTED SPACE FOR EXHAUST OF EXPLOSION PRODUCTS & FORCES. THIS PROTECTS AGAINST THE 122mm & 152mm - 2' SAND, VENTED VOID, 1' SAND, 18" CONCRETE.

FIGURE 51 A THRU D

and the trigger scree , (See Figure 51c, "Structuring of the Concept"). These voids are intended to be filled with either special or indigenous materials, which include but are not limited to, soil (sand, clay, and silt used separately or in combinations), soil-cement, concrete, gravel, asphaltic concrete, native woods, specially prepared composition materials such as metal grit and asphalt, or combinations of these materials (see Figure 51d). The addition of these heavy and thick materials are intended to counter direct hits from projectiles in the balance of the threat up to the 160 mm size. Figure 52, "Penetration of Bombs and Projectiles into Soil", gives the thickness of concrete or the various types of soil required to defeat conventional weapons of all sizes. For example, a sharp projectile with a striking velocity of 1,700 feet per second and weighing 60 pounds would require 12.5 feet of sandy loam to arrest it. The field commander should make use of the various combinations of materials available to him and place them in the proper thicknesses in accordance with Figure 52. Anticipating the worst case, the structural system in the basic core has been sized to support the two 0.4 inch steel shields, the trigger screen, 4 feet of sand and 2.2 feet of concrete. The 2.2 feet of concrete will defeat a 500 pound general purpose bomb having a 990 feet per second impact velocity and dropped from 20,000 feet. It is interesting to note that if this same bomb had an impact angle with respect to the horizontal

PENETRATION OF BOMBS AND PROJECTILES INTO SOIL



SOIL COMPOSITION

	SAND	SILT	CLAY
SAND	95%	5%	0%
SANDY LOAM	70%	20%	10%
LOAM	50%	35%	15%
CLAY	30%	30%	40%

REF 44

FIGURE 52

of 63 degrees, the bomb would ricochet. Figure 46, "Ricochet from Water, Soil and Concrete", yields the impact angles at which projectiles will ricochet given their striking velocities.

d. Choices of Terrestrial Environments

The provisions of Paragraph 3d "Terrestrial Environment of Structures", covered this subject. It is recommended that:

- Aircraft shelter be constructed on the surfaces and covered with protective materials,
- Barracks and C^3 facilities be placed initially in a partly buried environment and then covered with the earth excavated,
- POL be totally buried.

e. Structural Forms

The structural forms considered for application to passive protection measures were (Figure 53, "Structural Schemes"):

- o Arch
- o Truss
- o Cable
- o Plate Girder
- o Bridge Deck

General Limitations

Increases in span or loading causes structural economic problems with the plate girder as both shear buckling and bending instability are concerned. The truss suffers from connection costs and depth of construction. The arch suffers from compression buckling. The cable limitations are functions of dead weight, sag and anchorages.

Typical Cross Sections and Costs

Maximum clear spans for structures to be used for passive protection are on the order of 70 feet. These spans are not considered to be exceptionally long. Therefore, those structural systems, which are most economical for long spans, while very promising, are not necessarily the most economical systems for application to this particular task. The general relationships among types of structural systems, their spans and costs are shown in Figure 54, "Comparison of Costs of Structural Schemes as a Function of Span." It can be seen that the arch is the most cost effective system within the clear spans for the aircraft shelters under consideration in this study. Figure 55, "Comparison of Costs of Alternative Structural Schemes," summarizes the geometrical characteristics and unit costs for the various structural alternatives. Notwithstanding this general conclusion, however, all structural schemes were given the full consideration; and design, calculations and cost estimates were produced (See Section 5, "Preferred Concepts") which validate these conclusions.

ALTERNATE STRUCTURAL SCHEMES

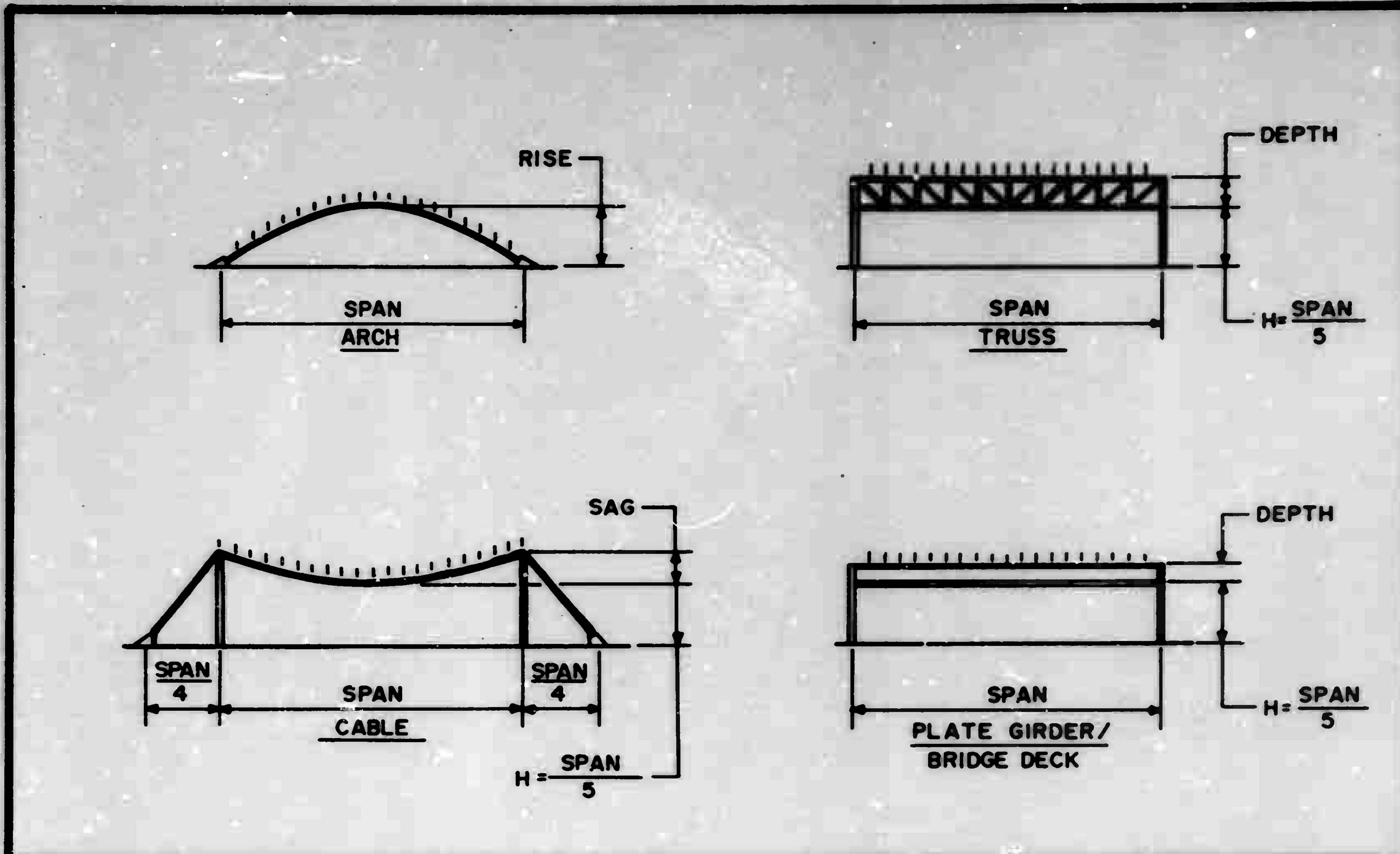


FIGURE 53

COMPARISON OF COSTS OF STRUCTURAL SCHEMES AS A FUNCTION OF SPAN

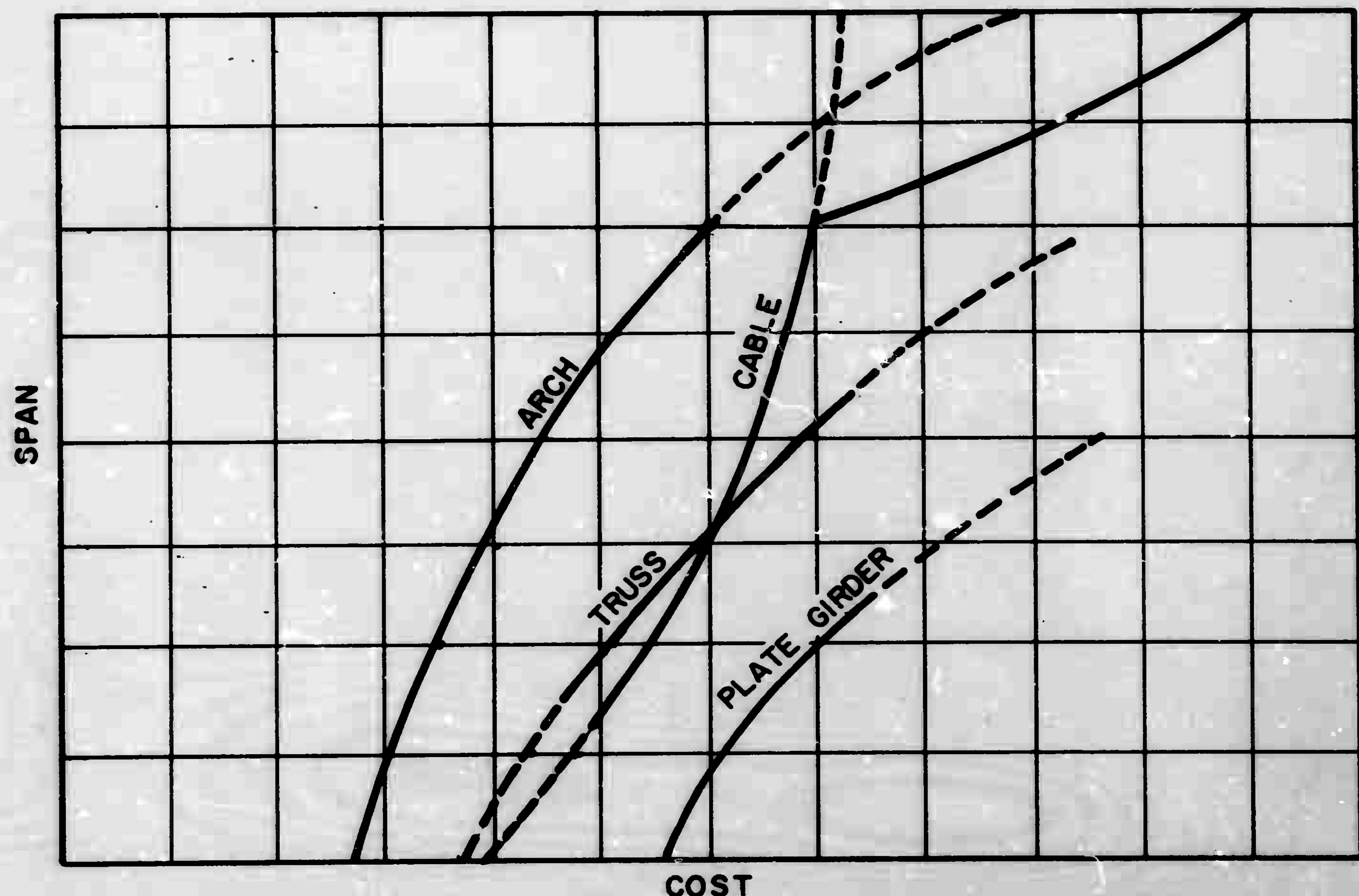


FIGURE 54

REF

COMPARISON OF COSTS OF ALTERNATE STRUCTURAL SCHEMES

	SPAN = 100 FEET				SPAN = 200 FEET				SPAN = 300 FEET			
	Θ	W_S	W_A	C	Θ	W_S	W_A	C	Θ	W_S	W_A	C
CABLE	1/10	550	4500	1.35 / 0.60	1/10	2200	8350	1.60 / 0.65	1/10	4950	11,460	1.75 / 0.70
ARCH	1/5	2000	1400	0.90 / 0.70	1/5	8000	5600	1.15 / 0.70	1/5	18,000	12,600	1.50 / 0.80
TRUSS	1/10	5800	4000	1.30 / 0.50	1/10	24,100	6000	1.75 / 0.50				
PLATE GIRDER	1/20	14,300	4000	1.80 / 0.50								

	SPAN = 400 FEET				SPAN = 500 FEET				SPAN = 600 FEET			
	Θ	W_S	W_A	C	Θ	W_S	W_A	C	Θ	W_S	W_A	C
CABLE	1/10	17,600	15,650	2.70 / 0.80	1/10	27,500	21,350	3.20 / 0.90	1/10	39,600	27,700	3.65 / 1.00

Θ = OPTIMUM SAG-RISE-DEPTH/SPAN RATIO

W_S = WEIGHT IN LB OF SPANNING ELEMENT PER 24 FT.-WIDE BAY

W = WEIGHT IN LB OF SUPPORTS AND/OR ANCHORAGES

C = UNIT COST PER SQ. FT. IN DOLLARS OF SUPER-STRUCTURE INCLUDING ACCESSORIES (UPPER FIGURE) - UNIT COST OF FOUNDATIONS (LOWER FIGURE)

FIGURE 55

f. Penetration Analysis

(1) Introduction

An analytical study of the penetration and/or perforation of various protective materials by projectiles would preferably be based on theoretically developed expressions which have been experimentally validated. Although efforts have been directed to the problem of developing a sound theory of penetration, there still remains a need for basic equations which consider all of the various dynamic phenomena associated with penetration. Only meager and poorly correlated information is available on: (1) the conditions of striking velocity, obliquity and target thickness under which projectiles will fail; (2) the prediction of the remaining velocity of a projectile as it penetrates successive layers of a composite protective material; and (3) the manner in which resisting forces of a material vary with depth, projectile shape, and velocity during penetration.

As a result of the above conditions, this study was based on selected empirical formulae which have been developed from the test data during the past twenty-five years.

In addition to providing the basis for development of conceptual protective structures, this study effort also produced computer programs which may be applied to penetration problems other than those addressed by this undertaking.

An empirically-based expression for predicting projectile penetration time through each layer of multilayered slabs of soil and concrete, and the identification of a method of predicting penetration of other materials by using their dynamic properties was derived in this effort.

The types of materials considered for use in the design of protective structures were: (1) soils, such as sand, loam, and clay; (2) concrete; (3) metals; (4) plastics; and (5) wood (Figure 56, "Identify Applicable Materials - Type"). Various combinations of the materials in different layer sequences were investigated, as well as single layers of the metals and plastics.

(2) Penetration of Soils and Concrete

(a) An expression which fits the curves shown in Figure 52, "Penetration of Bombs and Projectiles into Soil and Concrete," was used for predicting the penetration of soils and concrete by various caliber projectiles.

[AA] $$L = W^{\frac{1}{3}} K \operatorname{Log}_e \left[\left(\frac{V}{C}\right)^2 + 1 \right]$$

where:

L = Penetration (feet)

W = Projectile weight (pounds)

K = Curve fit constant $(ft/lb)^{\frac{1}{3}}$

C = Curve fit constant (fps)

V = Striking velocity (fps)

IDENTIFY APPLICABLE MATERIALS

TYPES

- WOOD
  - HARD
  - SOFT
  - PLY
  - FIBRE
- MINERAL
  - CEMENT
  - GLASS
  - ASBESTOS
  - GYPSUM
  - CERAMICS
  - SOILS
  - ASPHALT
- PLASTIC
  - THERMO
  - THERMO SET
  - COMBINATIONS
- METAL
  - FERROUS
  - NON-FERROUS
  - LIGHT ALLOY
- COMBINATION
  - WOOD
  - PLASTIC
  - MINERAL
  - METAL

FIGURE 56

Values of K and C developed by the Army Ballistic Research Laboratory are listed below:

Soil	Nose Shape	K	C	Limiting V
Clay	Blunt	1.0650	126.74	1800
	Average	1.0246	137.71	2000
	Sharp	1.0339	151.19	1600
Loam	Blunt	.9250	188.18	2000
	Average	.8833	191.96	2000
	Sharp	.8753	201.25	1800
Sandy Loam	Blunt	.8353	214.87	1900
	Average or Sharp	.7932	212.61	2000
Sand	All	.7220	249.21	1800
Reinforced Concrete	All	.2796	582.24	1800

(b) There are several limitations in the use of equation AA for penetration prediction. First, the expression applies only to normal impact, and the dependence of ricochet, splashing, spalling and perforation on obliquity must be considered separately. Secondly, since the stress wave generated by the projectile produces spalling at the back face of a finite concrete slab, a correction must be made to determine the thickness at which perforation results. Tests have shown that, within 10%, the thickness at which perforation results (T) can be expressed in terms of the depth of the penetration media (L) and the diameter of the projectile (d) by:

$$T = 1.26\,d + 1.13\,L$$

(c) There are three sources of errors in the values of L obtained. They are:

(1) The curves in Figure 52 agree with test measurements only to $\pm$ 20 per cent. This is because of the variation in weapon performance.

(2) The vertical penetration of a projectile is 10-30 per cent less than L (the penetration path length for solid due to curving of the projectile towards the surface).

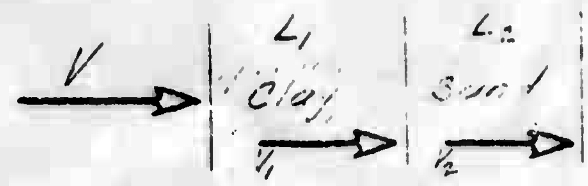
(3) There is a curve fit error of approximately $\pm$ 5 per cent above striking velocities of 1600-2000 fps. Finally, only one curve is shown (assumed to be for average nose shape) for concrete. (It should be noted that for a "worst case" condition, the limitation of zero obliquity is eliminated; i.e., the projectile can be assumed to strike successive layers of a composite material at normal incidence for maximum penetration).

(d) Equation AA can be rewritten for application to penetration of multilayered soil and concrete as follows:

[AB]

$$V = C\sqrt{e^{\left(\frac{L}{W \cdot K}\right)} - 1}$$

Consider penetration of a dual-layer material as shown below.



For specified values of L_1 and L_2, V_1 and V_2 can be determined. Note that when $\left(\frac{L_1 + L_2}{W^{1/3} K}\right) = 1$, V = 0. (Interaction between layers is assumed to be insignificant.)

Equation AB can be written as follows:

[AC] $$v = \frac{dx}{dt} = C\sqrt{e^{\left[\frac{L - x}{W^{1/3} K}\right]} - 1}$$

where:

v = Velocity at penetration x(fps)

x = Partial penetration (ft)

L = Total penetration (ft)

Integrating with respect to time,

$$Ct = \int_0^x \frac{dx}{\sqrt{e^{H(L-x)} - 1}}$$

where:

$$H = \frac{1}{W^{1/3} K}$$

Letting $u = H(L - x)$,

$$du = -H\,dx$$

$$Ct = \frac{1}{H}\int_0^u \frac{du}{\sqrt{e^u - 1}}$$

and

$$Ct = \frac{\tan^{-1}}{H} \sqrt{e^{u} - 1} \Bigg]_{H(L-x)}^{HL}$$

Therefore,

[AD] $$t = \frac{W^{1/3} K}{C} \left[\tan^{-1} \frac{V}{C} - \tan^{-1} \left(\frac{v}{C} \right) \right]$$

(e) Since the time of penetration through each layer can be calculated, the point at which delayed fuses will detonate can be predicted.

(3) Penetration of Metals and Plastics

(a) An empirical formula developed by the Denver Research Institute was used for predicting the thickness of metals and plastics required to prevent perforation.

[CA] $$T_s = C_1 \frac{M_p}{aL} \left\{ (V_{50}) - \frac{b}{a} \log_e \left[1 + \frac{a}{b} (V_{50}) \right] \right\}$$

where:

T_s = Thickness required to prevent perforation (with a .5 probability)

C_1 = Form factor related to projectile shape

M_p = Projectile (core) mass

L = Projectile (core) length

$(V_{50})n$ = Normal ballistic limit velocity

$a = \pi \sqrt{K\rho} \sin\phi \tan\phi + f$

K = Dynamic bulk modulus

ρ = Material density

ϕ = Projectile apex half-angle

f = Sliding coefficient of friction

$b = 2\pi \tau_s \tan\phi (\tan\phi + f) \log_e 2 Z_m$

τ_s = Dynamic compressive shear strength

$$Z_m = \frac{E}{\sigma y} \sqrt{\frac{1}{1 + \frac{2E}{\sigma y}}}$$

E = Young's modulus

σy = Static tensile yield strength

(Values of K, e, τ_s and E for typical armor materials are in Table IV)

Equation CA can be corrected for obliquity by using one of the following:

$V_{50} \cong (V_{50})_n \sec\theta$. when $\frac{T_s}{d} \leq 2$.

$(T_s)_\ell = T_s \sec\theta$. when $\frac{T_s}{d} \geq 2$.

where:

V_{50} = Ballistic limit velocity (θ)

θ = Impact obliquity

$(T_s)_\ell$ = Effective Thickness (θ)

(b) A limitation associated with the use of CA is that the equation has been validated using static rather than dynamic properties (K and τ_s) of metals. (However, predictions were reasonably close to experimental data.)

(c) Although dynamic properties of armor materials are not directly available, a method of determining such values for use in equation CA as originally intended will be outlined.

The following equation can be used to determine the dynamic compressive shear strength of a particular material from data obtained at the Hugoniot elastic limit:

[CB] $$\tau_s = \frac{\sigma_{he}}{2}\left(\frac{1-2\nu}{1-\nu}\right)$$

where:

τ_s = Dynamic compressive shear strength

σ_{he} = Hugoniot yield strength

ν = Poisson's ratio

(Shear strength equals one-half yield strength under a condition of one-dimensional compression)

(d) The dynamic bulk modulus of a material can be determined using the following equation:

TABLE IV. TYPICAL MATERIAL PROPERTIES*

	K psi (10^6)		ρ $\frac{lb\text{-}sec^2}{in^4}$ (10^{-4})	τ_s** psi (10^3)		E psi (10^6)	σ_y psi (10^3)	$\sqrt{K_c}$ $\frac{lb\text{-}sec}{in^3}$	
	Static	Dynamic		Static	Dynamic	Static	Static	Static	Dynamic
Steel Armor (350 BHN)	23	40	7.3	90	138	30	150	130	171
Glass	5.3	-	2.3	70	-	10	8	33	-
Lead Glass	5	-	5.8	70	-	7.4	8	56	-
Plexiglass	0.75	-	1.1	11	-	0.45	10	9	-
Lexan	0.45	-	1.2	9	-	0.32	10	7	-
Aluminum Oxide	(25-30)	70	3.5	150	570	44	28	93	157
Aluminum (5083-H113)	10	-	2.4	26	-	10.3	33	50	-
Aluminum (2024-T4)	10	-	2.6	35	-	10	47	51	-
Titanium (6Al-4V)	18.3	-	4.2	70	-	16.5	120	88	-
Magnesium (13Li-6Al)	6	-	1.6	22	-	6.5	2[illegible]	31	-
Doron (epoxy-Glass Cloth Laminate)	(est.)	-	1.8	20	-	3.0	30	19 (est.)	-

* Dynamic values are those associated with Hugoniot elastic limit and are used for illustrative purposes only. At 300 kilobars (4.3×10^6 psi) dynamic values of bulk modulus and shear strength will be lower than those observed at the Hugoniot elastic limit.

** Compressive

Source: NWC 4532

[CC] $$K = \frac{P^2}{\rho V^2}$$

where:

K = Dynamic bulk modulus

P = Impact pressure

ρ = Material density at P

V = Instantaneous velocity

Using a source of Hugoniot shock data such as described in Reference 42, the ratio $\frac{\rho}{\rho_o}$ corresponding to the pressure P at the Hugoniot elastic limit can be determined.

For metals, $P = A\mu + B\mu^2 + C\mu^3$ where experimental values of A, B and C are listed in Table V. For a given P, μ can be determined by means of a cubic root solution. Finally, using the formula $\rho = \rho_o(1 + \mu)$ the density corresponding to P can be calculated, and K can be determined.

(e) For plastics, $P = A(\eta - 1)\frac{\eta}{(K - \eta)^2}$ where values of A and K are listed in Table VI. For a given P, can be determined. Again, using the formula the density can be calculated, and the dynamic bulk modules K can be determined.

(4) <u>Penetration of Metal Plates</u>

(a) Equation CA was developed primarily for use in predicting perforation of thick and moderately thick materials,

TABLE V

Values of constants. (Pressure range in which fit was made is up to about 500 kilobars.)

Metal	A	B	C
Beryllium	1182	1382	0
Cadmium	479	1087	2829
Chromium	2070	2236	7029
Cobalt	1954	3889	1728
Copper	1407	2871	2335
Gold	1727	5267	0
Lead	417	1159	1010
Magnesium	370	540	186
Molybdenum	2686	4243	733
Nickel	1963	3750	0
Silver	1088	2687	2520
Thorium	572	646	855
Tin	432	878	1935
Titanium	990	1168	1246
Zinc	662	1577	1242
24 ST aluminum	765	1659	428
Brass	1037	2177	3275
Indium	496	1163	0
Niobium	1658	2786	0
Palladium	1744	3801	15230
Platinum	2760	7260	0
Rhodium	2842	6452	0
Tantalum	1790	3023	0
Thallium	317	938	1485
Zirconium	934	720	0
Lucite	83	163	322

TABLE VI

TABLE OF CONSTANTS

Material	A	K	Pressure range (kilobars)
Chopped Nylon Phenolic	59.1	2.24	39-274
Series 124 Resin	46.3	1.96	45-147
Avcoat	56.1	2.29	14-150
AVCO Phenolic Fiberglass	2,530	7.44	0-180
Tape Wound Nylon Phenolic	1,020	3.88	20-86
GE Phenolic Fiberglass	60,200	18.0	28-111
Oblique Tape Wound Refrasil	822,000	94.6	20-84
RAD 58B	184	-2.17	5-46
Avcoite	33.6	1.40	34-118
Pyrolytic Graphite	40.8	1.40	50-470
Kel-F	170.2	2.65	32-97
Polyethelene	11.9	1.73	2-65
Nylon	154	2.60	4-80
Plexiglas	217	2.80	17-160
Polystyrene	230	2.66	4-59
Teflon	45.1	2.08	10-76

although it can be used with reasonable accuracy for thin plates when the impact velocity is much higher than the limit velocity. However, a perforation formula originated solely for metal plates by the National Physical Laboratory (England) was used in this analysis to supplement results obtained from CA.

$$[DA] \quad T_s = \frac{d}{43.4\sqrt{B}}\left[\frac{(V_{50})_n}{d}\sqrt{\frac{W}{.1728\,d}} + \frac{54{,}000}{B_0 - B} - 747\right]$$

where:

T_s = Thickness required to prevent perforation

d = Projectile caliber

B = Brinell hardness number

$(V_{50})_n$ = Normal ballistic limit velocity

W = Projectile weight

B_0 = $500 - 160 \log_{10} \frac{d}{.1304}$

Equation DA can be corrected for obliquity, on the basis of data obtained by Aberdeen Proving Ground, as follows:

$$[DB] \quad T_s = \frac{d}{43.4\sqrt{B}} \cos\frac{3}{2}\theta \left(\frac{V_{50}}{d}\sqrt{\frac{W}{.1728\,d}} + \frac{54{,}000}{B_0 - B} + \frac{11{,}800}{65-\theta} - 929\right)$$

where:

θ = Impact obliquity

(b) As in the case of the previous penetration equations, several limitations pertain to equations DA and DB.

They have been validated experimentally only for plate thickness between .5 and 2 calibers ($\frac{T_s}{d}$) and a single nose shape of 1.4 caliber radius. Also, only steel plates with Brinell hardness numbers of 250 to 450 were tested.

(c) The primary use of equation DA was in determining steel plate perforation thickness for projectiles larger than 20 mm. The study considered much larger projectiles, and steel, of course, is one of the basic armor materials considered in an investigation of composite protective materials.

Finally, it is noted that DA could probably be used for other materials such as aluminum, magnesium and titanium, since the only explicit plate variable is Brinell hardness number. However, experimental validation would be desirable in view of the uncertain sensitivity of the numerical constants to material properties.

(5) <u>Penetration of Wood</u>

(a) An empirical formula has been developed by the Ballistic Research Laboratory which can be used to predict either the residual or the ballistic limit velocity of fragments and small caliber projectiles against various types of wood.

[EA] $$V_r = V - C_1 E^{C2} (\sec\theta)^{C3} V^{C4} m^{C5} A^{C6} H^{C7}$$

where:

V_r = Residual velocity (fps)

V = Striking velocity (fps)

E = Material areal density (psf) (Figure 57)

θ = Angle of obliquity

m = Weight of projectile (grams)

A = Area of projectile (function of θ)

H = Hardness of wood (pounds) (Table VII)

C7 = 0.3105

(The values of C1, C2, C3, C4, C5, and C6 are listed in Table IX for values of m and A.)

The ballistic limit velocity is obtained from EA by setting V_r to zero.

[EB] $$V_{50} = C_1 E^{C2} (\sec\theta)^{C3} m^{C4} A^{C5} H^{C6}$$

where:

V_{50} = Ballistic limit velocity (fps)

C6 = 1.3162

(The values of C1, C2, C3, C4, and C5 are listed in Table X for values of m and A.)

(b) Note that the values in Tables IX and X correspond a hardness of 50 pounds. Since typical woods vary in hardness from 20 to 90 pounds, an estimate of V_r or V_{50} for hardness other than 50 pounds may be required.

(c) The following equation can be used for estimating residual velocity:

[EC]

$$V_r^* = V - f_1 (V - V_r')$$

where:

V_r^* = Residual velocity at H_1 (other than 50 pounds)

V = Striking velocity

$f_1 = (\frac{H_1}{50})^{.3105}$

V_r^1 = Residual velocity at 50 pounds

(Values of f_1 can be obtained from Figure 58)

(d) A similar equation is used for ballistic limit velocity

[ED]

$$V_{50}^* = f_2 V_{50}'$$

where:

V_{50}^* = Ballistic limit velocity at H_1 (other than 50 pounds)

$f_2 = (\frac{H_1}{50})^{1.3162}$

V_{50}^1 = Ballistic limit velocity at 50 pounds

(Values of f_2 can be obtained from Figure 59)

TABLE VIII

Density and Hardness of Wood Targets

Type of Wood	Sample Density (lb/ft^3)	Hardness* (lb)
Pine, dry	22-25	38.7
Pine, wet	30	51.1
Maple, dry	35	76.9
Maple, wet	40	72.0
Green Oak, dry	51-59	88.1
Green Oak, wet	-	72.1
Marine plywood, dry	37	68.9
Marine plywood, wet	-	58.8
Balsa, dry	6	21.0
Balsa, wet	6	61.5
Fir plywood, dry	30	75.0
Fir plywood, wet	-	68.9
Corrisa	27	-
Hickory, dry	50	74.3
Hickory, wet	55	63.5

TABLE IX

RESIDUAL VELOCITY EQUATION FOR WOOD

Master Formula : $V_r = V - 41.10\, E^{0.5735} (\sec \Theta)^{0.5801}\, V^{0.7641}\, m^{-0.8543}\, A^{0.7763}\, H^{0.3105}$

Type of Formula : $V_r = V - C_1\, E^{C2} (\sec \Theta)^{C3}\, V^{C4}\, m^{C5}\, A^{C6}\, H^{C7}$

Set H = 50

CONDITION	C1	C2	C3	C4	C5	C6
Fragments and Projectiles	138.47	0.5735	0.5801	0.7641	-0.8543	0.7763
Compact Fragments ($A=.0077m^{2/3}$)	3.167	0.5735	0.5801	0.7641	-0.3368	
Caliber .22 Projectile (m=52 grains)						
Yaw - 0°; A = 0.0394 in^2	.3847	0.5735	0.5801	0.7641		
Yaw -90°; A = 0.1770 in^2	1.2342	0.5735	0.5801	0.7641		
Caliber .30 Projectile (m = 152 grains)						
Yaw - 0°; A = 0.0735 in^2	.24965	0.5735	0.5801	0.7641		
Yaw - 90°; A = 0.3090 in^2	.76118	0.5735	0.5801	0.7641		
Caliber .50 Projectile (m = 709.5 grains)						
Yaw = 0°; A = 0.2010 in^2	.14620	0.5735	0.5801	0.7641		
Yaw = 90°; A = 1.0520 in^2	.48832	0.5735	0.5801	0.7641		

TABLE X

BALLISTIC LIMIT EQUATION FOR WOOD

Master Formula : $V_o = 6938000 \quad E^{2.4311} \quad (\sec \theta)^{2.4591} \quad m^{-3.6215} \quad A^{3.2908} \quad H^{1.3162}$

Type of Formula : $V_o = C_1 \, E^{C2} \quad (\sec \theta)^{C3} \, m^{C4} \, A^{C5} \, H^{C6}$

SET H = 50

CONDITION	C1	C2	C3	C4	C5
Fragments and Projectiles	1,195,100,000	2.4311	2.4591	-3.6215	3.2908
Compact Fragments ($A=.0077m^{2/3}$)	132,53	2.4311	2.4591	-1.4276	
Caliber .22 Projectile (m=52 grains)					
Yaw=0° ; A=0.0394 in^2	0.017418	2.4311	2.4591		
Yaw=90°; A=0.1770 in^2	2.4443	2.4311	2.4591		
Caliber .30 Projectile (m=152 grains)					
Yaw=0°; A=0.0735 in^2	0.0002883	2.4311	2.4591		
Yaw=90°; A=1.0520 in^2	0.06686	2.4311	2.4591		

(e) Petal Solution

When the diameter of the penetrating projectile (d) is large with respect to the thickness of the plate (T_s) to be penetrated, a petal solution in lieu of a plate perforation solution must be used. The petaling will usually occur when the ratio of $T_s/d = 0.1$ or less. For a discussion of this phenomenon, refer to Paragraph (4)(g) below.

THICKNESS OF WOOD vs AREAL DENSITY

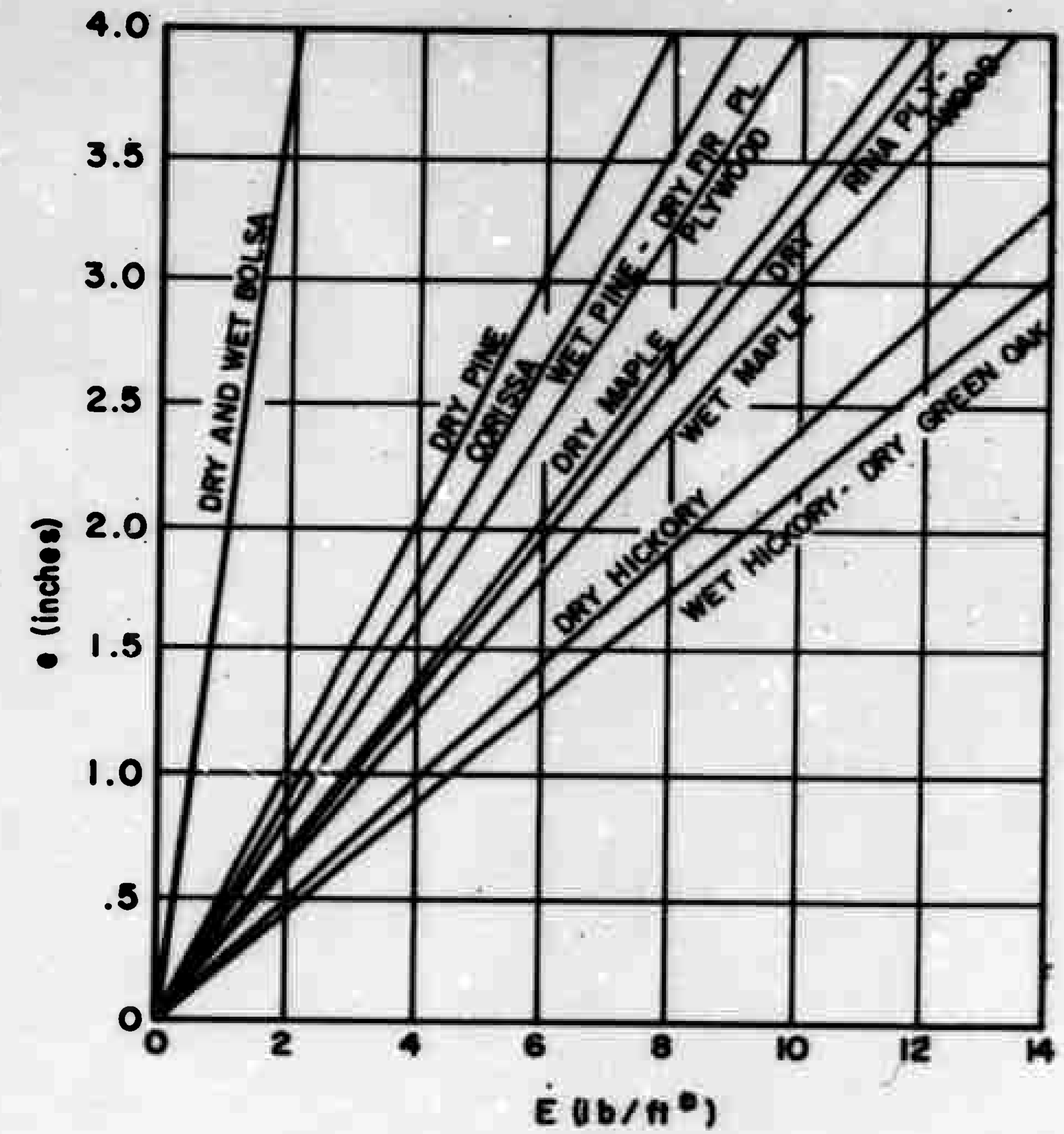
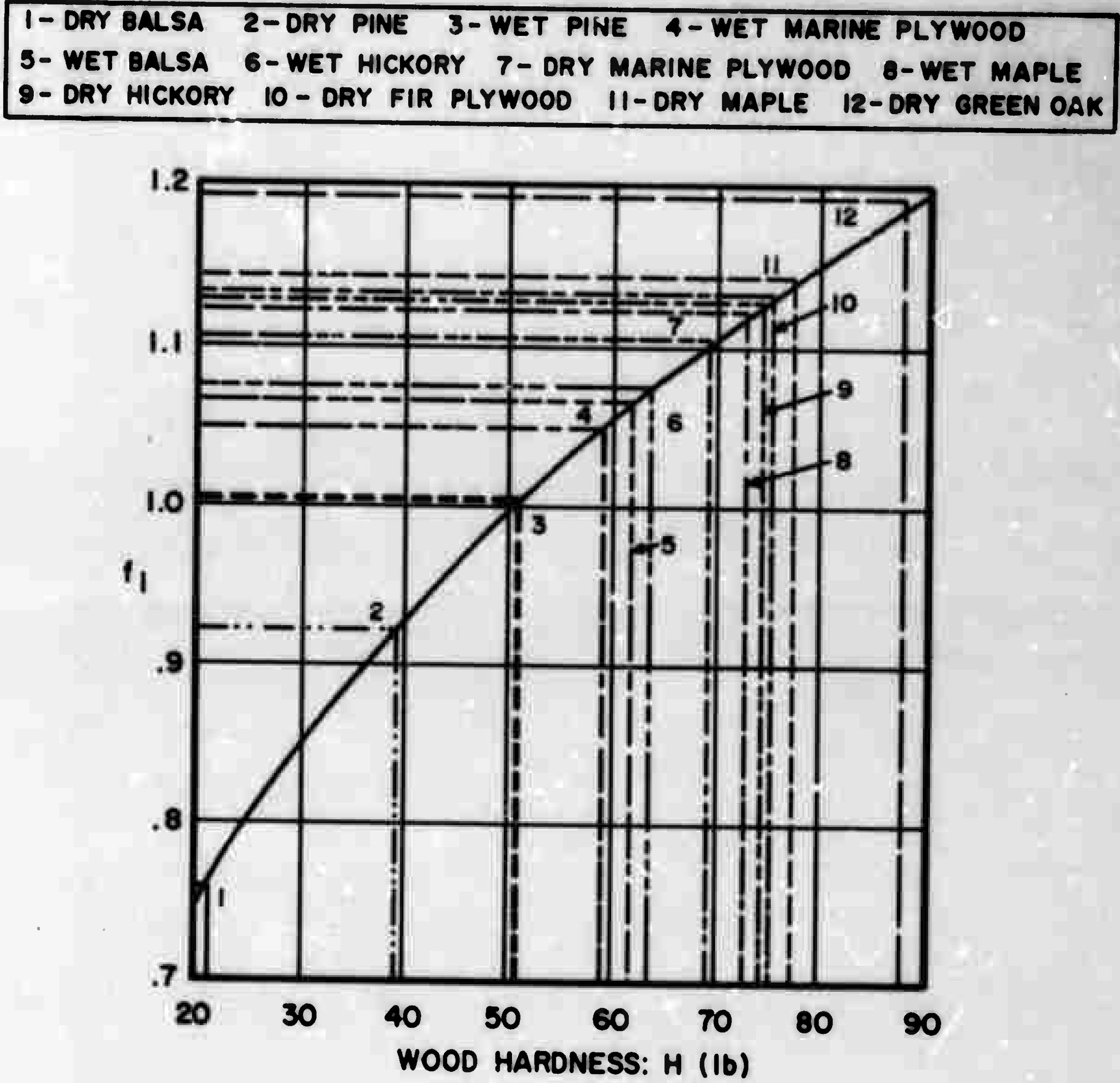


FIGURE 57

VARIATION OF f_1 WITH HARDNESS



NOTE:-
$$f_1 = \left(\frac{H}{50}\right)^{.3105}$$

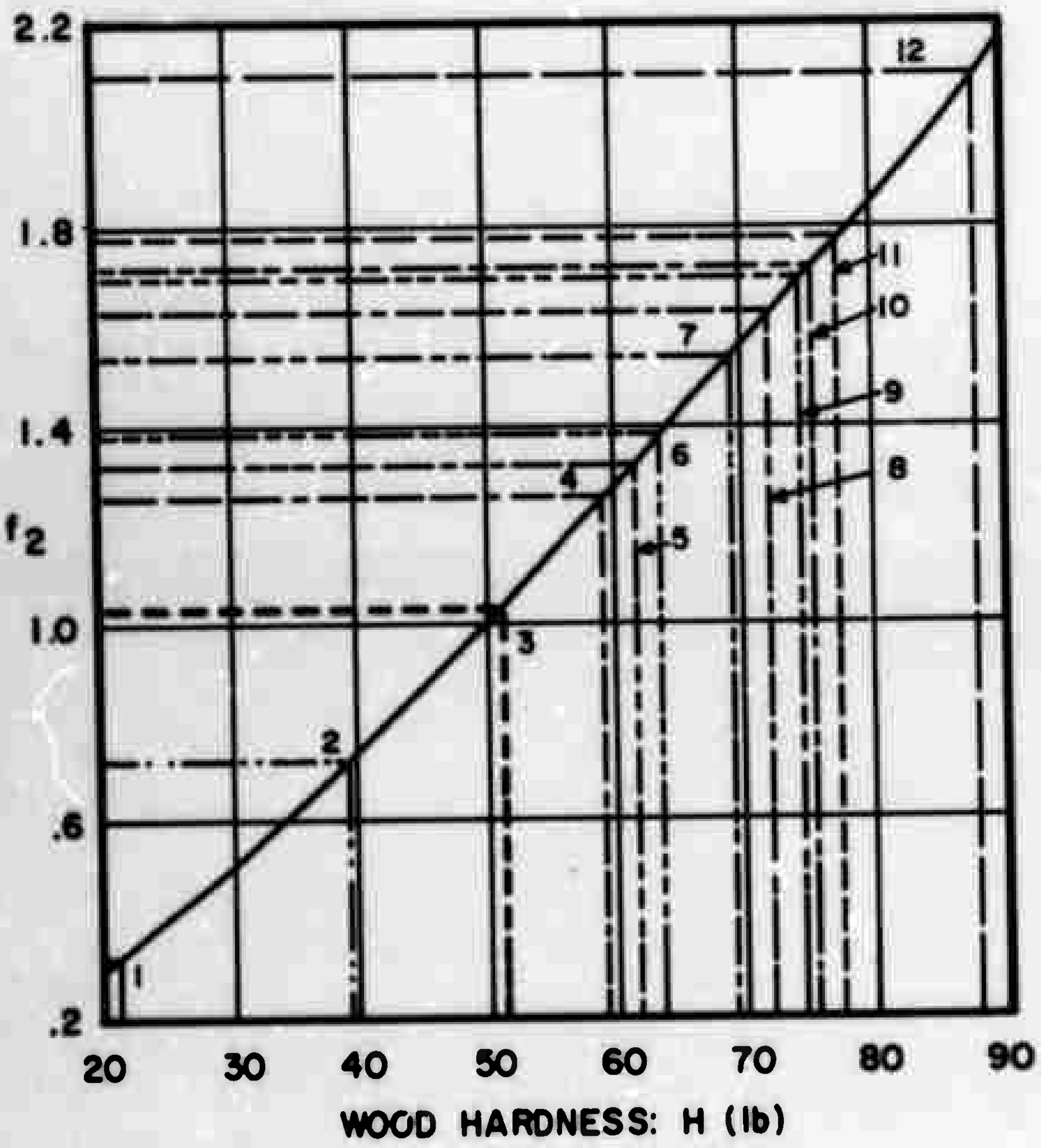
FIGURE 58

REF 42

VARIATION OF f_2 WITH HARDNESS

1 - DRY BALSA 2 - DRY PINE 3 - WET PINE 4 - WET MARINE PLYWOOD
5 - WET BALSA 6 - WET HICKORY 7 - DRY MARINE PLYWOOD 8 - WET MAPLE
9 - DRY HICKORY 10 - DRY FIR PLYWOOD 11 - DRY MAPLE 12 - DRY GREEN OAK

KEY



NOTE:-

$$f_1 = \left(\frac{11}{50}\right)^{1.3162}$$

FIGURE 59

REF 42

g. Application of Computer Techniques for Penetration Prediction

During the conduct of this study, a computer program was developed based on the theory described in paragraph 4f and several of the mathmatical relationships which were derived from available empirical formulas. This was done in an attempt to expand the available methods applicable to the prediction of penetration and perforation of projectiles and/or their fragments into various materials. The program is capable of handling 15 projectiles and 100 materials. A detailed description of the program is contained in paragraph 4h. The results of the computation from the operation of this program may be utilized in the thickness design of materials for passive protection against weapon attacks. The computer code is designed to run in one of three modes, the analysis mode, a design mode in which the front layer is variable and a design mode in which the rear or last layer is variable.

(1) Analysis Mode

The analysis mode is used to predict the penetration/perforation of either single or layered materials. The number of layers, the thickness of each and the sequence of layers is designated by the computer operator in response to questions made by the computer program. The operator also designates the projectile and its striking velocity upon query by the computer. The output of this program is the residual velocity of the projectile as it leaves each layer and the depth and time of penetration. This information may be used to estimate the suitability of the existing or postulated design and to approximate the point of fuse detonation. An instructive example of the analysis mode shows the results in penetrations of reversing the sequence of a projectile striking successive layers of clay, loam, sandy loam, and sand. Each layer was one foot thick. A one pound projectile with a striking velocity of 2,000 ft/second was used. These calculations result from operating equation [AA] described in paragraph 4f.

Striking Velocity = 2,000 feet/second

MATERIAL	RESIDUAL (EXIT) VELOCITY	CUMULATIVE TIME	CUMULATIVE PENETRATION
Clay	1246	0.0006	1.0
Loam	709	0.0011	2.0
S. Loam	346	0.0020	3.0
Sand	0	0.0055	3.78

This indicates the projectile was arrested after penetrating the sand 0.78 ft. Running the same materials backward yields the following:

Sand	977	0.0007	1.0
S. Loam	506	0.0014	2.0
Loam	252	0.0028	3.0
Clay	122	0.0056	4.0

Here, the projectile perforates the four material layers and has a residual velocity of 122 feet per second.

It can be seen that mere knowledge of the proper sequence of materials can make the difference between perforation and arrest. Sequencing is important.

This relationship is also illustrated in Figure 60, "Example of Interaction of 2 Materials." It can be seen that for the projectile described on Figure 60, approximately 3 feet of concrete was required to reduce the velocity of the projectile to zero. However, 13.3 feet of sand (example 2) was required to accomplish the same result. In example 3, in Figure 60, a reduction in both sand the concrete was accomplished when a combination was used. This is not a surprising result. Since from Example 1 and 2 it can be derived that 4.36 feet of sand is equivalent to one foot of concrete. However, in Example 3 this ratio is not maintained. The reduction of concrete by 1.85 feet required the addition of 9.8 feet of sand to stop the projectile. This gives an equivalency of 5.3 feet of sand for one foot of concrete. Obviously, the materials are sensitive to velocity so that sequence of the materials becomes important in the design of protective shelters. Example 4 shows the savings in concrete that can be achieved by placing it last in the sequence. The thickness is reduced from 1.2 feet when concrete comes first to 0.47

(2) <u>Design Mode-Front Layer Variable</u>

The situation may be encountered in which it is desirable to increase the protection of a structure against an

EXAMPLE OF INTERACTION OF 2 MATERIALS
(SAND AND CONCRETE)

INPUT
- PROJECTILE = 100 lbs
- ENTERING VELOCITY = V_0 = 1800 FT./SECOND
- EXIT VELOCITY = V_f = 0

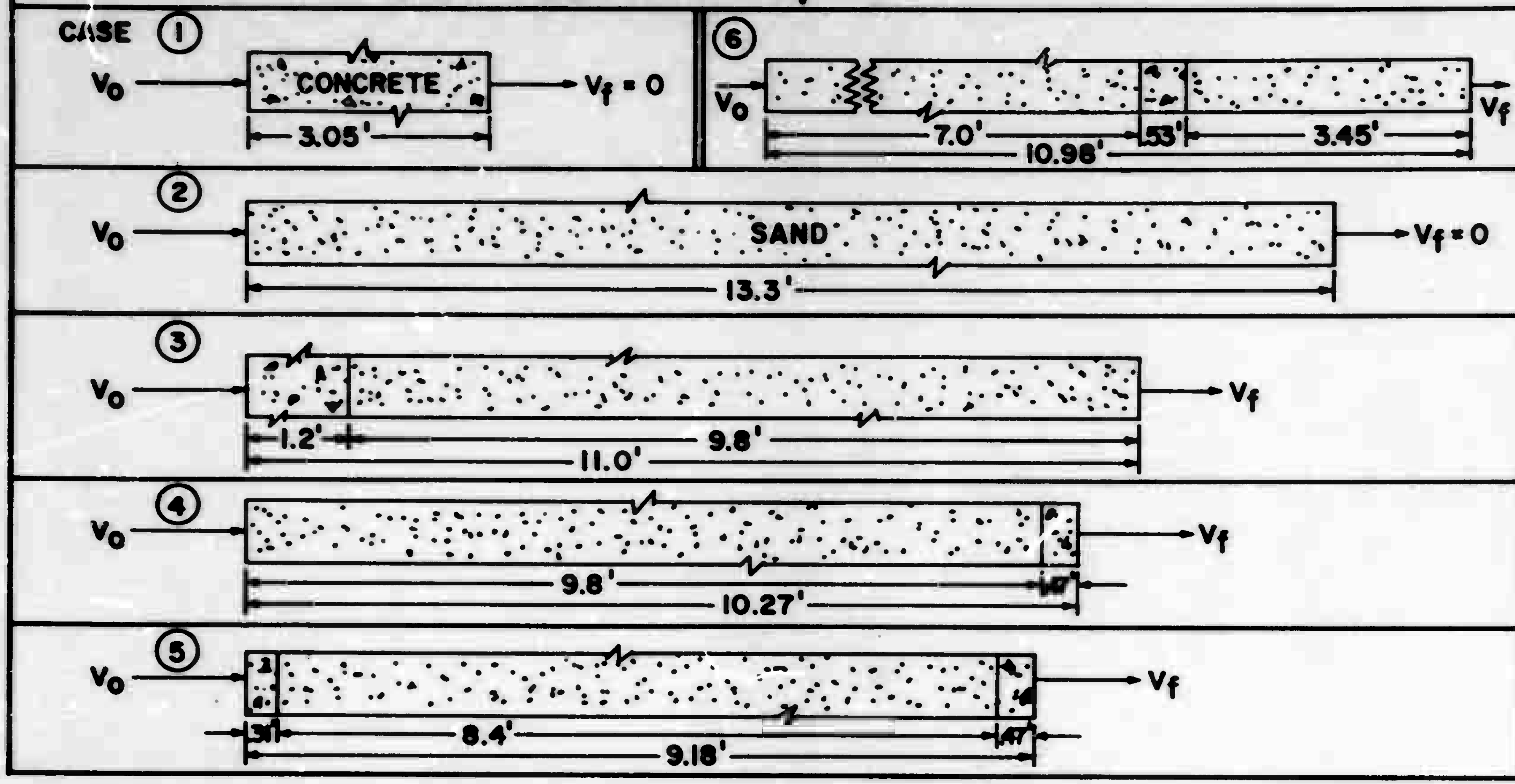


FIGURE 60

escalated threat. In most cases, it would seem easier to add layers to the outside. This mode is adaptable to this situation. The computer operator designates the projectile by code, its striking velocity and the sequence and code of materials in the layers in response to query from the computer. In this mode additional instructions by the operator must include the initial thickness of the first layer, which may be zero, the thickness of the succeeding layers, the number of iterations in the succeeding layers, and the thickness that the succeeding layers are to be increased for each iteration (or computer solution). In each iteration, the computer will add sufficient material to the first layer to stop the projectile. Thus, if the succeeding layers are fixed, the proper values are inserted into the computer and the computer will provide the required thickness of the first layer in one iteration. An alternate design method is available to the designer, or computer operator in this mode. If the succeeding layers are not fixed, then material may be added to the succeeding layers by designated incremental steps and for each iteration of the computer, a combination of the thickness of materials is presented which will stop the projectile. The first layer is reduced as the increments are added to the succeeding layers. Thus the designer may optimize a combination according to his desires.

Consider the results below, with the same projectile as in the previous example, where there is one foot of sand on the inside with a foot of sandy loam, a foot of loam and an unspecified amount of clay on the front layer.

The computer results are:

MATERIAL	RESIDUAL (EXIT) VELOCITY	CUMULATIVE TIME	CUMULATIVE PENETRATION
Clay	1482		.63
Loam	850	0.0009	1.63
S. Loam	431	0.0017	2.63
Sand	0	0.0061	3.63

The 0.63 feet of clay added on the front face is enough to cause arrest of the projectile in the sand.

A represented number of computer calculations were performed in this mode to illustrate the ability of the program to provide data for the construction of tables useful in the design of protective barriers. Reference Tables XIIIa-XIIIo "Thickness of Materials in Combination Required to Defeat A (Projectile name)" On these charts are tabulated a thickness of material "A" on the abscissa, a thickness of material "B" on the ordinate and for each value of A + B is tabulated a thickness of material "C" which is required to reduce the velocity of the projectile at the indicated velocity to zero. An almost infinite variety of charts may thus be constructed according to the desires of the designer.

(3) Design Mode - Rear Layer Variable

This mode is useful when it is desirable to add protective materials to a rear layer which is analogous to the addition of materials to the inside of a protective structure which has already been constructed. The computer operator must provide the number of layers, the thickness of the layers starting from the strike side, the projectile code and its striking velocity. The computer will calculate the time of penetration, the residual velocity through each layer and the total penetration of the projectile. By comparison of the penetration depth and the total thickness of all the materials a determination can be made as to whether the projectile would be stopped by the arrangement and where the projectile velocity would become zero. A computer result using this mode for a one pound projectile with a 2,000 fps striking velocity is as follows:

MATERIAL	RESIDUAL (EXIT) VELOCITY	CUMULATIVE TIME	CUMULATIVE PENETRATION
Clay	1246	0.0006	1.0
Loam	709.8	0.0011	2.0
S. Loam	346	0.0020	3.0
Sand	0.0	0.0055	3.78

In this mode the designer may choose a thickness of material which is too thin for a valid solution of equation [DA] and [CA] (par. 4f). This occurs when the plate thickness to projectile diameter ratio is equal to or less than 0.1. When the penetrating projectile to plate ratio is at or less than this value, a "petal" solution is used in the computer program. This solution is from the work of Burton and Zaid (Equation 24) (1958), Reference 51. Thus, the velocity change is for normal incidence.

$$\Delta V = \left(\frac{2\pi\ \gamma t\ \ R^2\ V_s}{W}\right)\ \left(0.249\left(\frac{r}{R}\right)^{2.6}\right)$$

Where: γ = Density of Plate

W = Weight of Projectile

V_s = Striking Velocity

t = Plate Thickness

R = Ogive Radius

r = Caliber Radius

(4) Validation of Computer Calculations

Data generated from the investigations of the National Defense Research Committee carried on after World War II were used to validate the results generated from the computer program for projectiles up to 75 mm. The results of plotting the computer calculations are shown on Figure 61 and 62,"Perforation of Mild Steel Armor by Uncapped AP Projectiles," for various Brinell Harndess steel plates. The results show good agreement in the range shown by the chart. The computer calculations can be made for velocities

PERFORATION OF MILD STEEL
ARMOR (BHN 100-150) BY UNCAPPED AP PROJECTILES

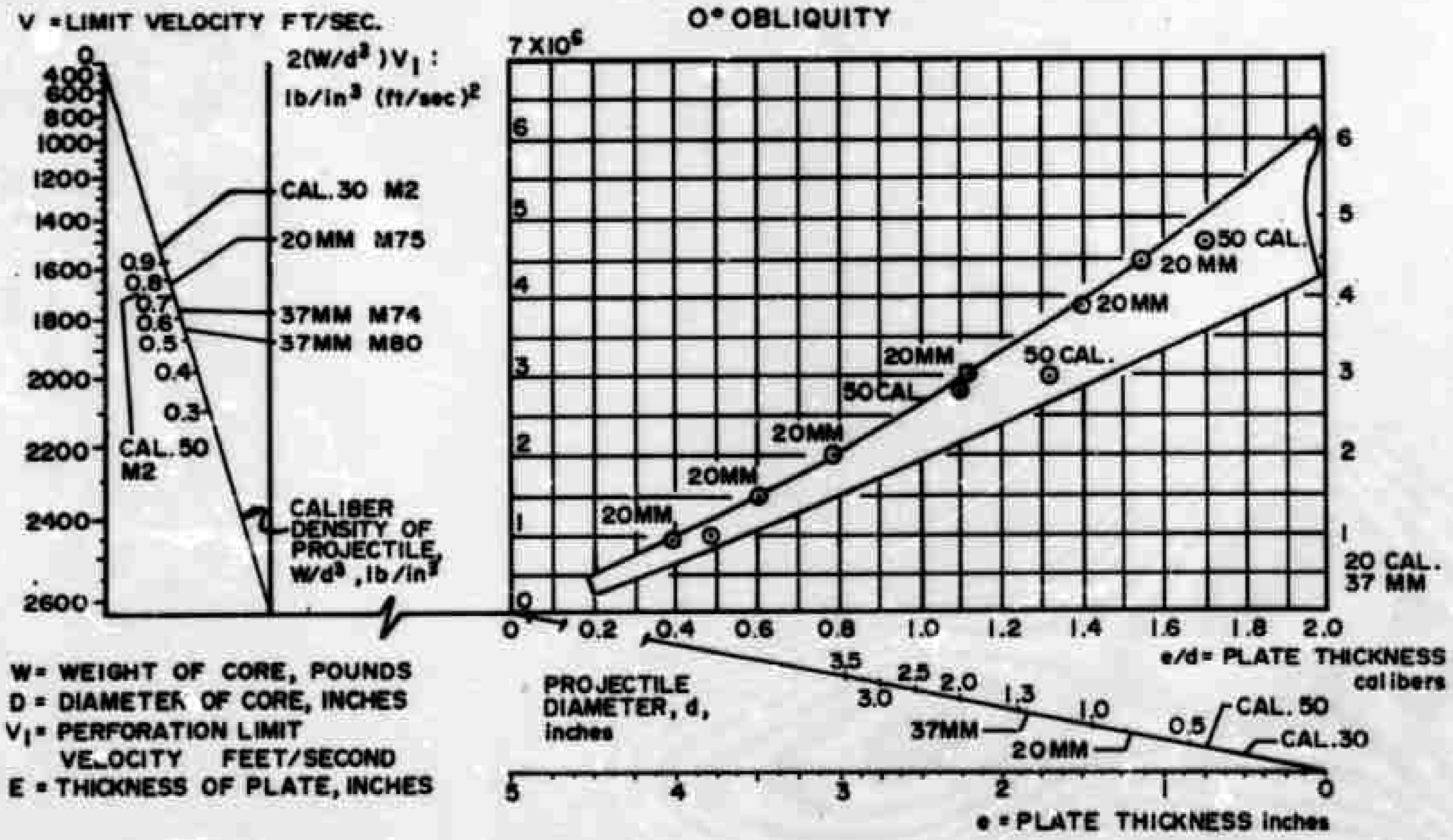


FIGURE 61

REF 44

PERFORATION OF HOMOGENEOUS ARMOR (BHN 250-300) BY UNCAPPED AP PROJECTILES

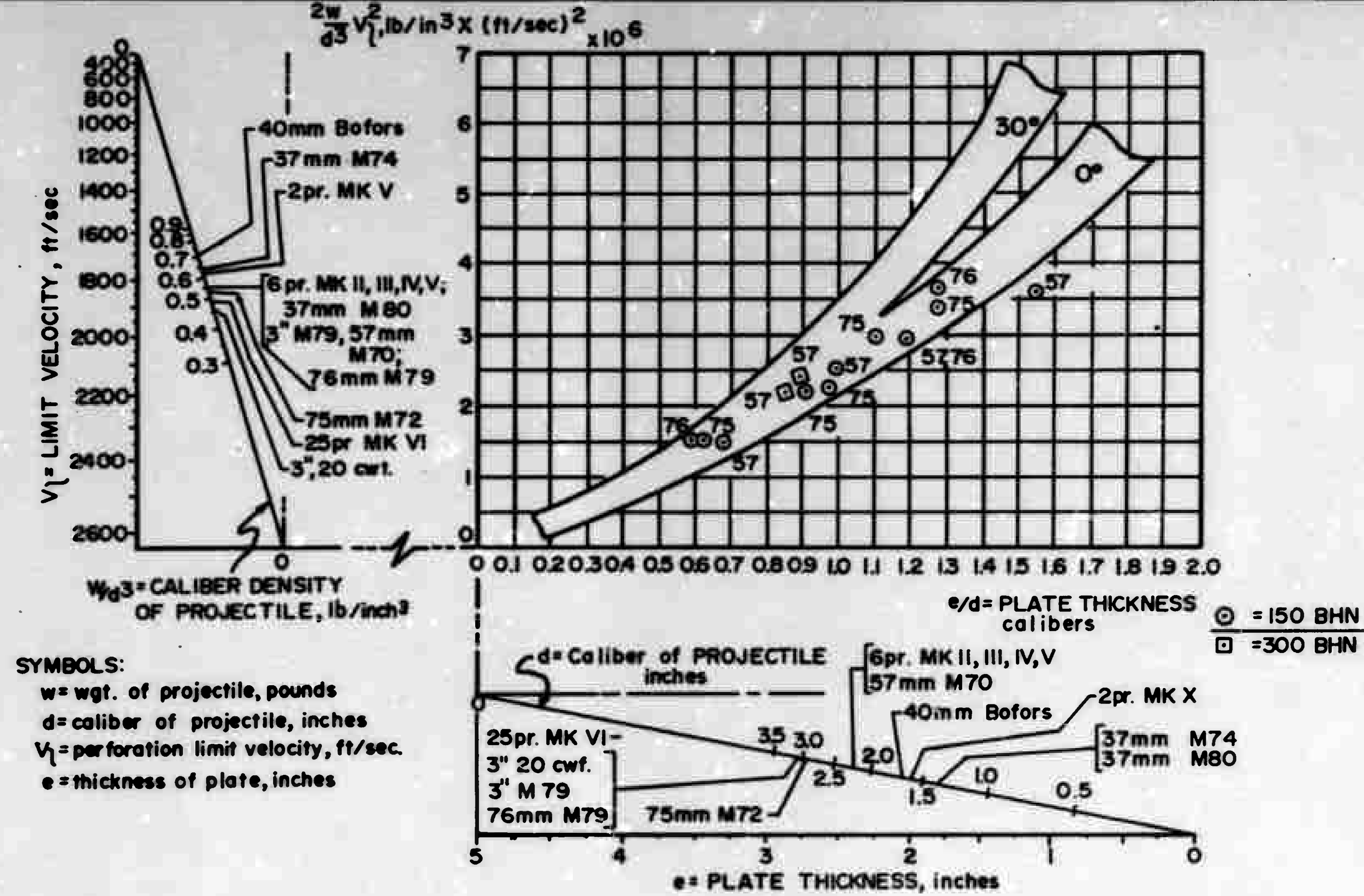


FIGURE 62

REF 44

and thicknesses which are beyond the chart portrayal. Figure 64 (Residual Velocity Prediction) indicates the correlation of the relationship

$$V_r = \sqrt{V_1^2 - V_{50}^2}$$

which was obtained from reference 35 with experimental data. This relationship is used in the computer program to obtain residual velocity through each layer.

The results of using equation CA (Paragraph 4f) in this computer program, which is adaptable for the insertion of dynamic material property values, have been plotted in Figures 64, 65, 66, "Penetration of (30)(50)(20 mm) Projectiles into Various Materials" at various velocities. Correlation of the values has been made and shows good agreement with results of Figures 4, 5 and 6 of Reference 35. Values of C_1 = 2.65 were used for all projectiles wherein the values used in Reference 35 were 2.62 and 2.69 for the 0.50 and 0.30 caliber respectively. The weight and radius of the core were used in this computer program. This approach was based on the assumption that all cores were stripped from their jackets upon impact with the plate.

RESIDUAL VELOCITY PREDICTION

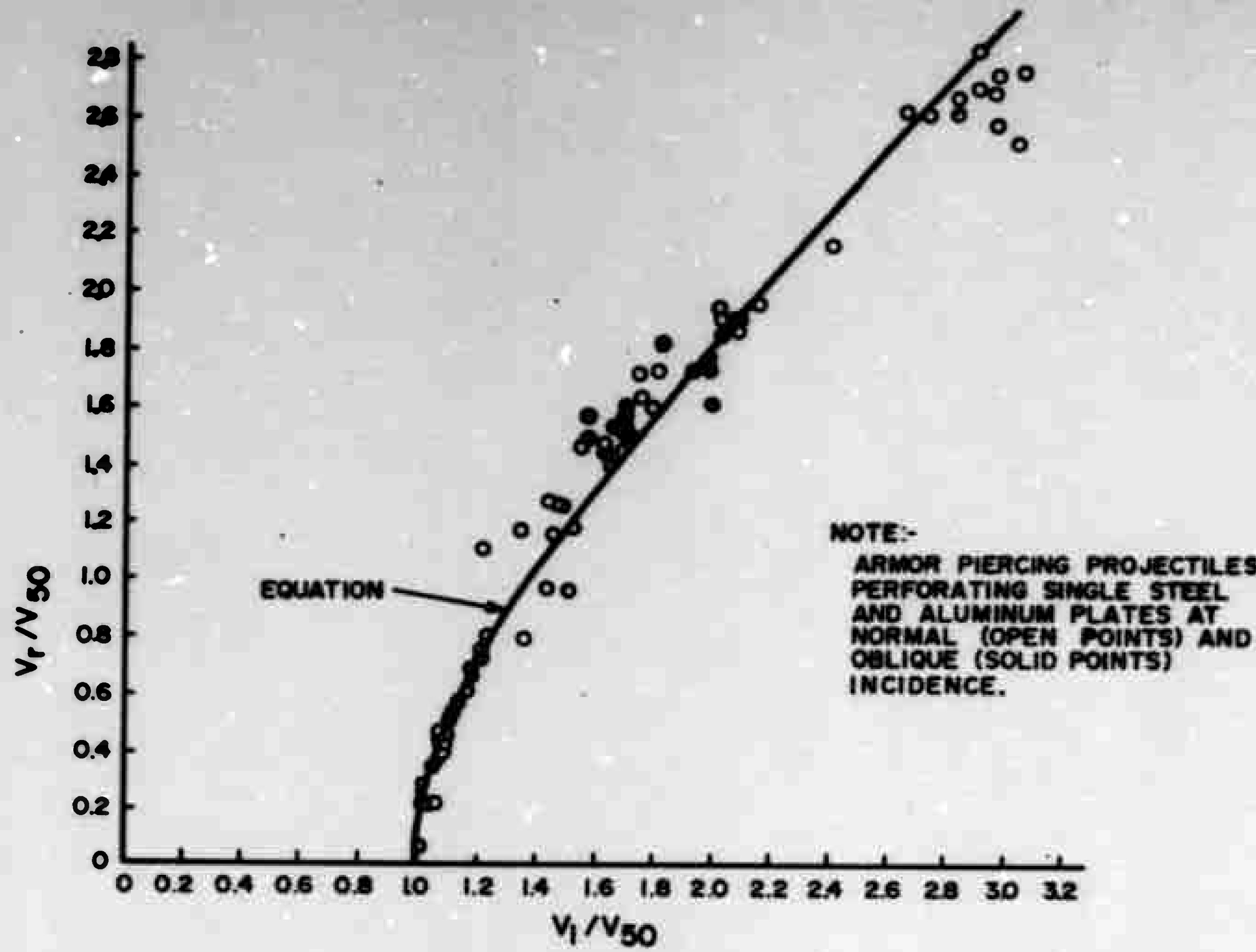


FIGURE 63

REF 37

PENETRATION OF 30 CALIBER PROJECTILE INTO VARIOUS MATERIALS
(USING HUGONIOT FORMULAE)

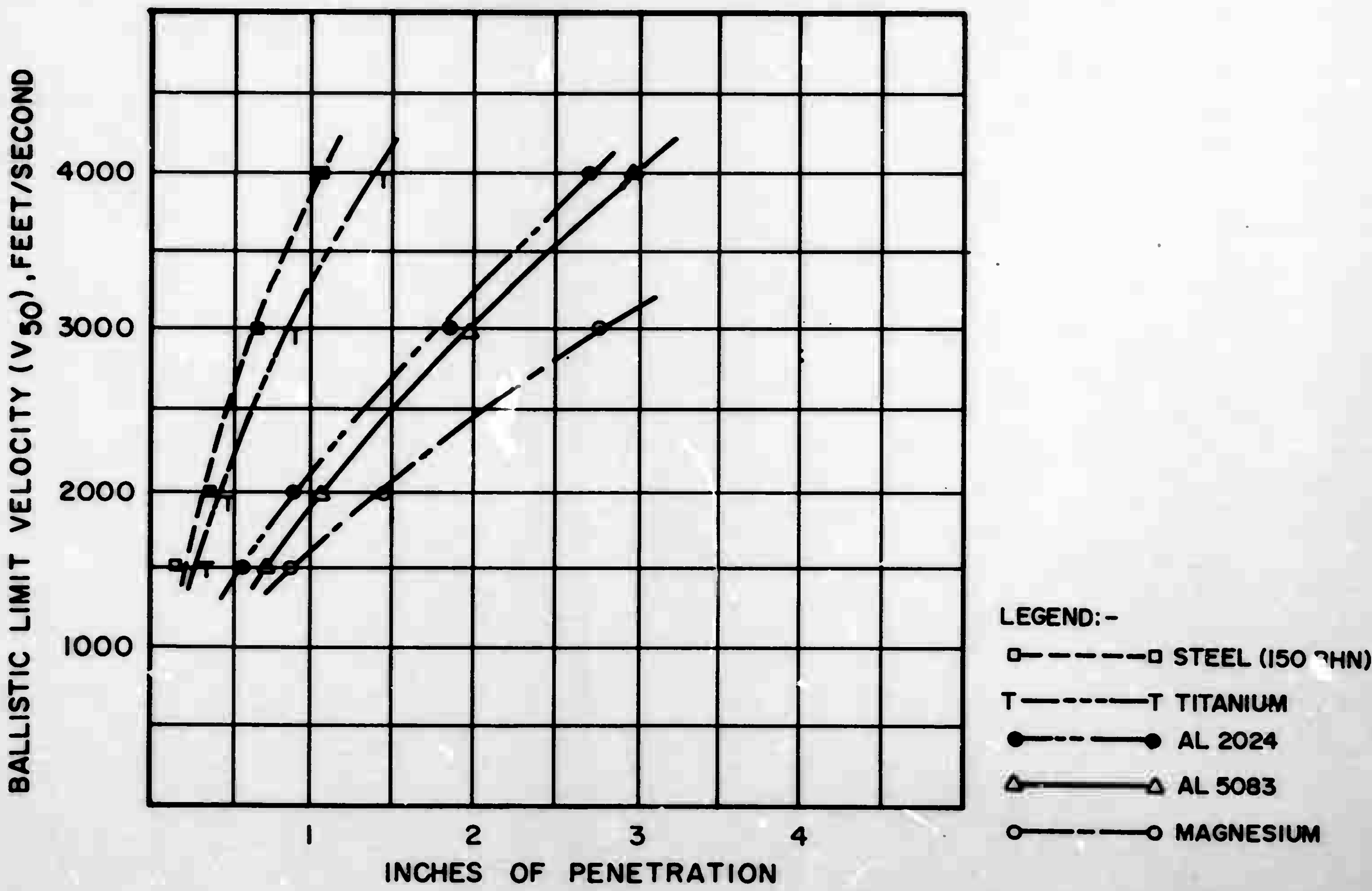


FIGURE 64

PENETRATION OF 50 CALIBER PROJECTILE INTO VARIOUS MATERIALS
(USING HUGONIOT FORMULAE)

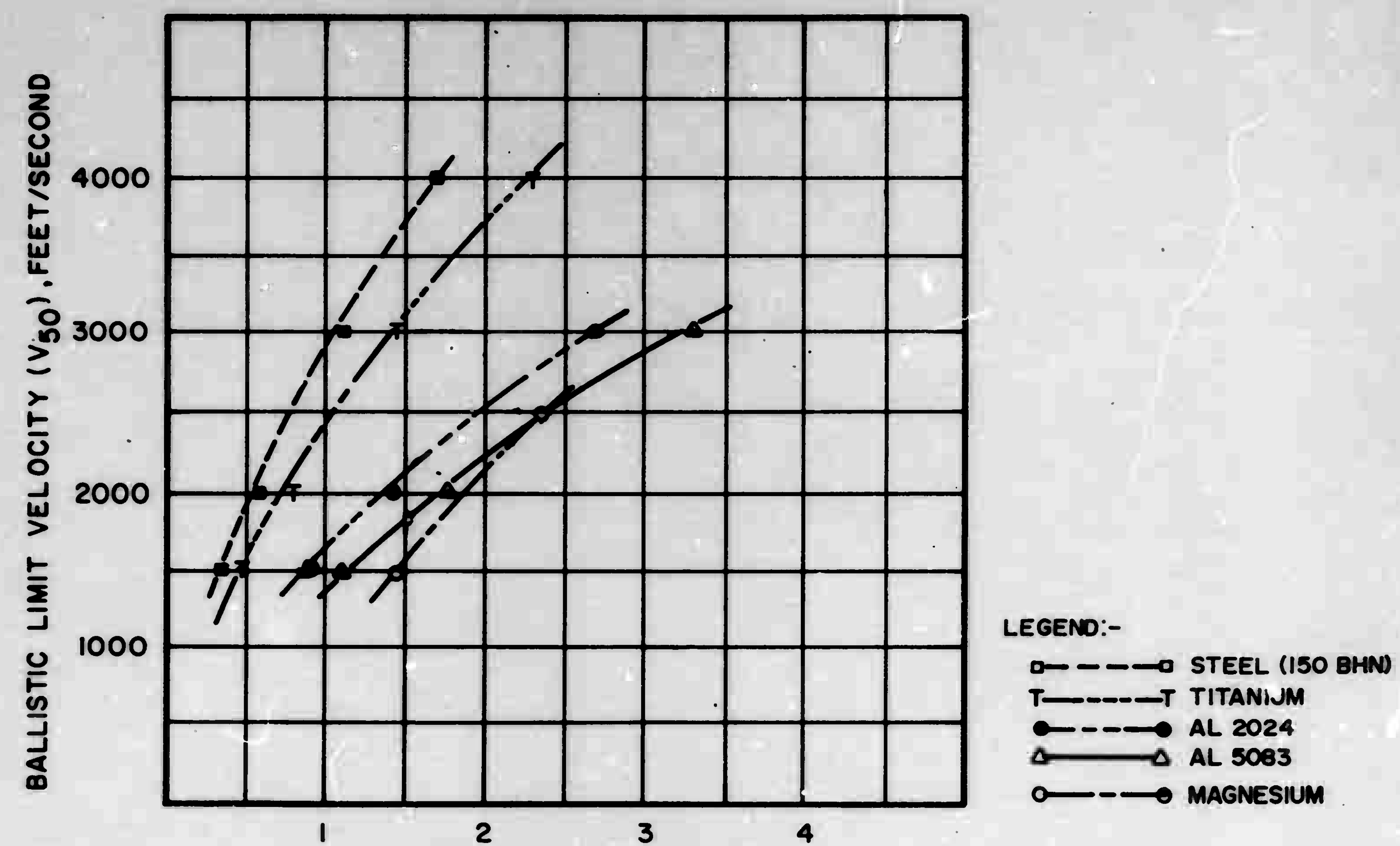


FIGURE 65

PENETRATION OF 20 MM PROJECTILE INTO VARIOUS MATERIALS
(USING HUGONIOT FORMULAE)

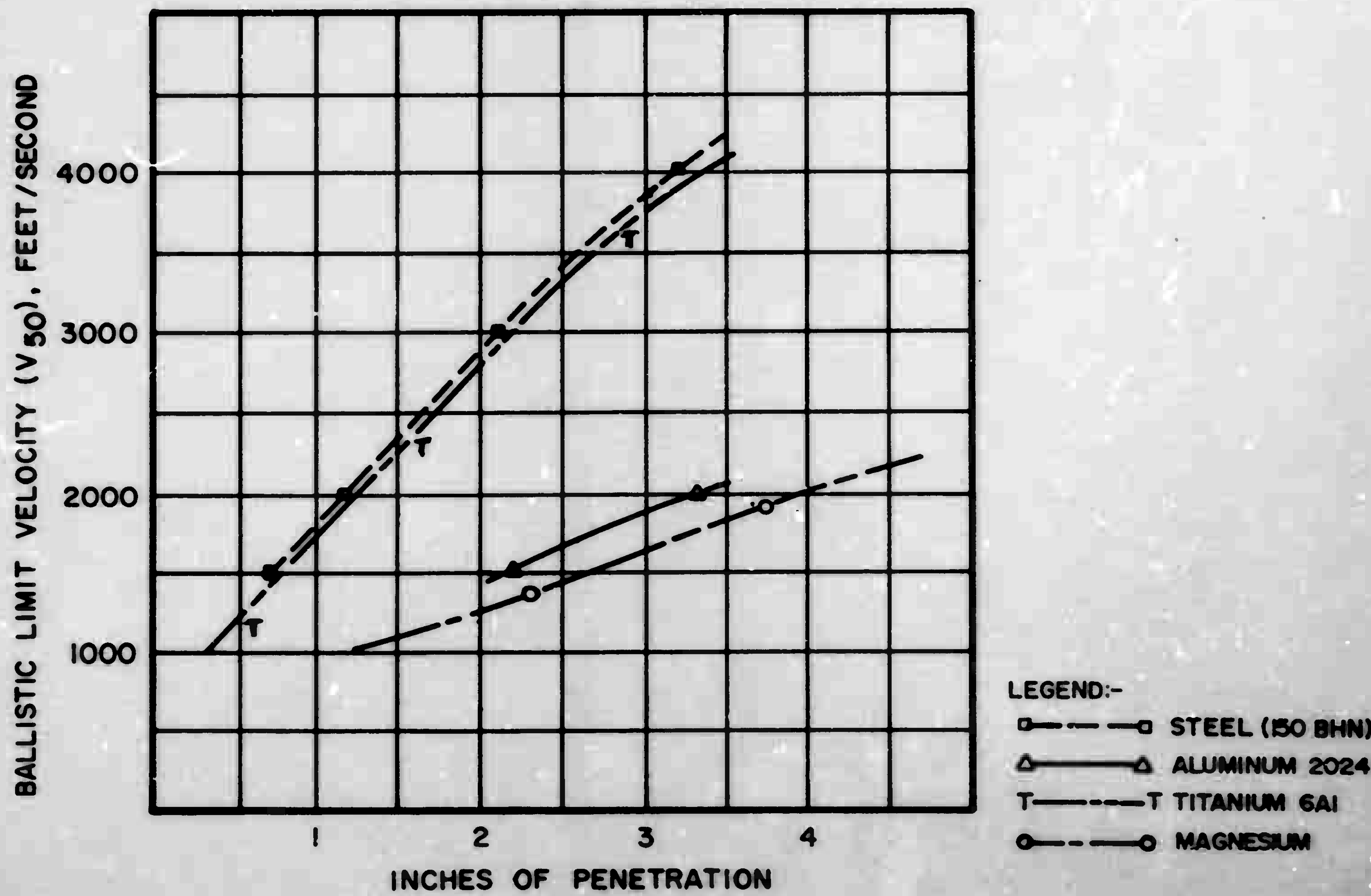
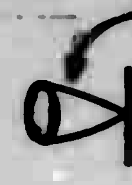


FIGURE 66

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM 1200 f/s



MATERIAL 1	MATERIAL 2	MATERIAL 3
LOAM	SAND	CONCRETE

THICKNESS OF SAND		THICKNESS OF CONCRETE											
		0"	3"	6"	9"	12"	16"	21"	24"	27"	30"	33"	36"
0"		14.6	10.5	8.13	6.41	4.98	3.74	2.61	1.57	0.56	-	-	-
3"		14.1	10.1	7.8	6.08	4.67	3.43	2.30	1.26	.269			
6"		13.7	9.76	7.47	5.76	4.35	3.11	1.99	.95	-			
9"		13.3	9.4	7.14	5.44	4.04	2.80	1.68	.63	-			
12"		12.9	9.06	6.81	5.12	3.72	2.49	1.37	.33	-			
15"		12.5	8.72	6.48	4.80	3.41	2.18	1.06	.02	-			
18"		12.1	8.38	6.16	4.48	3.09	1.86	0.75	-				
21"		11.7	8.04	5.84	4.17	2.78	1.56	.44	-				
24"		11.3	7.71	5.52	3.86	2.47	1.25	.137	-				
27"		10.9											
30"													
33"													

TABULATED VALUES ARE THICKNESSES OF LOAM (IN FEET)

TABLE XIIIa

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM at 1200 ft/sec

MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (150 BHN)	SAND	CONCRETE

THICKNESS OF SAND	THICKNESS OF CONCRETE											
	0"	3"	6"	9"	12"	15"	18"	21"	36"	54"	60"	66"
0"	.250	.230	.206	.176	.137	.086	.019	-				
3"	.248	.227	.201	.168	.126	.0705	-	-				
6"	.246	.224	.196	.160	.114	.053	-	-				
9"	.245	.221	.190	.151	.100	.033	-	-				
12"	.243	.217	.184	.141	.086	.010	-					
15"	.241	.213	.177	.131	.07	-						
18"	.240	.21	.17	.12	.05	-						
21"	.238	.205	.162	.106	.031	-						
24"	.235	.299	.153	.092	.009							
27"	.23	.194	.144	.077	-	-						
30"	.188	.133	.060	-	-							

TABULATED VALUES ARE THICKNESSES OF STEEL (150 BHN) (IN FEET)

TABLE XIIIb

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM 1200 f/s

MATERIAL 1	MATERIAL 2	MATERIAL 3
ASPHALT	SAND	CONCRETE

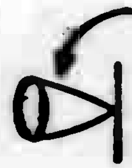
THICKNESS OF SAND		THICKNESS OF CONCRETE											
		0"	3"	6"	9"	12"	15"	18"	21"	24"	27"	30"	33"
0"		5.24	4.41	3.69	3.04	2.44	1.87	1.33	.81	.30			
3"		5.18	4.31	3.57	2.91	2.30	1.72	1.18	.65	.14			
6"		5.10	4.21	3.45	2.77	2.16	1.58	1.02	.49				
9"		5.03	4.11	3.33	2.64	2.01	1.42	0.87	.33	-			
12"		4.96	4.00	3.20	2.50	1.86	1.27	0.71	.17	-			
15"		4.88	3.89	3.07	2.36	1.72	1.12	0.55	.01	-			
18"		4.80	3.77	2.94	2.22	1.57	0.96	0.39	-				
21"		4.72	3.66	2.81	2.07	1.41	0.81	.23	-				
24"		4.63	3.54	2.67	1.93	1.26	.65	.07	-				
27"		4.54	3.42	2.54	1.78	1.10	.49	-					
30"		4.44	3.29	2.40	1.63	.95	.33	-					
33"		4.35	3.17	2.25	1.48	.79	.17	-					

TABULATED VALUES ARE THICKNESSES OF ASPHALT (IN FEET)

TABLE XIIIc

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM 1200 f/s



MATERIAL 1	MATERIAL 2	MATERIAL 3
CONCRETE	CLAY	LOAM

THICKNESS OF CLAY	THICKNESS OF LOAM											
	0"	3"	6"	9"	12"	15"	18"	21"	24"	27"	30"	33"
0"	2.15	2.14	2.13	2.12	2.11	2.10	2.08	2.07	2.06	2.04	2.03	2.00
3"	2.15	2.14	2.13	2.11	2.10	2.09	2.08	2.06	2.05	2.03	2.02	2.00
6"	2.14	2.13	2.12	2.11	2.10	2.08	2.07	2.05	2.04	2.02	2.00	1.98
9"	2.14	2.12	2.11	2.10	2.09	2.07	2.06	2.04	2.03	2.01	1.99	1.97
12"	2.13	2.12	2.11	2.09	2.08	2.07	2.05	2.03	2.02	1.99	1.98	1.96
15"	2.13	2.11	2.10	2.09	2.07	2.06	2.04	2.02	2.01	1.99	1.97	1.95
18"	2.12	2.11	2.09	2.08	2.06	2.05	2.03	2.01	1.99	1.98	1.95	1.93
21"	2.11	2.10	2.09	2.07	2.05	2.03	2.02	2.00	1.98	1.96	1.94	1.91
24"	2.11	2.09	2.07	2.06	2.05	2.02	2.01	1.99	1.97	1.95	1.93	1.90
27"	2.10	2.09	2.07	2.05	2.04	2.02	2.00	1.98	1.96	1.93	1.91	1.89
30"	2.09	2.07	2.06	2.04	2.02	2.00	1.98	1.96	1.94	1.92	1.89	1.87
33"	2.09	2.07	2.05	2.03	2.01	1.99	1.97	1.95	1.93	1.91	1.88	1.85

TABULATED VALUES ARE THICKNESSES OF CONCRETE (IN FEET)

TABLE XIIId

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

50 CALIBER AT 2850 f/sec

MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (BHN 150)	ASPHALT	STEEL (BHN 150)

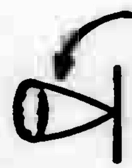
THICKNESS OF ASPHALT		THICKNESS OF STEEL (BHN 150)											
		0"	.02	.04	.06	.08	.10	.12	.14				
0"		.147	.141	.133	.122	.107	.088	.062	0.023				
3"		.381	.111	.079	.021	-	-	-	-				
6"		.071	-	-	-	-							
12"													
18"													
24"													
36"													
42"													

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 50) (IN FEET)

TABLE XIIIe

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

50 CALIBER AT 2850 f/sec



MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (BHN150)	ASPHALT SHOT (TEN)	STEEL (BHN 150)

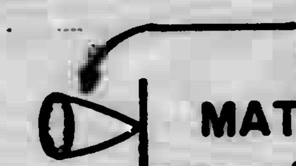
THICKNESS OF ASPHALT SHOT (TEN)		THICKNESS OF STEEL (BHN.150)											
		0"	.02	.04	.06	.08	.10	.12	.14	.16			
0"		.147	.141	.133	.122	.107	.088	.062	0.023				
3"		.119	.09	.037	-	-							
6"													
12"													
18"													
24"													
36"													
42"													

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 150) (IN FEET)

TABLE XIIIf

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

50 CALIBER AT 2850 f/sec



MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (BHN 150)	SHOT TEN	STEEL (BHN 150)

THICKNESS OF SHOT (TEN)		THICKNESS OF STEEL (BHN·150)											
		0"	.02	.04	.06	.08	.10	.12	.14	.16			
0"		.147	.141	.133	.122	.107	.088	.062	0.023				
3"		.120	.095	.057	-	-	-	-	-				
6"		.105	.050	-									
12"													
18"													
24"													
36"													
42"													

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 150) (IN FEET)

TABLE XIIIg

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

30 CALIBER AT 2850 f/sec

MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (BHN 150)	SAND	STEEL (BHN 150)

THICKNESS OF SAND		THICKNESS OF STEEL (BHN·150)											
		0"	.02	.04	.06	.08	.10	.12					
0"		.093	.086	0.076	.059	.033	-	-					
3"		.083	.057	-	-	-							
6"		.041											

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 150) (IN FEET)

TABLE XIIIb

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

20 MM AT 2850 f/sec

MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (BHN 150)	CLAY	STEEL (BHN 150)

THICKNESS OF CLAY	THICKNESS OF STEEL (BHN 150)									
	0"	.02	.04	.06	0.08	0.10	0.12	0.14	0.16	0.18
0"	.212	.205	.198	.189	.178	.164	.148	.124	.105	.075
3"	.207	.199	.187	.174	.157	.136	.109	.074	.023	-
6"	.201	.188	.172	.151	.124	.087	.033	-	-	
9"	.192	.174	.149	.115	.065	-	-			
12"	.179	.151	.110	.046	-					
15"	.159	.114	.036	-						
18"	.128	.045	-							

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 150) (IN FEET)

TABLE XIII1

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

20 MM AT 2850 f/sec

MATERIAL 1	MATERIAL 2	MATERIAL 3
STEEL (BHN 150)	SAND	STEEL (BHN 150)

THICKNESS OF SAND	THICKNESS OF STEEL (BHN 150)											
	0"	.02	.04	.06	.08	0.10	0.12	0.14	0.16	0.18		
0"	0.212	0.205	0.198	0.189	0.178	0.164	0.148	0.129	0.105	0.075		
3"	0.204	0.194	0.181	0.164	0.143	0.117	0.083	0.03	-	-		
6"	0.192	0.175	0.151	0.119	0.074	-	-	-				
9"	0.171	0.139	0.090	-	-							
12"	0.132	0.061	-	-								

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 150) (IN FEET)

TABLE XIIIJ

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

20 MM AT 2850 f/sec

MATERIAL 1 — STEEL (BHN 150) | MATERIAL 2 — ASPHALT (TEN) | MATERIAL 3 — STEEL (BHN 150)

THICKNESS OF ASPHALT (TEN)		THICKNESS OF STEEL (BHN·150)											
		0"	.02	.04	.06	.08	0.10	0.12	0.14	0.16	0.18		
0"		0.212	0.205	0.198	0.187	0.178	0.164	0.148	0.129	0.105	0.075		
3"		0.198	.185	.167	.145	.117	0.078	0.016	-	-	-		
6"		0.167	0.135	0.089	.0003	-	-	-					
9"		0.087	-	-	-								
12"		-											

TABULATED VALUES ARE THICKNESSES OF STEEL (BHN 150) (IN FEET)

TABLE XIIIk

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM AT 1200 f/sec

MATERIAL 1: CONCRETE | MATERIAL 2: CLAY | MATERIAL 3: ASPHALT

THICKNESS OF CLAY	THICKNESS OF ASPHALT											
	0"	3"	6"	9"	12"	15"	18"	21"	24"	27"	30"	33"
0"	2.15	2.08	2.00	1.93	1.84	1.75	1.67	1.57	1.47	1.38	1.28	1.17
3"	2.15	2.07	1.99	1.91	1.82	1.73	1.64	1.55	1.45	1.35	1.24	1.13
6"	2.14	2.06	1.98	1.89	1.81	1.71	1.62	1.52	1.42	1.31	1.21	1.10
9"	2.14	2.06	1.97	1.88	1.79	1.69	1.59	1.49	1.39	1.28	1.17	1.05
12"	2.13	2.05	1.96	1.86	1.77	1.67	1.57	1.46	1.35	1.24	1.13	1.01
15"	2.12	2.03	1.94	1.85	1.74	1.64	1.53	1.43	1.31	1.205	1.09	0.97
18"	2.12	2.03	1.93	1.83	1.72	1.62	1.51	1.40	1.28	1.17	1.05	0.93
21"	2.11	2.02	1.91	1.81	1.70	1.59	1.48	1.36	1.25	1.13	1.01	0.88
24"	2.11	2.00	1.89	1.79	1.68	1.56	1.45	1.33	1.21	1.09	0.97	0.84
27"	2.10	1.99	1.88	1.77	1.65	1.54	1.42	1.30	1.17	1.05	0.92	.80
30"	2.09	1.98	1.86	1.75	1.62	1.51	1.38	1.26	1.13	1.01	0.88	.75
33"	2.08	1.97	1.85	1.73	1.60	1.48	1.35	1.22	1.10	.97	.84	.70

TABULATED VALUES ARE THICKNESSES OF CONCRETE (IN FEET)

TABLE XIII1

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

1 b PROJECTILE 1400 f/sec

MATERIAL 1 ASPHALT | MATERIAL 2 SAND | MATERIAL 3 CONCRETE

THICKNESS OF SAND		THICKNESS OF CONCRETE											
		0"	.0625	0.125	.1875	.25	.3125	.3750	.4375				
0"		1.27	1.06	0.88	0.73	0.58	.44	.31	.12				
.125		1.23	1.01	0.83	0.66	0.51	0.37	0.23	0.11				
.25		1.19	0.95	0.76	0.59	.43	.29	0.15	0.03				
.375		1.15	0.89	0.69	0.56	0.36	0.21	0.07	-				
.5		1.11	.83	.62	0.44	0.28	0.13	-	-				
.625		1.06	.77	.55	.36	.20	.05	-	-				
.75		1.01	0.70	0.47	0.29	0.12	-	-					
.875		0.95	0.63	0.40	0.21	0.04	-						

TABULATED VALUES ARE THICKNESSES OF ASPHALT (IN FEET)

TABLE XIIIm

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM AT 1200 f/sec

MATERIAL 1	MATERIAL 2	MATERIAL 3
CONCRETE	ASPHALT	SAND

THICKNESS OF ASPHALT		THICKNESS OF SAND											
		0"	3"	6"	9"	12"	15"	18"	21"	24"	27"	30"	33"
0"		2.15	2.13	2.11	2.09	2.07	2.04	2.02	2.00	1.97	1.94	1.91	1.88
3"		2.08	2.06	2.04	2.02	2.00	1.97	1.95	1.92	1.89	1.86	1.82	1.79
6"		2.01	1.99	1.96	1.94	1.92	1.89	1.46	1.84	1.81	1.77	1.74	1.71
9"		1.93	1.91	1.88	1.86	1.83	1.81	1.78	1.75	1.72	1.69	1.65	1.62
12"		1.84	1.82	1.80	1.77	1.75	1.72	1.69	1.66	1.63	1.59	1.56	1.52
15"		1.75	1.73	1.71	1.68	1.65	1.63	1.59	1.57	1.53	1.50	1.46	1.43
18"		1.67	1.64	1.62	1.59	1.56	1.54	1.50	1.47	1.44	1.39	1.36	1.32
21"		1.57	1.55	1.52	1.50	1.47	1.44	1.40	1.37	1.34	1.30	1.26	1.22
24"		1.48	1.45	1.43	1.39	1.37	1.33	1.30	1.27	1.23	1.19	1.15	1.11
27"		1.38	1.35	1.33	1.30	1.26	1.23	1.20	1.16	1.13	1.09	1.04	1.00

TABULATED VALUES ARE THICKNESSES OF CONCRETE (IN FEET)

TABLE XIIIn

THICKNESSES OF MATERIALS IN COMBINATION REQUIRED TO DEFEAT A

155 MM 1200 f/sec

MATERIAL 1 CLAY | MATERIAL 2 ASPHALT | MATERIAL 3 CONCRETE

THICKNESS OF ASPHALT		THICKNESS OF CONCRETE 0"	3"	6"	9"	12"	16"	21"	24"	27"	30"		
0"		20.0	13.4	10.5	7.8	6.03	4.51	3.14	1.88	.69	-		
3"		19.0	12.6	9.56	7.39	5.64	4.12	2.76	1.50	.32	-		
6"		18.2	12.1	10.1	6.99	5.25	3.74	2.40	1.13	.47	-		
9"		17.4	11.7	9.97	6.59	4.87	3.37	2.01	.76	-	-		
12"		16.7	11.2	8.3	6.2	4.48	2.99	1.64	.40	-			
15"		16.1	10.8	7.90	5.81	4.1	2.61	1.27	.03	-			
18"		15.5	10.3	7.49	5.41	3.72	2.24	0.90	-				
21"		14.9	9.88	7.09	5.03	3.34	1.87	0.53	-				
24"		14.3	9.44	6.69	4.65	2.97	1.50	0.16	-				
27"		13.8	9.02	6.29	4.27	2.59	1.13	-	-				
30"		13.3	8.60	5.90	3.88	2.22	0.76	-					
33"		15.3	11.2	5.51	3.51	1.84	.39	-					

TABULATED VALUES ARE THICKNESSES OF CLAY (IN FEET)

TABLE XIIIo.

h. Operation of the Computer Program

(1) General

The computer program is designed to assist the planner in predicting the penetration of projectiles into materials. The program is equipped to handle 15 projectiles and 100 materials.

The program operates in three modes. The modes are:

Mode 1 - Analytical

Mode 2 - Design of Front Layer of Material

Mode 3 - Design of Back Layer of Material

The intent of each mode is discussed in the following paragraphs:

(a) Analytical - (Mode 1)

The purpose of the Analytical Mode is to analyze the performance of an existing or postulated combination of materials when they are subjected to attack by a specified projectile. In other words, the analytical mode predicts the penetration of a specified projectile into a single or set of materials. When operated properly, the output is the residual velocity (if any) upon exit from each layer of material, the depth of penetration through, or into, each material and the time of penetration. Paragraph (2) below, entitled "How to Operate the Program," will give the reader a step-by-step procedure on the techniques for employing the computer in all three operational modes.

(b) Design of the Front Layer - (Mode 2)

When operated in this mode, the computer will yield the thickness of the first layer of material such that the projectile is stopped in the last layer of material. In addition to calculating the required thickness of the first (front) material, the residual velocity through each material is calculated. As in the case of the Analytical Mode, penetration times through each layer will also be calculated in Mode 2.

(c) Design of the Back Layer - (Mode 3)

In this mode the thicknesses of layers in front of the last layer are given. The computer will then calculate the thickness of the final layer of material so that the projectile will be arrested in it. This mode should also be used in designing the thickness of a single material required to counter a designated projectile.

(2) How to Operate the Program

Two systems have been devised for utilizing the computer. The systems are:

The Time Share System

The Non-time Share System

Only the procedure for the Time Share System will be described here. Punch cards and print-outs for both systems have been provided, however. Both systems are written in FORTRAN.

(a) The Time Share System

This is a very simple procedure. No special skills are required to operate it, and it can be employed at any place where there is a convenient telephone. The system operates in a conversational manner; that is, following entrance, it asks for the required inputs. After receiving the inputs in coded form, the computer will confirm the inputs in the vernacular. Finally, the answers (output) will be given in a simple format. Repeating, there are four main steps in operating the Time Share System. They are:

Entrance

Input

Confirmation

Answers (Output)

(b) Entrance

To "unlock" the system, do the following:

1. Dial the designated telephone number and confirm the required computer "tone" has been received.

2. Place the telephone in the interconnect cradle.

3. Turn on the "teletype" portion of the system.

4. The teletype will immediately ask "User Code." It does this so that no one else can use this program and also so that the "time share" organization will know who to charge for the computer time.

5. Type your Code Number and then press the Carriage Return Key. Always press this key after completing

each input.

6. The computer will validate the authenticity of both User Code and Password. If all is proper, the computer operator will issue special instructions peculiar to the facility status, etc. These instructions are usually of no consequence vis-a-vis the program. This action completes the Entrance phase and we are now hooked to the computer proper.

(c) Input

To activate the program for calculating the penetration of projectiles into materials, do the following:

1. Using the teletype, command the computer to LOAD PONS. PONS is a nickname fc the program and is technically called the source code. PONS, incidentally, is short for Poncelet. It was chosen because the Poncelet equations are used in some of the calculations for penetration of projectiles. After typing LOAD PONS, command the computer to RUN. This will suffice to completely start the program. To save compiling time everytime the system is used (LOAD and RUN), and thus to reduce costs, it is advantageous to use an "object code" instead of the source code. An object code would have PONS already compiled. So instead of using PONS, simply command the computer to execute the object code. The object code is P099. The command to execute P099 is given by "EXE P099." Then "Return Carriage."

(Note: From this point on, it would be beneficial for the reader to refer to Figure V on page XVI entitled "Method for Predicting Penetration of Materials." Reference to the "Work Sheet" on page 4-129 will also be of assistance.)

2. The computer will ask:

TYPE THE NUMBER OF LAYERS, THE PROJECTILE CODE, AND OPERATION MODE CODE (See box C-2 on Figure

3. To the above, the replys would be:

QUERY	REPLY
NUMBER OF LAYERS	Type the exact number and follow it immediately with a comma. For example, 3, means that 3 layers of materials are involved for either analysis or design.
PROJECTILE CODE	All projectiles currently in the program have been codified as follows:

To Designate	Reply
1 lb. Projectile	1
30 Caliber	2
50 Caliber	3
20 mm	4
Test Projectile (to be specified)	(6,7&8)

To Designate	Reply
57 mm	9
75 mm	10
76 mm	11
90 mm	12
105 mm	13
155 mm	14
122 mm	15

For example, if the 122 mm Rocket is the projectile trying to penetrate, the answer would be 15,

OPERATION MODE CODE

If it is desired to analyze an existing or postulated material or combination of materials, the answer would be 1, to design the front layer, the answer would be 2, to design the back layer, the answer would be 3,

(Summarizing, the reply to the query "TYPE THE NUMBER OF LAYERS, THE PROJECTILE CODE AND OPERATION MODE CODE" would be:

3, 15, 1 for 3 materials, the 122 mm rocket, and analysis of the 3 materials vis-a-vis the 122 mm. Return Carriage)

4. The computer needs additional information to perform the penetration calculation. This information pertains to the type of materials and their thicknesses. Accordingly, the machine will ask, "TYPE LAYER THICKNESS (FT) IN SEQUENCE FROM STRIKE SIDE."

5. The replies to the above query would be:

For Thicknesses in Inches of	Reply in Feet
1/8 inch	.0104
1/4 "	.0208
1/2 "	.0417
3/4 "	.0625
1 "	.0833
2 "	.1667
3 "	.2500
4 "	.3333
5 "	.4167
6 "	.5000
7 "	.5833
8 "	.6667
9 "	.7500
10 "	.8333
11 "	.9167
12 "	1.0000

For thicknesses exceeding 1'-0", simply add the decimal equivalents to the number of feet.

The reply to "TYPE LAYER THICKNESS (FT) IN SEQUENCE FROM STRIKE SIDE" would be 4.0, 1.5, .0417. This would be the case only if the first layer were 4'-0" thick, the second layer 1'-6" thick and the last layer 1/2 inch thick.

6. The next input is concerned with the type of material. The question will take the form of: "TYPE EACH LAYER CODE IN SEQUENCE FROM STRIKE SIDE." The input relative to this query will be:

For	Answer	Formulas Used
CLAY	1	Poncelet Equations Used (AA)
LOAM	2	
SANDY LOAM	3	
SAND	4	
ASPHALT (DATA TENTATIVE)	5	
REINFORCED CONCRETE	6	
SOFT WOOD	7	
MEDIUM HARD WOOD	8	
HARD WOOD	9	
RICH CLAY	10	
STEEL GRIT	11	
ASPHALT WITH STEEL GRIT	12	
(RESERVED FOR FUTURE MATERIALS)	(13-50)	
STEEL (BHN 150)	51	Empirical Formulas Used (DA)
STEEL (" 250)	52	

For	Answer	Formulas Used
STEEL (BHN 300)	53	Empirical Formulas Used (DA)
STEEL (" 350)	54	
STEEL (" 400)	55	
STEEL (" 500)	56	
STEEL (" 350)	57	Hugoniot Equations Used (CA)
TITANIUM (6Al-4V)	58	
MAGNESIUM (13LI-6Al)	59	
ALUMINUM (5083)	60	
ALUMINUM OXIDE	61	
DORON	62	
PLEXIGLAS	63	
LEXON	64	
GLASS	65	
LEAD GLASS	66	
ALUMINUM (2024)	67	
UNBONDED NYLON	68	
(RESERVED FOR FUTURE MATERIALS)	(69-100)	

If the materials under examination were sand, reinforced concrete and steel (BHN 150), the reply to "TYPE EACH LAYER CODE IN SEQUENCE FROM STRIKE SIDE" would be 4, 6, 51.

7. The final input pertains to the velocity of the projectile. The query is, "TYPE STRIKING VELOCITY IN FEET/SECOND." The answer is given directly without the

use of code. For eleven hundred feet per second, type 1100.00. This completes the Input phase. The computer will now start to confirm and to expand the inputs you have commanded it to process.

EXCEPTION EXCEPTION EXCEPTION EXCEPTION

8. Where the operation mode code is 2 (Design of Front Layer), the computer needs additional data. It will ask, "TYPE NO. ITERATIONS ON SECOND LAYER. TYPE NO. ITERATIONS ON THIRD LAYER." If it is desired to have the number of iterations on the second and third layer be 2 and 1 respectively, the reply would be 2,1. The next query relates to the amount of material which is to be added in increments to the second and third layers. The query will be, "TYPE INCREMENT IN FEET TO SECOND LAYER. TYPE INCREMENT IN FEET TO THIRD LAYER." In replying to this query, use the same technique described in step 5 above. The reasons for having the computer operate in this fashion were covered in Section 4g(2), "Design Mode - Front Layer Variable," beginning on page 4-91. Before proceeding further, 4g(2) should be reviewed at this time.

(d) Confirmation

The commands to the computer are completed by following the procedure delineated under Section 4h(2)(c), "Input," above. To confirm that the inputs were correct before

WORK SHEET

	CODE	
NUMBER OF LAYERS		
PROJECTILE CODE NAME ______		
OPERATION MODE 1 ANALYSIS OF DESIGN 2 DESIGN OF FRONT LAYER 3 DESIGN OF BACK LAYER		FOR MODE 2 ONLY ITERATIONS ON 2nd LAYER ___ ITERATIONS ON 3rd LAYER ___ INCREMENT ON 2nd LAYER ___ INCREMENT ON 3rd LAYER ___
THICKNESS OF LAYER (FT)		
1st LAYER		
2nd LAYER		
3rd LAYER		
MATERIAL OF EACH LAYER		
1st LAYER		
2nd LAYER		
3rd LAYER		
STRIKING VELOCITY		

processing them, the computer will "play back" the data given to it in a conversational manner. The confirmation begins by giving relevant data such as:

NUMBER OF MATERIAL LAYERS =	3
CODE OF PROJECTILE =	15
CODE OF OPERATION =	1
SAND THICKNESS IS =	4.00 FEET (CODE 4)
CONCRETE THICKNESS IS =	1.5 FEET (CODE 6)
STEEL (BHN 150) THICKNESS IS =	0.0417 FEET (CODE 51)
INITIAL VELOCITY =	1100.00 FEET/SECOND
TYPE PROJECTILE	122 MM
LENGTH OF CONE	17.09 INCHES
DIAMETER	4.80 INCHES
CONE ANGLE	0.14 RADIANS
WEIGHT	43.00 POUNDS
NOSE TYPE	3
CUBERT OF WEIGHT	3.50

If no mistakes are noticed in the above confirmation, the computer will automatically process the data and do the calculations with respect to the interaction between the designated projectile and the materials.

(e) Answers or Output

Having received the problem and confirmed the data, the computer will, for each material, now calculate and print out:

The Residual Velocity

The Time of Penetration

The Depth of Penetration

The methods used for the calculations are shown in Section 4f of this document. Examples of the print-out for each operation mode are contained in the pages immediately following.

```
COMNET TIME SHARING
ENTER USER CODE, PLEASE-W6345
AND YOUR PASSWORD
[redacted]
YOU HAVE LINE 01,
12/11/68  4:40 PM.

EXECUTE PONS
 RUNNING

 TYPE THE NUMBER OF LAYERS ,THE PROJECTILE  CODE
 AND OPERATION MODE CODE
?3,15,1,
 TYPE LAYER THICKNESS(FT) IN SEQUENCE FROM  STRIKE SIDE
?4.0,1.5,0.0417
 TYPE EACH LAYER CODE IN SEQUENCE FROM  STRIKESIDE
?4,6,51,
TYPE STRIKING VELOCITY IN FEET/SECOND
?1100.0


 NUMBER OF MATERAL LAYERS =    3
        CODE OF PROJECTILE =   15
       CODE OF OPERATION =    1

       SAND    THICKNESS IS =     4.0000  FEET    (CODE =    4)

    CONCRETE THICKNESS IS =     1.5000  FEET    (CODE =    6)

 STEELBHN150 THICKNESS IS =     0.0417  FEET    (CODE =   51)

 INITIAL VELOCITY =    1100.00 FEET/SEC

 TYPE PROJECTILE  122MM
 LENGTH OF CONE    17.09 INCHES
 DIAMETER           4.80 INCHES
 CONE ANGLE         0.14 RADIANS
 WEIGHT            43.00 POUNDS
 NOSE TYPE             3
 CUBERT OF WEIGHT  3.50

      SAND

 RESIDUAL VELOCITY =  446.7191

 TIME              =    0.0058
 PENETRATION       =    4.0000

    CONCRETE

 RESIDUAL VELOCITY =    0.0000

 TIME              =    0.0022
 PENETRATION       =    0.4534


        TOTAL TIME =    0.00801  SECONDS
 TOTAL PENETRATION =    4.45343     FEET
```

```
-ENTER USER CODE, PLEASE-W6345
AND YOUR PASSWORD
[redacted]
YOU HAVE LINE 14,
12/13/68  5:23 PM.

EXECUTE PONS
 RUNNING

 TYPE THE NUMBER OF LAYERS ,THE PROJECTILE  CODE
 AND OPERATION MODE CODE
?3,15,2,
 TYPE LAYER THICKNESS(FT) IN SEQUENCE FROM  STRIKE SIDE
?0.0,3.0,0.47,
 TYPE EACH LAYER CODE IN SEQUENCE FROM  STRIKESIDE
?3,4,6,
TYPE STRIKING VELOCITY IN FEET/SECOND
?1100.0
 TYPE NO. ITERATIONS ON SECOND  LAYER
 TYPE NO. ITERATIONS ON THIRD LAYER


?1,1,
 TYPE INCREMENT IN FEET TO SECOND LAYER
 TYPE INCREMENT IN FEET TO THIRD LAYER

?1.0,0.0<5
 CR2=     1.0000  CR3=     0.5000



 NUMBER OF MATERAL LAYERS =    3
        CODE OF PROJECTILE =  15
       CODE OF OPERATION =   2

  SANDY LOAM THICKNESS IS =    0.0000  FEET    (CODE =   3)

     SAND   THICKNESS IS =    3.0000  FEET    (CODE =   4)

   CONCRETE THICKNESS IS =    0.4700  FEET    (CODE =   6)

 INITIAL VELOCITY =   1100.00 FEET/SEC

 TYPE PROJECTILE  122MM
 LENGTH OF CONE   17.09 INCHES
 DIAMETER          4.80 INCHES
 CONE ANGLE        0.14 RADIANS
 WEIGHT           43.00 POUNDS
 NOSE TYPE            3
 CUBERT OF WEIGHT  3.50

1 PENETRATION SOLUTION

 LAYER   3

   CONCRETE

 STRIKING VELOCITY =  456.8899

 TIME              =     0.0022
 PENETRATION       =     0.4700

 LAYER   2

     SAND

 STRIKING VELOCITY =  908.1208

 TIME              =     0.0047
 PENETRATION       =     3.0000


      TOTAL TIME =     0.00694  SECONDS
 TOTAL PENETRATION =   3.47000     FEET

 LAYER   1

  SANDY LOAM

 STRIKING VELOCITY = 1100.0000
```

```
TYPE THE NUMBER OF LAYERS ,THE PROJECTILE  CODE
AND OPERATION MODE CODE
?3,15,2,
 TYPE LAYER THICKNESS(FT) IN SEQUENCE FROM  STRIKE SIDE
?0.0,3.0,0.47,
 TYPE EACH LAYER CODE IN SEQUENCE FROM  STRIKESIDE
?3,4,6,
TYPE STRIKING VELOCITY IN FEET/SECOND
?1100.0
 TYPE NO. ITERATIONS ON SECOND  LAYER
 TYPE NO. ITERATIONS ON THIRD LAYER


?1,1,
 TYPE INCREMENT IN FEET TO SECOND LAYER
 TYPE INCREMENT IN FEET TO THIRD LAYER

?1.0,0.0<5
 CR2=     1.0000  CR3=     0.5000



 NUMBER OF MATERAL LAYERS =    3
        CODE OF PROJECTILE =  15
       CODE OF OPERATION =    2

  SANDY LOAM THICKNESS IS =    0.0000  FEET    (CODE =    3)

     SAND    THICKNESS IS =    3.0000  FEET    (CODE =    4)

   CONCRETE THICKNESS IS =    0.4700  FEET    (CODE =    6)

 INITIAL VELOCITY =   1100.00 FEET/SEC

 TYPE PROJECTILE  122MM
 LENGTH OF CONE   17.09 INCHES
 DIAMETER          4.80 INCHES
 CONE ANGLE        0.14 RADIANS
 WEIGHT           43.00 POUNDS
 NOSE TYPE            3
 CUBERT OF WEIGHT  3.50

1 PENETRATION SOLUTION

 LAYER   3

   CONCRETE

 STRIKING VELOCITY =  456.8899

 TIME               =     0.0022
 PENETRATION        =     0.4700

 LAYER   2

     SAND

 STRIKING VELOCITY =  908.1208

 TIME               =     0.0047
 PENETRATION        =     3.0000


        TOTAL TIME =     0.00694  SECONDS
 TOTAL PENETRATION =     3.47000     FEET

 LAYER   1

  SANDY LOAM

 STRIKING VELOCITY = 1100.0000

 TIME               =     0.0361
 PENETRATION        =     1.0190


        TOTAL TIME =     0.04301  SECONDS
 TOTAL PENETRATION =     4.48899     FEET
```

B

```
COMNET TIME SHARING
ENTER USER CODE, PLFASF-W6345
AND YOUR PASSWORD
[redacted]
YOU HAVE LINE 04,
12/13/68 12:06 PM.

EXECUTE PONS
 RUNNING

 TYPE THE NUMBER OF LAYERS ,THE PROJECTILE  CODE
 AND OPERATION MODE CODE
?3,15,3
 TYPE LAYER THICKNESS(FT) IN SEQUENCE FROM  STRIKE SIDE
?1.0,3.0,0.0
 TYPE EACH LAYER CODE IN SEQUENCE FROM  STRIKESIDE
?3,4,6
TYPE STRIKING VELOCITY IN FEET/SECOND
?1100.00


 NUMBER OF MATERAL LAYERS =    3
        CODE OF PROJECTILE =  15
       CODE OF OPERATION =    3


  SANDY LOAM THICKNESS IS =     1.0000  FEET    (CODE =   3)

     SAND   THICKNESS IS =     3.0000  FEET    (CODE =   4)

   CONCRETE THICKNESS IS =     0.0000  FEET    (CODE =   6)


 INITIAL VELOCITY =   1100.00 FEET/SEC


 TYPE PROJECTILE  122MM
 LENGTH OF CONE   17.09 INCHES
 DIAMETER          4.80 INCHES
 CONE ANGLE        0.14 RADIANS
 WEIGHT           43.00 POUNDS
 NOSE TYPE            3
 CUBERT OF WEIGHT  3.50

1 PENETRATION SOLUTION


  SANDY LOAM

 RESIDUAL VELOCITY =  911.3996

 TIME             =    0.0010
 PENETRATION      =    1.0000
     SAND

 RESIDUAL VELOCITY =  458.8797

 TIME             =    0.0047
 PENETRATION      =    3.0000


        TOTAL TIME =    0.00568  SECONDS
 TOTAL PENETRATION =    4.00000     FEET


   CONCRETE

 RESIDUAL VELOCITY =    0.0000
```

```
TYPE THE NUMBER OF LAYERS ,THE PROJECTILE  CODE
AND OPERATION MODE CODE
?3,15,3
TYPE LAYER THICKNESS(FT) IN SEQUENCE FROM  STRIKE SIDE
?1.0,3.0,0.0
TYPE EACH LAYER CODE IN SEQUENCE FROM  STRIKESIDE
?3,4,6
TYPE STRIKING VELOCITY IN FEET/SECOND
?1100.00


NUMBER OF MATERAL LAYERS =    3
       CODE OF PROJECTILE =   15
      CODE OF OPERATION =    3


 SANDY LOAM THICKNESS IS =     1.0000  FEET    (CODE =    3)

     SAND   THICKNESS IS =     3.0000  FEET    (CODE =    4)

   CONCRETE THICKNESS IS =     0.0000  FEET    (CODE =    6)

INITIAL VELOCITY =   1100.00 FEET/SEC


TYPE PROJECTILE  122MM
LENGTH OF CONE   17.09 INCHES
DIAMETER          4.80 INCHES
CONE ANGLE        0.14 RADIANS
WEIGHT           43.00 POUNDS
NOSE TYPE            3
CUBERT OF WEIGHT  3.50

1 PENETRATION SOLUTION

 SANDY LOAM

RESIDUAL VELOCITY =  911.3996

TIME              =    0.0010
PENETRATION       =    1.0000
     SAND

RESIDUAL VELOCITY =  458.8797

TIME              =    0.0047
PENETRATION       =    3.0000


       TOTAL TIME =    0.00568   SECONDS
TOTAL PENETRATION =    4.00000      FEET


   CONCRETE

RESIDUAL VELOCITY =    0.0000

TIME              =    0.0022
PENETRATION       =    0.4733


       TOTAL TIME =    0.00793   SECONDS
TOTAL PENETRATION =    4.47325      FEET
```

B

5. PREFERRED CONCEPTS

a. General

The derivation of a preferred concept for shelters for passive protection requires the consideration of many driving forces which conflict. Variation of the threat capabilities is balanced by many options available to the defender. But a poor choice of options can result in too high risk or excessive cost if a predicted threat capability range does not materialize. When the number of rounds fired is low, size and shape which result in low probabilities of hit have greater importance than when large numbers of rounds aimed at a target are fired by the enemy. When large numbers of rounds can be fired, the structures must be constructed not only to defeat a hit, but must protect against multiple hits. Cost, then, becomes high and the structures become complex. The advantages of material and weight savings by the use of oblique surfaces to the impact of projectiles and fragments should almost always be utilized. However, obliquity loses its effectiveness as the velocities and masses encountered become higher. Reduction of velocity of projectiles, under these conditions, then becomes a prime consideration so that ricochet can be induced by an oblique surface in the path of the projectile as it proceeds into the material of the structure. The objective, here, is to disengage the projectile from the structure when explosion occurs because the effectiveness of the projectile can thereby be greatly reduced. If the projectile explodes within the defensive material of a structure, then provision should be made for attenuation of the blast by venting or by frangible or crushable materials within the blast area to absorb the energy. This is probably a worthwhile consideration only when the number of events is low. The use of revetments against small arms fire and fragments from explosive projectiles with short delay fuses appears to be a good option when impact angles are low. However, protective roofs are required to be sufficient to defeat AP projectiles equipped with delayed fuses when the angles of impact are 30 degrees or above and the total number of cumulative rounds expected is on the order of 40. The efficiency with which various materials stop the penetration of projectiles especially in the lower caliber ranges has considerable variation. However, from the standpoint of cost effectiveness, structural steel, concrete, soils, and wood appear to be the best materials for passive defense structures. Consideration of these many factors has lead to the preferred concepts for specific applications discussed in the following paragraphs.

b. Aircraft Shelters

(1) Size

Aircraft shelters for the future should be sized to accept aircraft now in the Concept Formulation Phase. Two such aircraft are the FX and the A-X. The desirability to have a structure with a small presented area is recognized, but the function in the case of shelters for aircraft is overriding. The size and the shape of the shelter can also influence the presented area of the structure. The possibility of proposing the structure with the smallest presented area by varying its shape will be considered in the next paragraph. Suffice it to say, at this juncture, that the aircraft shelter should have a clear height of 22'-0" with a 5 foot clearance on each side. The width at 1'-6" above the wing-tip should be such that it can accept aircraft with 55'-0" wing spans. Each wing-tip should have a horizontal clearance of at least 3'-0". The overall width of the shelter, then, should be at least 61'-0". The length of the shelter should accommodate an aircraft with an overall length of 72'-0". The nose of the aircraft should be 20'-0" from the front of the shelter and the tail of the airplane should be at least 8'-0" from the back of the structure. The effective length of the structure should be about 100'-0". However, where real-estate becomes a limiting consideration, shelters of an 84'-0" dimension could be utilized.

In summary, with respect to size, the shelter should have a clear height of 22'-0". Its width should be at least 61'-0" but preferably 64'-0". Its length should be between 84'-0" minimum and 100'-0" maximum. This size will accommodate all present fighter type aircraft, those now in concept formulation and their growth versions. Provision should be made for a tunnel on the back of the shelter to exhaust the jet gases. This tunnel is not included in the effective length of the shelter. For general rationale on size and shape for structures, the reader is referred to pages 3-4 through 3-14 and 4-1 through 4-17.

(2) Shape

The shape of the structure influences the area and the obliquity presented to an attacking missile. The matter of obliquity is addressed in the next paragraph; therefore, this portion of the report will consider shape as a function of presented area. The presented area of the structure, combined with the circular error probable (CEP) of the attacking weapon determines the probability of the structure being hit. It, therefore, is desirable to minimize the area that a shelter presents to the weapon. The structural form which presents the smallest area is a structure having a combination of straight walls 10'-0" high and an arched roof on top of the walls (see discussion and figures beginning on page 4-3). This scheme, however, presents expensive roof framing problems and aircraft clearance difficulties. The same effect can be obtained by placing the bottom of the arch on ground level and then filling the "unusable" space between the arch and the wing-tip clearance line with protective materials.

In summary with respect to shape, an arched type shelter with a radius of 34'-0" is desirable. The center of the semi-circular arch is, however, about 9'-0" below the surface such that a chord measuring 66'-0" on the surface is subtended. Again, the reader is referred to sections 3 and 4 (pages 3-4 through 3-14 and 4-1 through 4-17 respectively) for the rationale covering the shape of aircraft shelters.

(3) Obliquity

As stated above, the shape of a structure influences the obliquity that a target presents to an attacking weapon. A wall inclined 20 degrees toward the attacking weapon encourages ricochet. By the same taken, a roof that is flat and horizontal encourages ricochet. It is necessary, however, when considering attacks by large weapons (75 mm plus) that a scheme be devised to slow down the velocity of the attacking missile so that it can ricochet from properly configured structural surfaces. Sand and/or other classifications of soil can be used for this purpose. Obliquity for structural surfaces is covered in sections 3 and 4 on pages 3-14 through 3-18 and 4-17 through 4-39, respectively.

(4) Strength

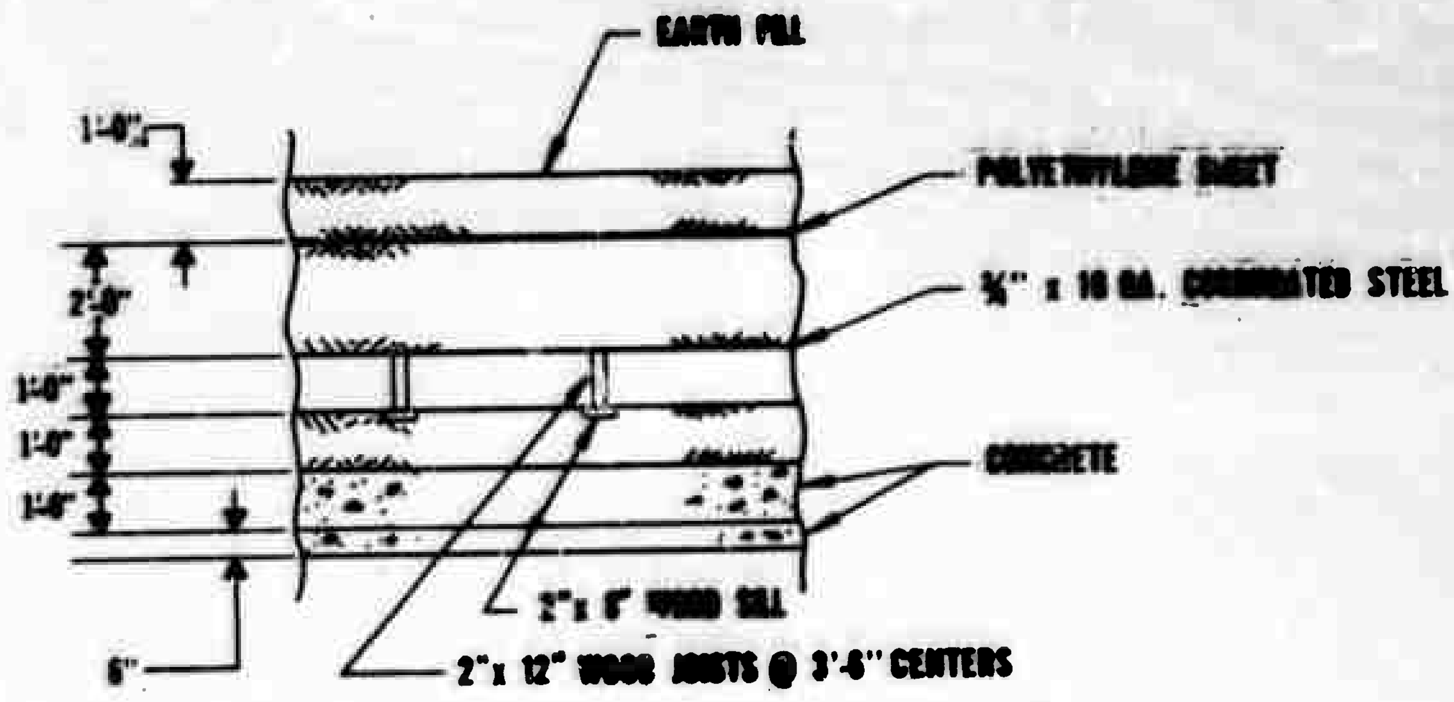
The structure must resist blast, fragments and penetration from direct hits by projectiles. The structure derives its strength to protect against these phenomena from the materials and the manner in which they are employed. The functions of the materials used for passive protection are covered in Section 3 (pages 3-17 through 3-49). The application of these materials to concepts is discussed in Section 4 (pages 4-40 through 4-60). On balance, the most cost effective materials are mild steel, concrete and earth. The reaction of these and of the other materials in the passive protection role are contained in the aforementioned pages and also in section 4 under "Penetration Analysis" beginning on page 4-65.

(5) Terrestrial Environment

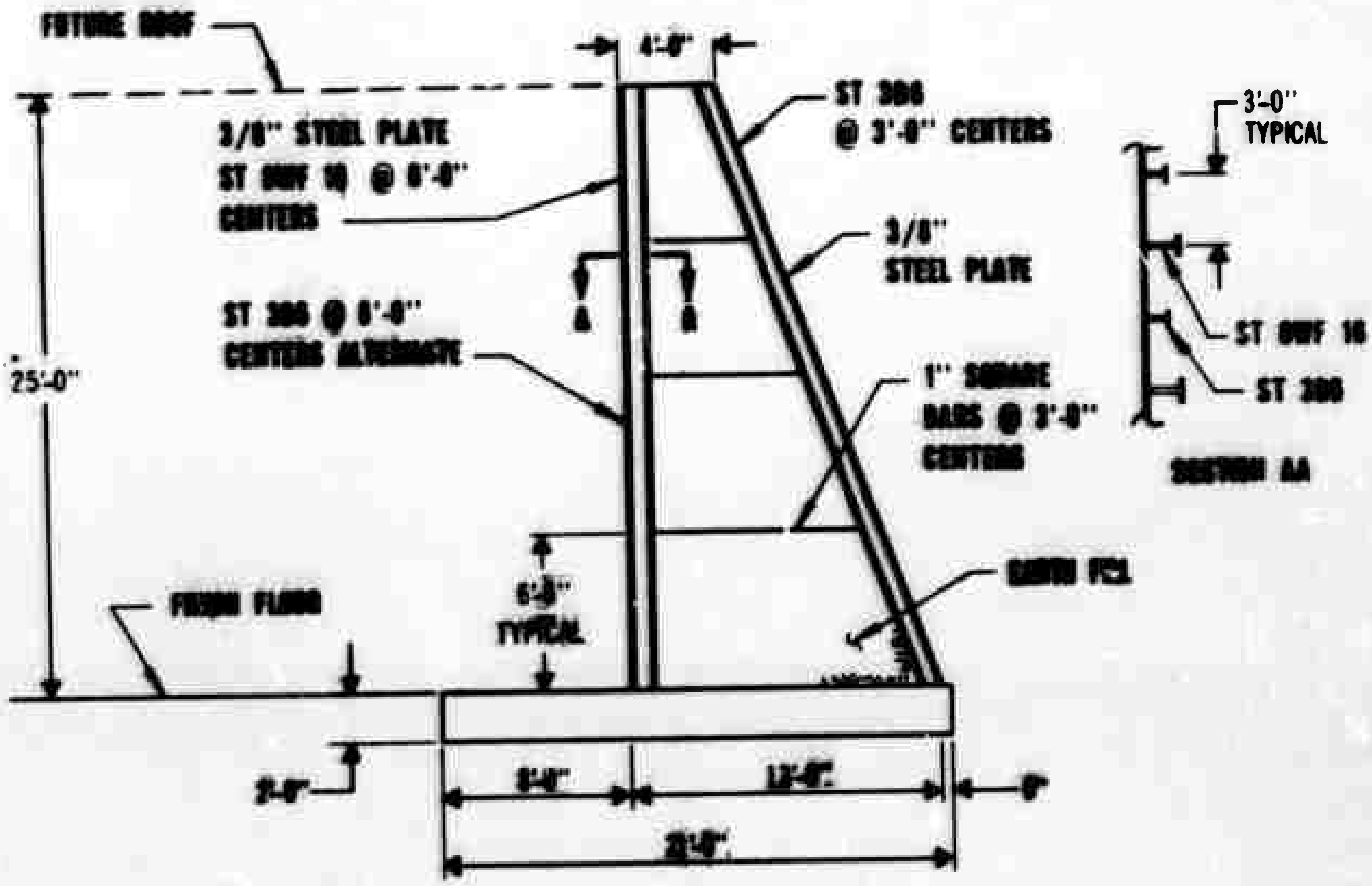
Because of the operational problems associated with partly buried or totally buried structures for aircraft shelters, the above ground environment was chosen for these structures. The relative advantages and disadvantages of this approach are discussed and listed on pages 3-35 and 3-50 through 3-54.

(6) Structural Forms for Aircraft Shelters

Protection against small arms fire (30 and 50 caliber) can be obtained for aircraft by using earth revetments. If it is anticipated that escalation of the attack will require protection against mortars and large caliber rocket fire, it will be necessary to add roof structures to provide the desired degree of protection. When a roof is necessary, it is cost effective to provide interior vertical walls for the enclosures as this needs only approximately two-thirds the roof area required when walls are inclined outward at 20 degrees in a single plane. The typical wall construction shown in Figure 67 does not take advantage of a forced angle of obliquity as this will, as mentioned above, increase the required roof area. It is possible to provide one vertical 3/4 inch thick steel plate for protection against 30 caliber small arms fire and the addition of a tumble or trigger screen will make this effective against 50 caliber projectiles. The erection of a 3/4 inch plate wall will require supporting steel framework. The cost of this framework more than offsets the cost of earth fill between two 3/8 inch steel plates which have been tied together to resist the horizontal forces of the earth fill. Thus, the wall construction would consist of a vertical 3/8 inch interior steel plate and an exterior 3/8 inch steel plate which has been sloped at approximately 20 degrees inward and with the two plates tied together with steel bar ties. The sloped face of the exterior wall will provide an angle of



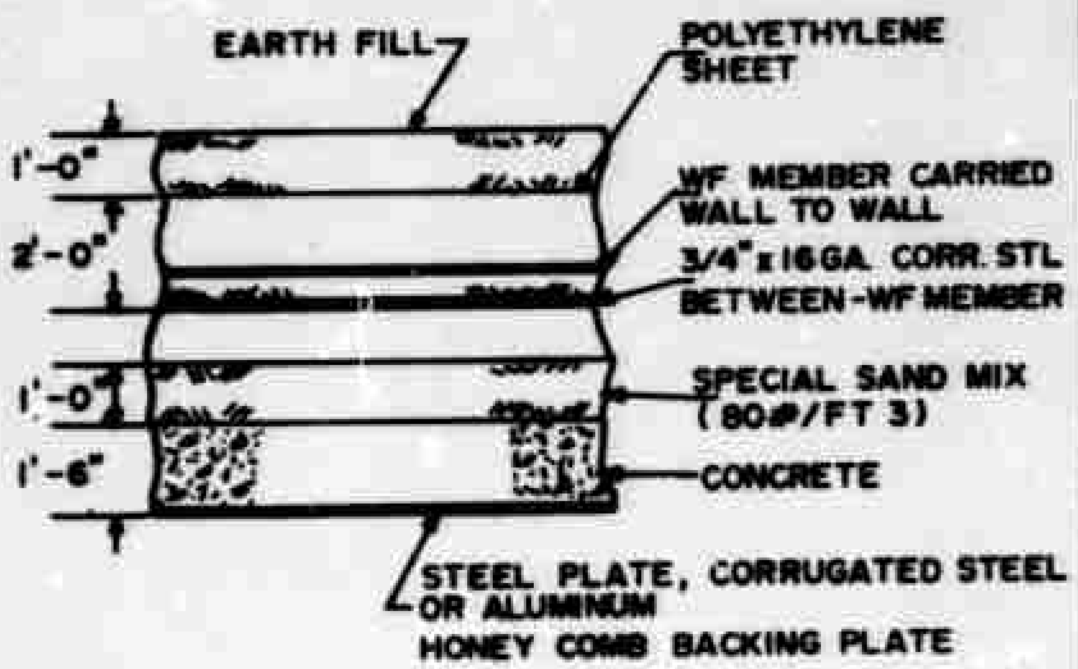
TYPICAL ROOF CONSTRUCTION



TYPICAL WALL CONSTRUCTION

FIGURE 67

CONSTRUCTION OPTION



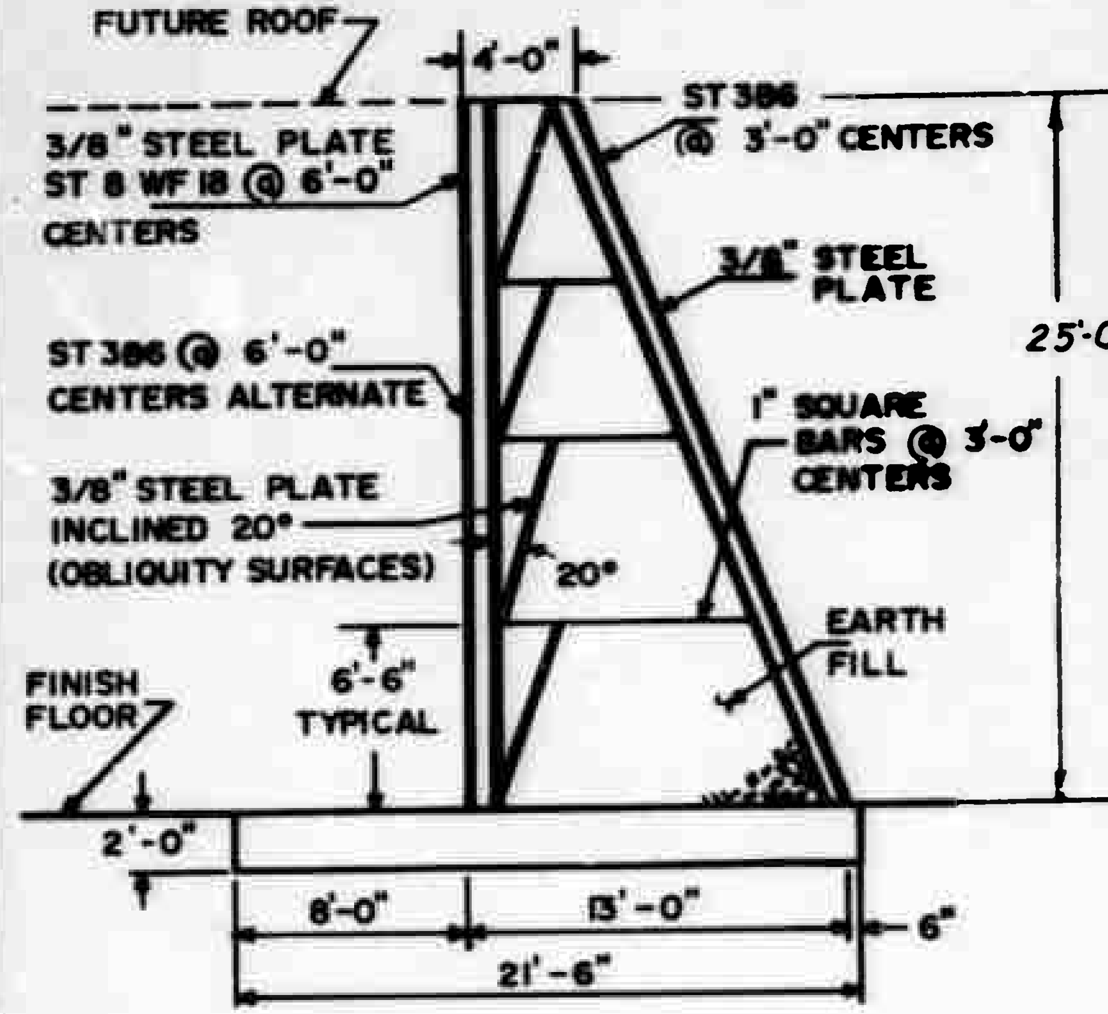


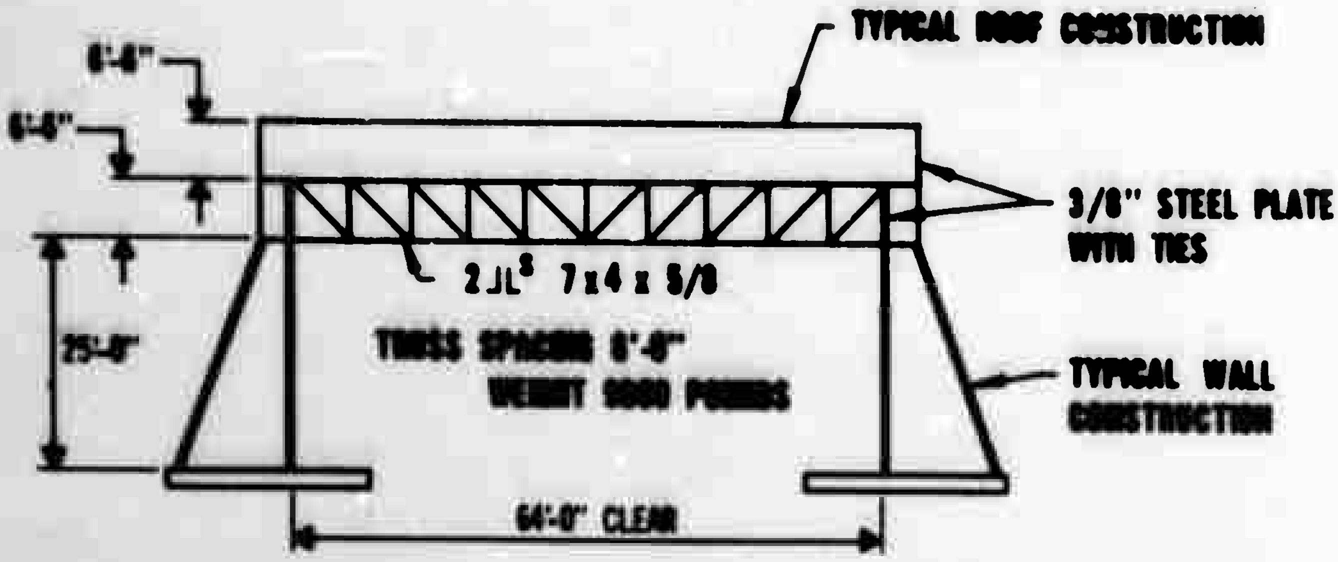
FIGURE 67A

obliquity for most of the probable threats and provides sufficient stability to the wall so that it may be used for a roof support.

The typical roof construction indicated in Figure 67 provides a 1 foot vented void to reduce the contained explosion effect of any projectiles which penetrate the roof earth fill and explode near the roof structure. The 1 foot dimension is a conceptual figure and should be validated for blast attenuation prior to actual design. The vent outlets should be "diffuser" shaped, and, if vertical, they should be covered with a burst diaphragm. The diaphragm is used for weather protection.

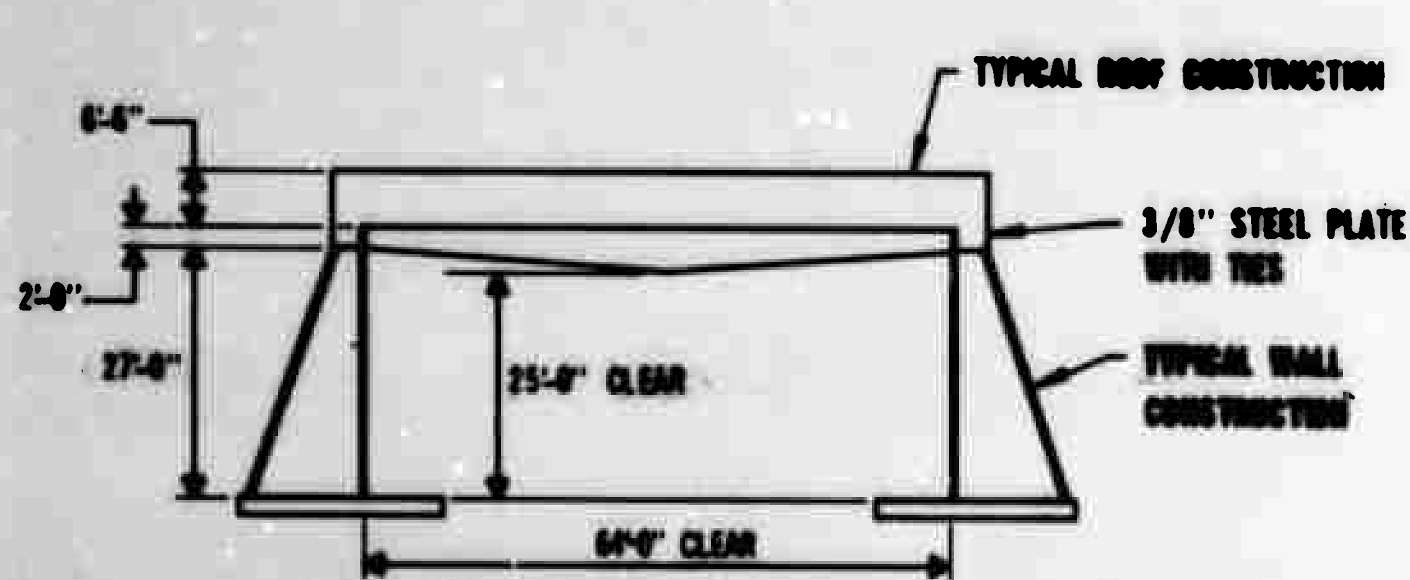
An alternative typical wall and roof are shown in Figure 67 A. The alternative wall features obliquity plates within the wall inclined toward the attack by 20 degrees. The segmented scheme for these plates incorporates the very desirable obliquity attribute without increasing the thickness of the wall or the dimensions of the roof. An alternative roof concept eliminates the wooden sills and joists from the basic concepts and replaces them with wide-flange structural members. This alternative frees the vented void space from all obstructions and allows the designer to increase the volume of the void to more nearly match the explosive charge. The cost of this concept is not included in Figure 70, "Estimate of Cost."

As stated in Section 4e, "Structural Forms," several supporting systems for the roof have been investigated. These include steel trusses (Figure 68), tapered girders (Figure 68), bridge



LONG SPAN STEEL JOISTS 3'-4" DEEP No. 40LH16
JOIST SPACING 1'-8" CENTERS
JOIST WEIGHT 2700 POUNDS

TYPICAL ROOF TRUSS CONSTRUCTION



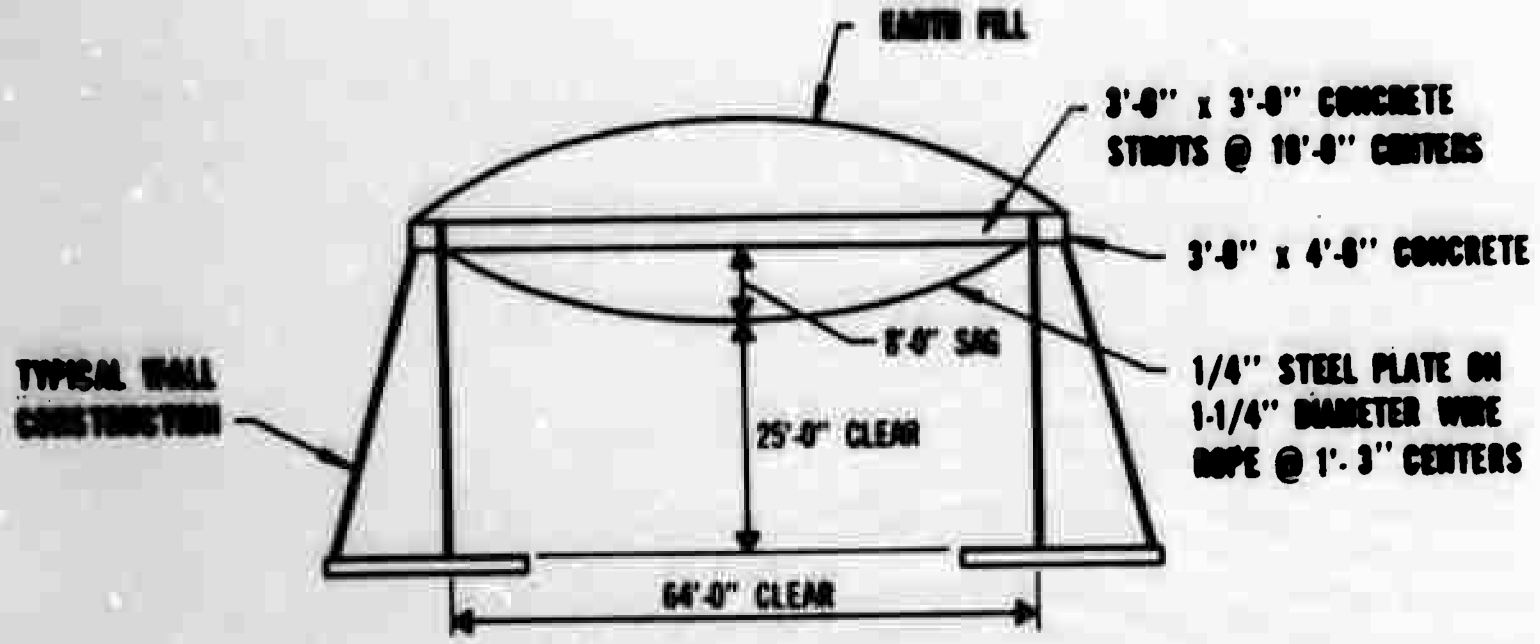
TAPERED GIRDER SPACING 7'-0"
WEIGHT 14,700 POUNDS
COMPOSITE STEEL CONCRETE (BRIDGE DECK DESIGN)
SPACING 7'-0"
WEIGHT [illegible] POUNDS

TYPICAL BEAM DESIGN

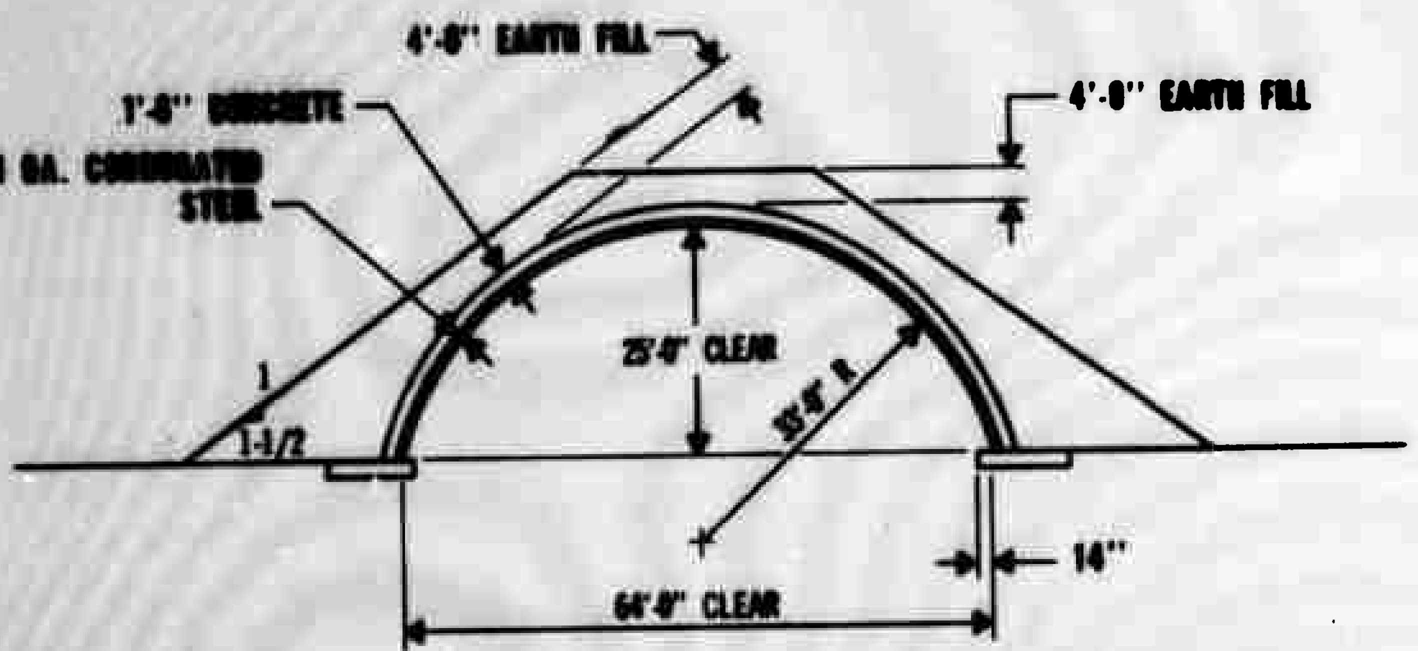
FIGURE 68

decks (using a composite design), and a cable suspension roof (Figure 69). Because of the sloped underside of the tapered girders and of the cable suspension system, it is necessary to increase the height of the side walls to provide the same clear height given by the truss of the bridge deck design.

Present protection for aircraft for some specific weapons has been provided by use of a corrugated steel building in the shape of a semi-circular arch covered with 18 inches of concrete and possibly additional earth fill. The arch type shelter proposed in this study is larger than the present one being procured. The larger size will accommodate the next generation of combat aircraft. Their wingspans will approximate 55 feet unless the wings are either folded or "swung." Comparative cost estimates for these systems have been completed, and on the basis of these cost estimates (Figure 70, "Estimate of Cost"), as each of the systems will provide an equivalent degree of protection, it is recommended that the arched type shelter configured in this study be used for passive protection for aircraft. The presented area of the arch, and hence its probability of being hit, is lower than for any other structural scheme. The low probability of hit is most valuable where the cumulated number of attacking rounds is low. The cross section of the arch more nearly fits the contour of an aircraft than any other structural scheme. The ratio of the volume of the aircraft to the volume of the structure is higher for the arched configuration than any other scheme. This indicates a



TYPICAL CABLE SUSPENDED ROOF



TYPICAL ARCH CONSTRUCTION

FIGURE 69

ESTIMATES OF COST

TYPE CONSTRUCTION	TOTAL COST PER FOOT OF SHELTER, 64'-0" CLEAR INSIDE	TOTAL COST FOR SHELTER 84'-0" LONG
ROOF TRUSS	$ 1,763.39	$ 148,125
STEEL TRUSS	1,717.44	144,265
TAPERED GIRDER	1,835.09	154,158
COMPOSITE STEEL/CONCRETE	1,572.31	132,079
CABLE SUSPENDED	1,254.38	105,368
ARCH	932.94	78,367

FIGURE 70

more efficient utilization of space than is presented by other configurations. Since the surface area of the arch is the lowest for the volume provided, this results in the lowest cost for protective materials.

c. Barracks

Facilities for housing personnel for protection should be placed in a partially buried environment. The earth removed to provide the inherent protection of a below ground facility can then be used to make revetments to protect the above ground portion of the facility or to cover the facility in the same manner as proposed for the protection of aircraft.

Several configurations were considered. All configurations were rectangular in plan. Cross sections considered were rectangular, semi-circular, circular segments and combinations. Dimensions were varied to arrive at the optimum configuration for each type. Since structures can be configured to give equal protection, the choice of the configuration becomes the one which provides the protection for the least cost per individual person protected. For the purpose of making this comparison, it is assumed that a 40 man barrack is required and that each man is allocated 80 square feet of usable area. Usable area, as applied here, is defined as that floor area above which there is at least 5 feet of head room. Latrines and storage areas are also treated as usable areas. Stairways for two story barracks are also included as usable areas.

Arched-type structures for barracks could be utilized, but the volumetric efficiency (i.e., usable volume vs. total space) for single story barracks with a semi-circular or a circular segment cross section is lower than barracks with a rectangular cross section. The presented area to an attacking projectile by barracks with either semi-circular or circular segment cross sections is generally smaller than one with a rectangular cross section. Hence, the probability of hitting the individual barracks of the same floor area is less for a semi-circular structure. As pointed out earlier, however, the utilization of the rectangular structure for barracks, as opposed to aircraft, is greater than the arch type. It was found that 40 man barracks with a rectangular cross section required 640 cubic feet per man while the various concepts of the semi-circular arched-type, for the same number of men, varied between 915 cubic feet per man and 744 cubic feet per man. The average for the arch type was 797 cubic feet per man. On the basis of volume, then, the barracks with the rectangular cross section uses all that is bought.

On the basis of 80 square feet per man, the total surface of a rectangular 40 man barrack with a single floor varied between 5120 square feet and 6080 square feet. The average was 5551 square feet. For the arched type, a single floor barracks, the total average surface was 5980 square feet. In this analysis, as the radius of the arch was increased, however, the possibility of using a second floor and decreasing the length of the barrack became warranted. Where a second floor was utilized in the arch type barracks, the total surface was reduced to a low of 4281 square feet. This barrack, however, had a diameter of 41 feet and a length of 46 feet. The excavation required to partially bury (15 feet) the arch-type, two-story barrack would be 27,600 cubic feet. This would provide enough material to cover the entire structure with soil to a thickness of about 9 feet. For a single story rectangular structure 30 feet wide and 106 feet long, partially buried (6 feet), the excavation required would be 19,080 cubic feet, enough to cover the entire structure to a depth of about 5 feet.

The Air Force is presently using semi-circular arch type structures with a 48'-0" diameter for aircraft shelters. Because of this and because troops will have been trained in the handling and erection of these structures, it was decided to examine the possible use of a segment of the arch, whose chord is about 29'-0", for the roof of a barrack. In one conceptual version, the roof would rest on vertical walls which incorporate obliquity plates. Two wall heights were examined, 5'-0" and 6'-0" respectively. The combination of the arched roof and the straight sides (with obliquity plates) may be warranted. This scheme gives the lowest probability of hit of either barracks with the rectangular or the arch cross sections. For comparative purposes, the structure employing a combination of the straight sides and the arch has a total surface of 5330 square feet (less than the 29'-0" wide rectangular barracks). Its volume is 30,360 cubic feet. When partly buried, this structure would present a low silhouette to the attacker.

By using Figure 52 on page 4-59, it can be seen that about 11 feet of earth (sandy loam) is required to stop a 152 mm projectile impacting at its normal striking velocity of 1,000 feet per second. It is emphasized that the projectile is stopped at 11 feet in earth and its explosion takes place at that point (approximately). Hence, additional earth or other materials must be made available and installed to totally protect personnel in all cases. A combination of earth, concrete and steel in that order would provide excellent protection.

In view of the fact that, for single story structures, the combined straight-wall/circular-segment cross section gives the same protection for less total surface, and generally has less unused space; the "combination" building should be used for barracks and it should be partially buried (See Figure 72, "Concept for Barracks"). However, the arch-type barracks (partially buried) becomes more cost effective when two story arch-type structures with diameters on the order of 36 feet are contemplated. (See graph and table on Figure 71.)

The dimensions for a 40 man rectangular or a combined cross-sectioned single story structure should have inside dimensions of 29 feet wide by 110 feet long. The two story arch type should have a diameter of 36 feet, and be 58 feet long. For the arch type building, the usable area on the first floor would be 34.5 feet by 58 feet and the usable area on the second floor would be 21 feet by 58 feet.

d. <u>Command, Control and Communications (C^3) Facilities</u>

The structural concepts and protective principles which have been

GEOMETRIC DATA ON BARRACKS CONFIGURATIONS

(3200 SQUARE FEET OF USABLE AREA FOR 40 PERSONNEL)

ARCH

DIAMETER	LENGTH	TOTAL SURFACE	GROSS FLR AREA	VOLUME
22.2 ft.	160 ft.	5964	3552	30,950
27	128	5996	3456	36,625
31.4	77	4570	4343	29,799
36.	58	4295	3538	29,993
41*	46	4281	3551	30,360

RECTANGLE

WIDTH	LENGTH	HEIGHT	TOTAL SURFACE	GROSS FLOOR AREA	VOLUME
20 ft.	160 ft.	8 ft.	6080	3200	25,600
25	128	8	5648	3200	25,600
29	110	8	5414	3190	25,520
30	106	8	5356	3180	25,440
40	80	8	5120	3200	25,600

COMBINATION ARCHED ROOF & STRAIGHT SIDES

29 ft.	110 ft.	11 ft. Max.	5330	3190	30,360

*TWO FLOORS

WIDTH OR ARCH DIAMETER OF 40 MAN BARRACKS VS TOTAL SURFACE

(3200 SF OF USABLE AREA)

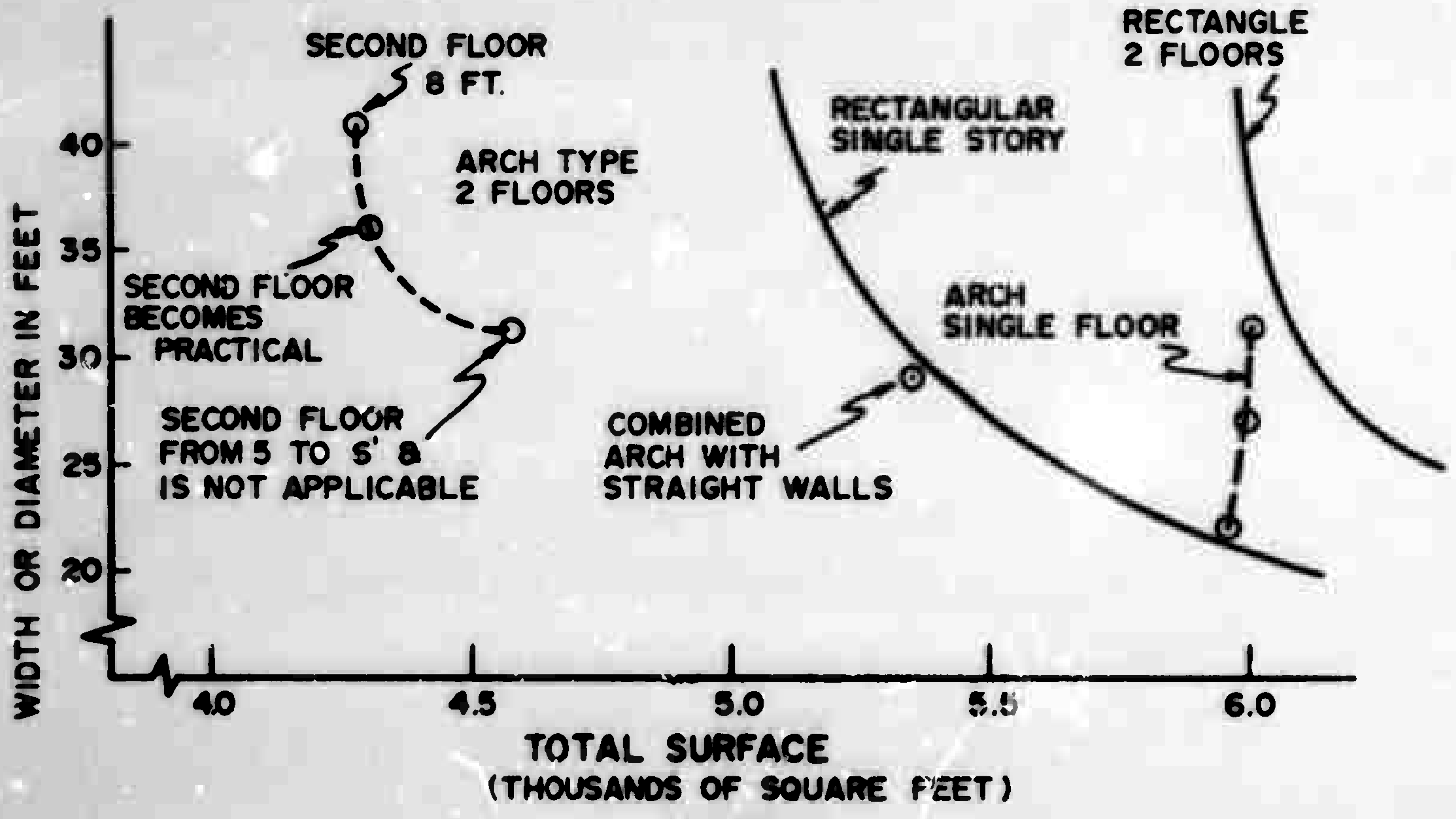


FIGURE 71

CONCEPT FOR BARRACKS OR C³

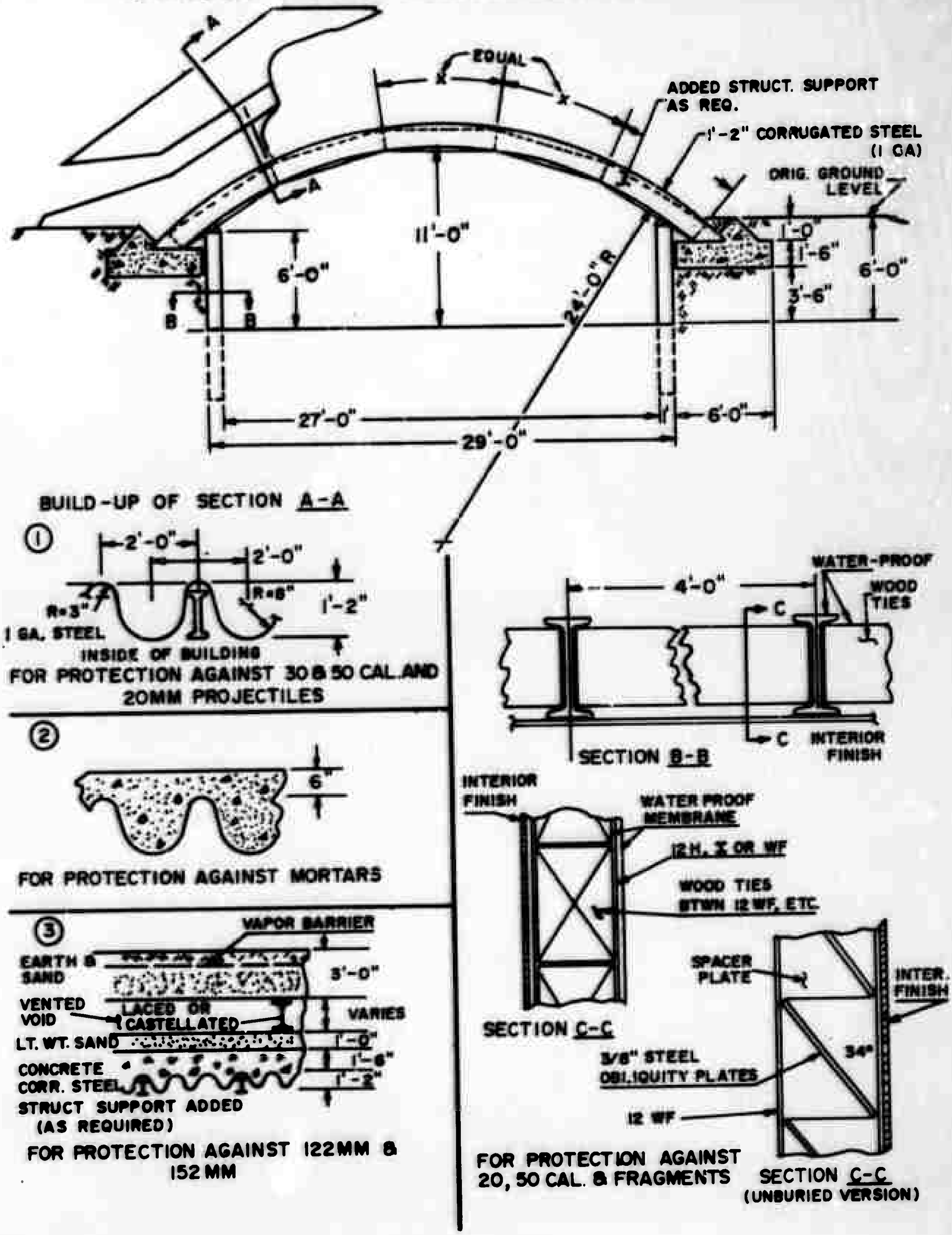


FIGURE 72

proposed for personnel protection in this report can be sized to the requirements for housing command and control facilities and equipment with the exception of antennas. Since the vulnerable area of command and control equipment is higher in relationship to its overall size than in the case of aircraft, a higher level of protection against the penetration of fragments and projectiles is probably worth serious consideration. Doors and other openings become a relatively simplified problem for C^3 facilities because only the provision for daily entrance and egress of personnel and an occasional equipment item must be provided for. The structures do not pose any electromagnetic interference problems which result from their shape or the addition of protective materials. All the metal materials must be electrically bonded in accordance with normal practice. Antenna constructed at some distance from the site should be cantilever construction rather than truss and guy-wire for better protection against damage by projectiles and fragments. The base of a cantilever antenna should be protected by a bulwark constructed of non-metallic materials. Retractable antenna are within the current state-of-the-art for many applications. For important communications hubs, retractable antenna should be provided to guard against sabotage and other hostile actions.

e. Petroleum, Oil and Lubricants (POL)

Protection for POL can be obtained in the following ways:

- o Protective terrestrial environment
- o Above ground in a protective shelter or revetment
- o An integral protective system
- o Combinations of the above

(1) Protective Terrestrial Environment refers to the placement of the POL containers below ground. The depth of burial is a function of the threat to be countered.

(a) Protection against projectiles may require placing the POL containers anywhere between 3.5 feet for a 75 mm dud and 11 feet for a 240 mm dud. (Refer to Figure 13B on Page 2-23, "Projectile Penetration into Clay-Sand Soils.") If these weapons are equipped with operable delayed fuses, the depths of burial would be 4.25 feet for the 75 mm and 14 feet for the 240 mm. Excavation to these depths may not be desirable, therefore, selected materials having penetrations and explosive resistant qualities could be positioned between the POL containers and the projectile to attenuate the effects of weapons. A scheme similar to that shown in Figure 26, "Sequence of Materials," on page 3-28 is applicable. By using the principles described in Paragraph 3c(1) on pages 3-27 through 3-29, a below ground POL storage area could be configured. Application of those principles against projectiles are described in 4b(4) beginning on page 4-33, "Howitzers and Guns." A configuration for a buried POL tank is shown in Figure 73, "Typical Buried POL Container."

The dimensions for this configuration would vary depending on the materials available and used. Typical dimensions for countering various weapons not equipped with instantaneous fuses are shown below.

TYPICAL BURIED POL CONTAINER

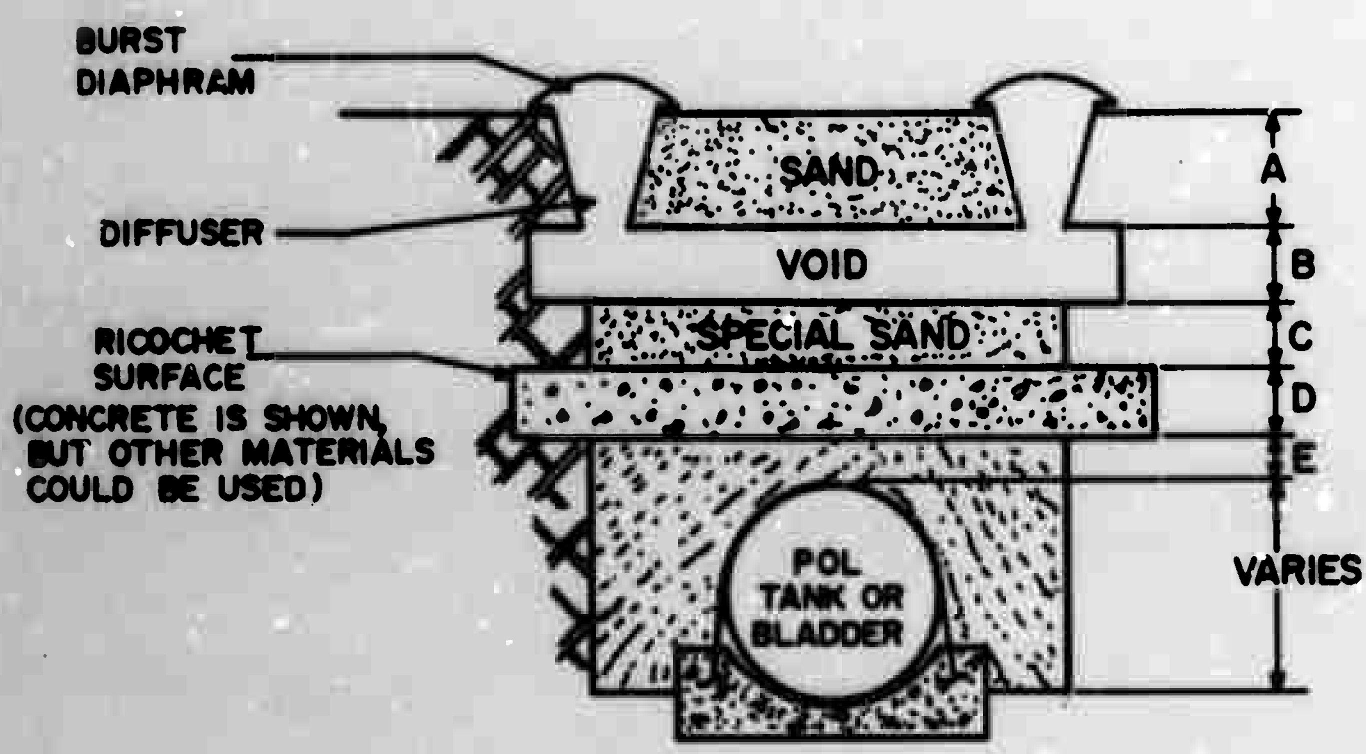


FIGURE 73

DELAYED FUSES AND/OR DUDS

Weapon and Typical Striking Velocity

DIMENSION	20mm (3000 fps)	75mm (910 fps)	105mm (900 fps)	122mm (1100 fps)	155mm (1000 fps)
A	36"	48"	36"	36"	36"
B	Not Required	Not Required	To be Designed	To be Designed	To be Designed
C	"	"	12"	12"	12"
D	"	"	12"	12"	18"
E	"	"	12"	12"	12"

As noted in Figure 73, the materials shown may not be readily available and materials with equivalent projectile resistance characteristics may have to be substituted for those shown. For example, mild steel may be substituted for the concrete ricochet surface and wood-earth combination could reduce the earth fill requirements.

(2) Above Ground in a Protective Shelter amounts to simply placing the POL container in a shelter similar to the aircraft or personnel shelter. The dimensions of these protective structures would vary depending on the size of the bladder or tank used for POL.

(3) An Integral Protective System can be provided by:

- o Placing Reticulated Foam Baffling in the POL container, or
- o Structuring the container so that it will be self-sealing.

(a) Placing Reticulated Foam Baffling in the Tank provides fire and explosion suppressant qualities even when struck with incendiary projectiles. The foam should have 10 pores per cubic inch. It should be a thermally reticulated polyurethane weighing 2 pounds per cubic foot and have excellent resistance to jet, aviation or automotive type fuels.

Since the foam is used in the fuel system, its cleanness and freedom from contamination is a necessity. Fabrication and packaging methods should be such that the limit of contamination is 1 milligram per gallon of fuel or less.

The foam must be engineered to clear the tank internal plumbing such as pumps and gauges. It should be supplied in a multi-piece kit form to permit easy installation through the largest available tank opening.

The reticulated foam would displace approximately 3 per cent of the total capacity of the fuel tank, however, the fire and explosion suppressant resistance gained from use of the foam will compensate for the loss in fuel capacity under sufficiently high levels of attack.

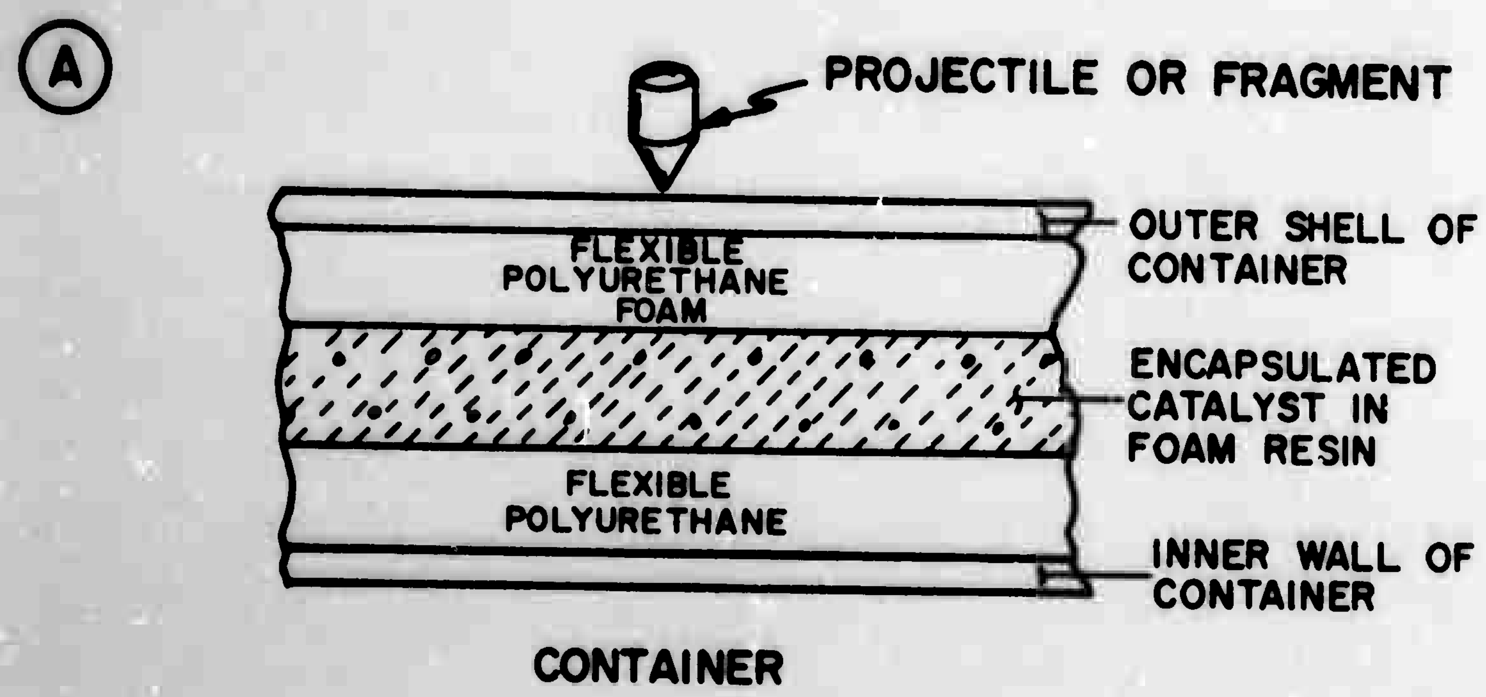
(b) Structuring the Container so that it will be self-sealing can be accomplished by:

[1] Employing fabric liner self-sealing constructions. These fabrics are known as US-180 material against 30 caliber weapons or US-182 material against 50 caliber weapons. These two materials may be purchased "off-the-shelf" and configured into the desired sizes of tanks or bladders. The US-180 weighs 0.49 pounds per square foot and the US-182 weighs 0.86 pounds per square foot. These materials are relatively new. They replace the heavy rubber liner which had been a standard material in the past. It must be emphasized at this juncture that these materials are only effective against weapons and fragments equivalent in size and velocity to the 50 caliber projectile.

[2] Other methods of self-sealing include the provision of double-walled vessels. The void between the double walls would be equipped with chemical sealants such as a polymer resin and a catalyst. These two chemicals would be automatically released by the penetrating action of an impacting object and brought into contact. An extremely fast chemical reaction would ensue, resulting in a sealing plug that is rigid, semi-rigid or flexible depending on the nature of the resin.

The two chemicals can be stored in flat plastic bags, or some form of micro-encapsulation can be used. The advantages of using micro-encapsulation are:

A SELF SEALING METHOD FOR TANKS



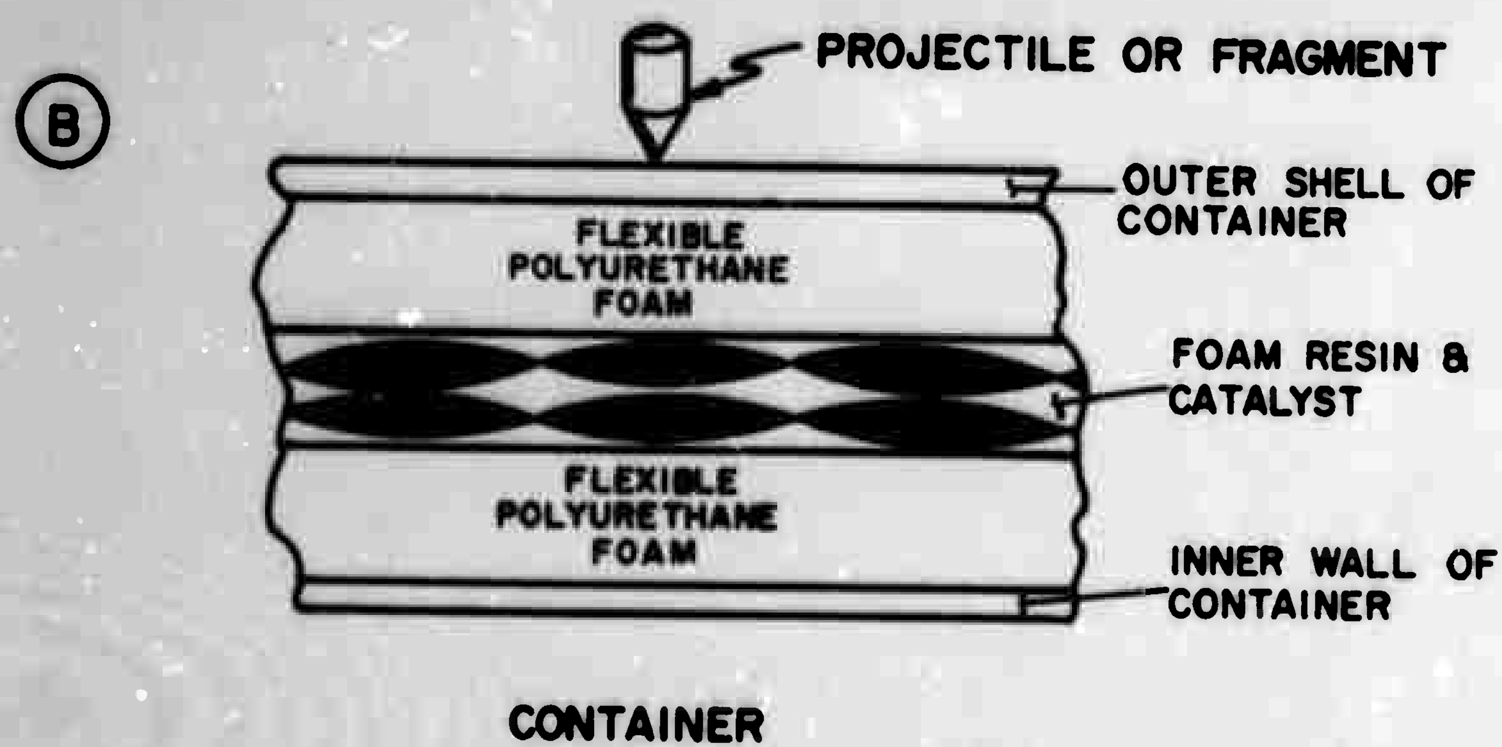


FIGURE 74

- Simplification of the wall's chemical compartment
- Easier handling of the chemicals during wall assembly
- A more highly localized chemical reaction, which makes it possible for a single self-sealing cell to deal with several punctures in a relatively small area
- Adequate mixing even when chemicals of high viscosity are used.

Encapsulation also has disadvantages or complications. They are:

- Shelf stability must be outstanding
- The material must be compatible with POL or other products stored in the container
- The size and wall thickness of the capsules must be chosen so as to encourage mixing.

Figure 74, "A Self-Sealing Method for Tanks," schematically depicts the two methods of self-sealing just described.

(4) <u>Combinations of Terrestrial Protection, Shelters and Integral Protection</u>

The placing of a network (reticulated) of foam baffles inside the tank would suppress explosion and fire, but would not necessarily stop leakage and possible combustion of materials outside the POL container. The Integral Wall methods might stop the leakage but would not stop explosion and fire inside the vessel. It would appear desirable to have both of these capabilities. Therefore, a POL tank configured according to the methods described in the foregoing paragraphs would incorporate the network of foam baffles, and self-sealing integral wall or be composed of fabric liner self-sealing construction materials of the US-180 or US-182 type. These would be effective against weapons and fragments whose sizes and velocities are the equivalent of 50 caliber. When it is desired to protect against projectiles larger than the 50 caliber and still have a reasonable chance to survive, it will be necessary to place the POL container in a shelter or underground. Of the two, the underground environment provides the better protection at the least cost. Figure 73 and several of the methods denoted in Reference 35 depict underground storage configurations.

(5) Inert Gas Injection

For years the Air Force used a water system in conjunction with POL storage and handling. This system insured that the tanks were full of gas, water or a combination of gas and water. The danger of explosion was thereby lessened because no space was available for fumes to ignite. Where a water system is not employed, it is suggested that consideration be given to the injection of inert gases into the tank so that if intrusion of the projectile does occur, the probability of explosion will be low. The inert gas system is not intended to replace any of the passive protection measures delineated above, but rather, it is intended that it be used as a supplement thereto.

⚠ 1

24 December 1968

PROTECTIVE CONSTRUCTION CONCEPTS

Supplemental Note Number 1

SUBJECT: Supplemental Notes

1. General

From time to time it may be desirable to issue clarification or additional information relating to passive protection and associated subjects. Accordingly, a system of Supplemental Notes will be issued as the need arises. The Supplemental Notes will serve as a media for updating the "Protective Construction Concepts" document.

2. Methodology

a. Whenever HQUSAF decides that a subject is of sufficient importance, Supplemental Notes will be prepared and issued. All "notes" will follow the same format as used in this paper. That is, the note will be given a number and it will contain a Subject, a General discussion, a Methodology, and an Example. Supplemental Notes will normally not exceed two pages.

b. Holders of the "Passive Protection Concepts" document can request the issuance of Supplemental Notes. They can also prepare notes for issuance to all other interested personnel. For control purposes, however, all requests for Supplemental Notes will be forwarded to HQUSAF (AFOCE-K) for processing. Where a Supplemental Note is prepared by an organization outside HQUSAF, the draft of the note will be forwarded to HQUSAF (AFOCE-K) for finalization, numbering and distribution.

3. Example

Additional data is desired by an organization on "Variation of Penetration of Concrete by Projectiles with Respect to the Compressive Strength of Concrete." A letter requesting that a note be issued will be addressed to AFOCE-K. The letter should stress (justify) the need for the additional data.

2

24 December 1968

PROTECTIVE CONSTRUCTION CONCEPTS

Supplemental Note Number 2

SUBJECT: Variation of Penetration of Concrete by Projectiles with Respect to the Compressive Strength of Concrete

1. General

   a. There is a definite relationship between the penetration of concrete by projectiles and the compressive strength of the concrete. This relationship is not as simple as is indicated in the generalized "rule of thumb" which is discussed under paragraph 2 below. The size of the aggregate has a small but definite effect on penetration. Increases, within limits, in size and amount of aggregate tends to decrease penetrations.

   b. The rough rule delineated in paragraph 2 below seems to hold whenever the kind, amount, and size distribution of the aggregate component remains unchanged, and the increase in compressive strength is obtained by increase in the cement content of the mix. An exception to the above has been identified. It is the manner in which the concrete is cured. Dry-cured concrete, when compared with moist-cured concrete, showed up to 20 per cent increase in the resistance to penetration. This phenomena took place even though the compressive strength of companion concrete samples decreased 40 to 50 per cent because of the dry-curing process. Confirmation by test is suggested.

2. Methodology for Assessing the Effect of Compressive Strength of Concrete on Penetration by Projectiles

   a. For a given projectile and striking velocity, the normal depth of penetration is inversely proportional to the square root of the compressive strength of the concrete. For example, an increase in 10 per cent in compressive strength will reduce penetrations by 5 per cent under otherwise similar circumstances.

3. Example

a. Given

A projectile penetrates concrete that has a compressive strength of 3,000 psi. The depth of penetration is 2.8 feet.

Find

How far will the same projectile with the same striking velocity penetrate concrete whose compressive strength is 6,000 psi.

Solution

$$\frac{\text{Depth of Penetration into 3,000 psi } (P_{3,000})}{\text{Depth of Penetration into 6,000 psi } (P_{6,000})} = \frac{\sqrt{6,000}}{\sqrt{3,000}}$$

$$\frac{2.8'}{P_{6,000}} = \frac{77}{55}$$

$$P_{6,000} = \frac{(2.8)(55)}{77} = \frac{134}{77}$$

$$P_{6,000} = 2.0 \text{ Feet}$$

b. Given

4,000 psi compressive strength concrete. Two aggregate mixes are available. One has a fineness modulus of 3.0, 1/8" maximum size, 65 per cent by volume. The other has a fineness modulus of 5.0, 1" maximum size, 75 per cent by volume.

Find

Which aggregate to use to minimize penetration.

Solution

From statistical and test evidence, the aggregate with the 5.0 fineness modulus should be used and penetrations should decrease by about 20 per cent. No quantitative method has been devised which gives a definite way to calculate the specific aggregate parameters vs. penetration. As a general rule, as it pertains to projectile penetration only, it is advantageous to use as large a fineness modulus and as large a proportionate volume of aggregate as possible in the concrete. The maximum size of aggregate will be limited in the usual way by the availability of a reasonably good gradiation below the maximum.

3

24 December 1968

PROTECTIVE CONSTRUCTION CONCEPTS

Supplemental Note Number 3

SUBJECT: Relationship between Penetration Perforation and Scabbing (Spalling) of Concrete

1. General

a. When a projectile strikes a concrete surface, penetration starts. The penetration continues until the projectile either ricochets, stops in the target material (is arrested), perforates the slab or causes scabbing (spalling) on the back of the slab.

b. Penetration is quantified by measuring the distance a projectile travels into massive concrete. Massive concrete is defined as that thickness of concrete at which scabbing will not occur. When a projectile is said to penetrate concrete to a depth of 18 inches, it means that the projectile penetrated concrete of infinite thickness to a depth of 18". Knowledge of the depth of penetration is prerequisite to calculating perforation and scabbing (spalling) of slabs of finite thickness.

2. Methodology for Detaining Penetration, Perforation and Scabbing (Spalling)

a. Penetration

The depth of penetration (x) of concrete should be obtained by the procedures delineated on Figure v, "Method for Predicting Penetration of Materials." Where computer services are not available, the mathematical and/or graphical methods can be employed. For quick approximations, Figure 52, "Penetration of Bombs and Projectiles into Soil and Concrete," can be utilized. Figure 52 is for use with concrete having a compressive strength of 4,000 psi. For compressive strengths other than 4,000 psi, imploy the methodology described in Supplemental Note Number 2, Subject: "Variation of Penetration of Concrete by Projectiles with Respect to the Compressive Strength of Concrete." Where it is desired to make a direct calculation without using the formula beginning on page 466, the following expression may be employed:

(Equation 1) $$\frac{x}{d} = \left[\frac{1}{2} + 282 S^{-\frac{1}{2}} \left(\frac{w}{d^3}\right) d^{0.215} \left(\frac{V}{1,000}\right)^{\frac{3}{2}}\right] \phi(\theta)$$

Where

x = Penetration in inches

d = Diameter of the Projectile (inches)

S = Compressive Strength of Cement (psi)

V = Striking velocity (fps)

ϕ (θ)= Function of obliquity

Values of ϕ (θ)

θ	0°	5°	10°	15°	20°	25°	30°	35°
ϕ (θ)	1.00	0.95	0.89	0.82	0.75	0.67	0.58	0.47

b. Perforation

If the concrete is not thick enough to fully absorb the effects of penetration, the target material will either perforate or scab (spall). Perforation can occur even if the thickness of the slab is greater than the depth of penetration. This is caused by the interaction of incident and rarefaction waves generated in the concrete which tend to break up the concrete ahead of the projectile. See the explanation for this phenomena beginning on page 3-29 of the report. Figure 29, "Generation of Waves from Impact," on page 3-34 graphically portrays the interaction of the waves. Perforation will occur when the thickness (e) of the concrete is less than the value given by:

(Equation 2)
$$\frac{e}{d} = 1.23 + 1.07\frac{x}{d}$$

Where:

e = Thickness of Concrete (inches

x = Depth of Penetration (inches) (From Equation 1)

d = Diameter of Projectile (inches)

c. Scabbing or Spalling

When the concrete is too thick for full penetration (perforation), scabbing takes place. The thickness(es) at which scabbing barely stops can be obtained by applying the following formula:

(Equation 3)
$$\frac{s}{d} = 2.28 + 1.13\frac{x}{d}$$

3. Example

Given

A 122 mm rocket, where the projectile including propellant casing engages a concrete slab. The portion of the rocket striking the slab weighs 81 pounds, is 4.8 inches in diameter (122 mm), and the striking velocity is 1,100 feet per second. The compressive strength of the concrete is 3,500 psi.

Find

The depth of penetration, the thickness of concrete at which perforation will stop and the thickness at which no scabbing will occur.

Solution - Penetration

Figure 52 gives a penetration of 22 inches. This is for 4,000 psi concrete. Because the concrete penetrated in this problem is 3,500 psi, the penetration will be about 25 inches (see Supplemental Note Number 2). Notwithstanding the graphical solution, the results will be checked against the formulas discussed in paragraph 2 above.

Using Equation 1 (Penetration)

$$\frac{x}{4.8''} = \left[\frac{1}{2} + (282)(3500)^{-\frac{1}{2}}\left(\frac{81}{110.6}\right)(4.8)^{0.215}\left(\frac{1100}{1000}\right)^{\frac{3}{2}}\right] 1$$

$$\frac{x}{4.8''} = \left[\frac{1}{2} + (282)(.0168)(.73)(1.03)(1.15)\right] 1$$

$$\frac{x}{4.8''} = 0.50 + 4.09 = 4.59$$

x = 22.03 -- This means that the 122 mm rocket will penetrate 22.03 inches into 3,500 psi massive concrete.

Solution - Perforation

Using Equation 2 (Perforation)

$$\frac{e}{4.8} = 1.23 + 1.07\ (4.59)$$

$$\frac{e}{4.8} = 1.23 + 4.91 = 6.14$$

e = 29.5 inches -- A concrete slab whose thickness is greater than 29.5 inches should not perforate

Solution - Scabbing

Using Equation 3 (Scabbing)

$$\frac{s}{4.8} = 2.28 + 1.13\ (4.59)$$

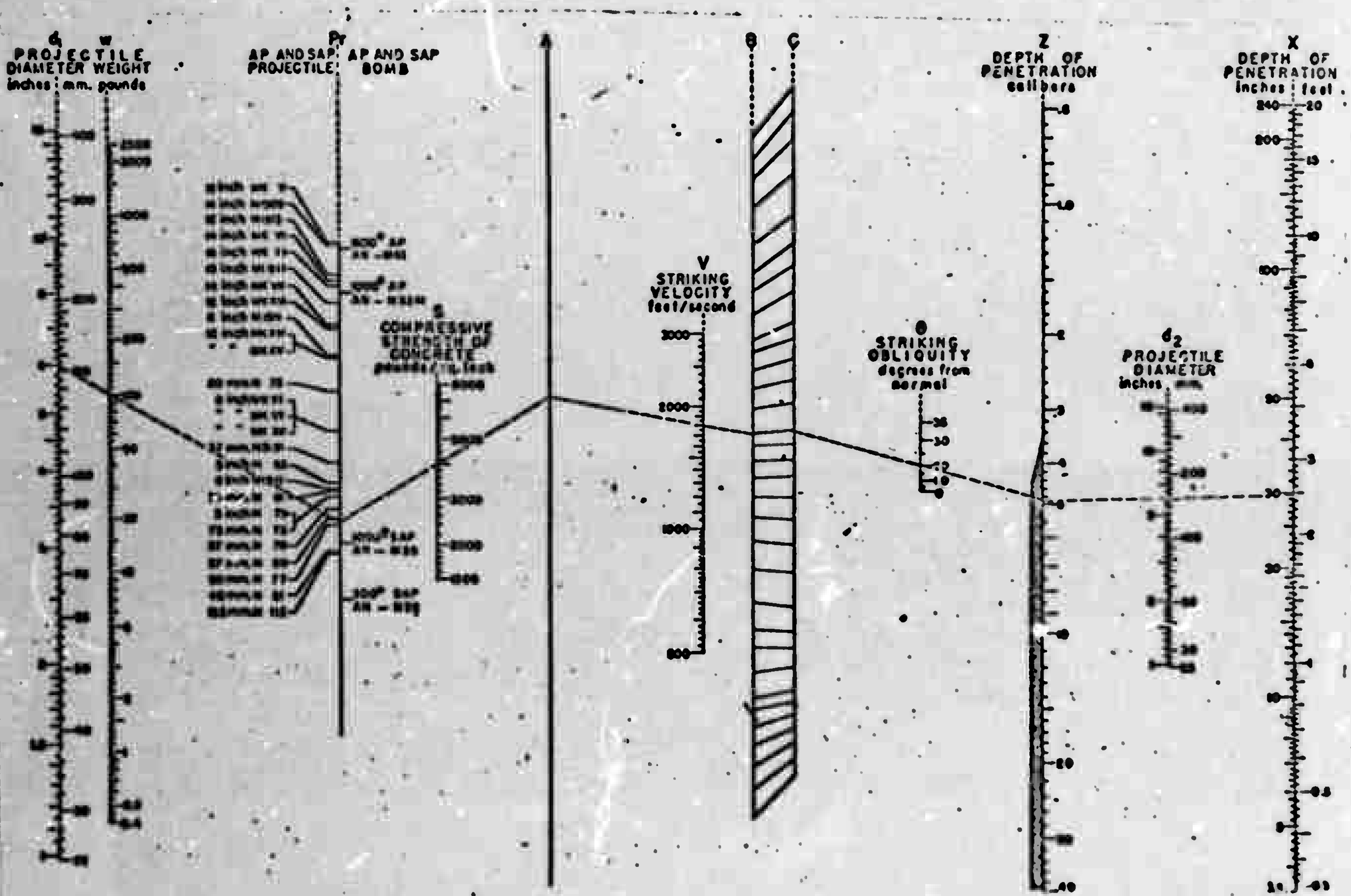
$$\frac{s}{4.8} = 2.23 + 5.19 = 7.47$$

$$s = 35.9 \text{ inches}$$ -- Slabs thicker than 35.9 inches should not spall.

4. Additional Data

To assist the designer in making a quick determination of the penetration of projectiles and bombs into reinforced concrete, a nomogram which considers the cogent parameters of the projectile and the concrete, is attached. Perforation and scabbing can then be calculated by using the formulas delineated above.

PENETRATION OF REINFORCED CONCRETE BY AP PROJECTILES AND AP AND SAP BOMBS



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January 14, 1969

PROTECTIVE CONSTRUCTION CONCEPTS

Supplemental Note Number 4

SUBJECT: Perforation of Nylon by Fragments from the 122 mm Rocket

1. General

Fragments from rockets, projectiles and bombs obtain initial velocities according to the ratio of the mass of the explosive (m_x) to the mass of the shell (m_s). The velocities decay with distance and their area to mass ratio ($\frac{A}{m}$). Therefore, the fragments traveling the same distance will strike surfaces at various velocities according to their $\frac{A}{m}$ ratio.

2. Methodology

The methodology used for determining the behavior of fragments is delineated on pages 2-12 and 2-13 of "Protective Construction Concepts." A flow diagram, Figure iii, showing the steps required to implement the method is located on page xiv.

3. Example (Figures referred to in this example are attached for ready reference)

Given: A 122 mm rocket explodes 30'-0" in front of a 108 ply nylon curtain.

Find: The size and the striking velocity of fragments that will penetrate the nylon curtain.

Solution:

a. Determine the characteristics of the weapon.

1) Weight of Warhead = 41 pounds

2) Weight of Explosive = 14.5 pounds (m_x)

3) Weight of Shell = 26.5 pounds (m_s)

b. Calculate the ratio of the weight of the explosive (m_x) to the weight of shell (m_s).

$$\frac{m_x}{m_s} = \frac{14.5 \text{ lbs.}}{26.5 \text{ lbs.}} = 0.55 \text{ lbs.}$$

c. From Figure 8, "Initial Velocity of Fragments as a Function of Ratio m_x/m_s on page 2-13, determine the initial velocity of fragments.

1) For a $\frac{m_x}{m_s} = 0.55$, the initial velocity of the fragments is found to be approximately 5,100 feet per second.

d. As a baseline, determine the weight of the smallest fragment of interest.

1) In this case 10 grains is assumed.

e. From Figure 9, "Ratio of Area to Grains as a Function of Grain Weight for Random Steel Fragments," on page 2-14, determine the $\frac{A}{m}$ ratio for 10 grain and larger size fragments.

1) In this case the following were obtained from Figure 9:

Size Fragment	$\frac{A}{m}$
10	0.27
20	0.20
50	0.16
70	0.14
80	0.13

f. Since the velocity of fragments decays with distance, the striking velocity is obtained by using Figure 10, "Ratio of V/V_0 as a Function of Distance Traveled by Fragments," on page 2-15. A distance of 30'-0" was given. The initial velocity of fragments (5,100 fps), obtained in step "c", is used to calculate the striking velocity. The following resulted:

Size Fragment	$\frac{A}{m}$	V/V_0	Striking Velocity (V)
10	0.27	0.81	4,131 fps
20	0.20	0.85	4,386 fps
50	0.16	0.88	4,488 fps
80	0.13	0.89	4,589 fps

g. Using the charts prepared for unbonded nylon as shown in reference 41, plot the thickness of nylon and the data from paragraph f above on the chart.

1) 108 plys of unbonded nylon measures 2.48 inches thick.

2) It can be seen that the "velocity of fragments at 30 feet" curve intercepts the thickness line at about 22 grains and 4,500 fps. Therefore, the 108 plys of nylon should defeat all fragments smaller than 22 grains. It is interesting to note that the nylon curtain should defeat all fragments from 10 grains to 400 grains <u>if</u> their velocities are 4,800 fps and 3,500 fps or less respectively.

4. Additional Information

The final chart, attached, displays the number of fragments in the 120 mm mortar. Assuming that approximately the same number of fragments will be issued from the 122 mm rocket, it can be seen, from the chart, that 38,725 fragments of the 40,790 total (95 per cent) should be arrested by the 108 plys of unbonded nylon.

10 Jan '69

INITIAL VELOCITY OF FRAGMENTS AS A FUNCTION OF RATIO M_X / M_S

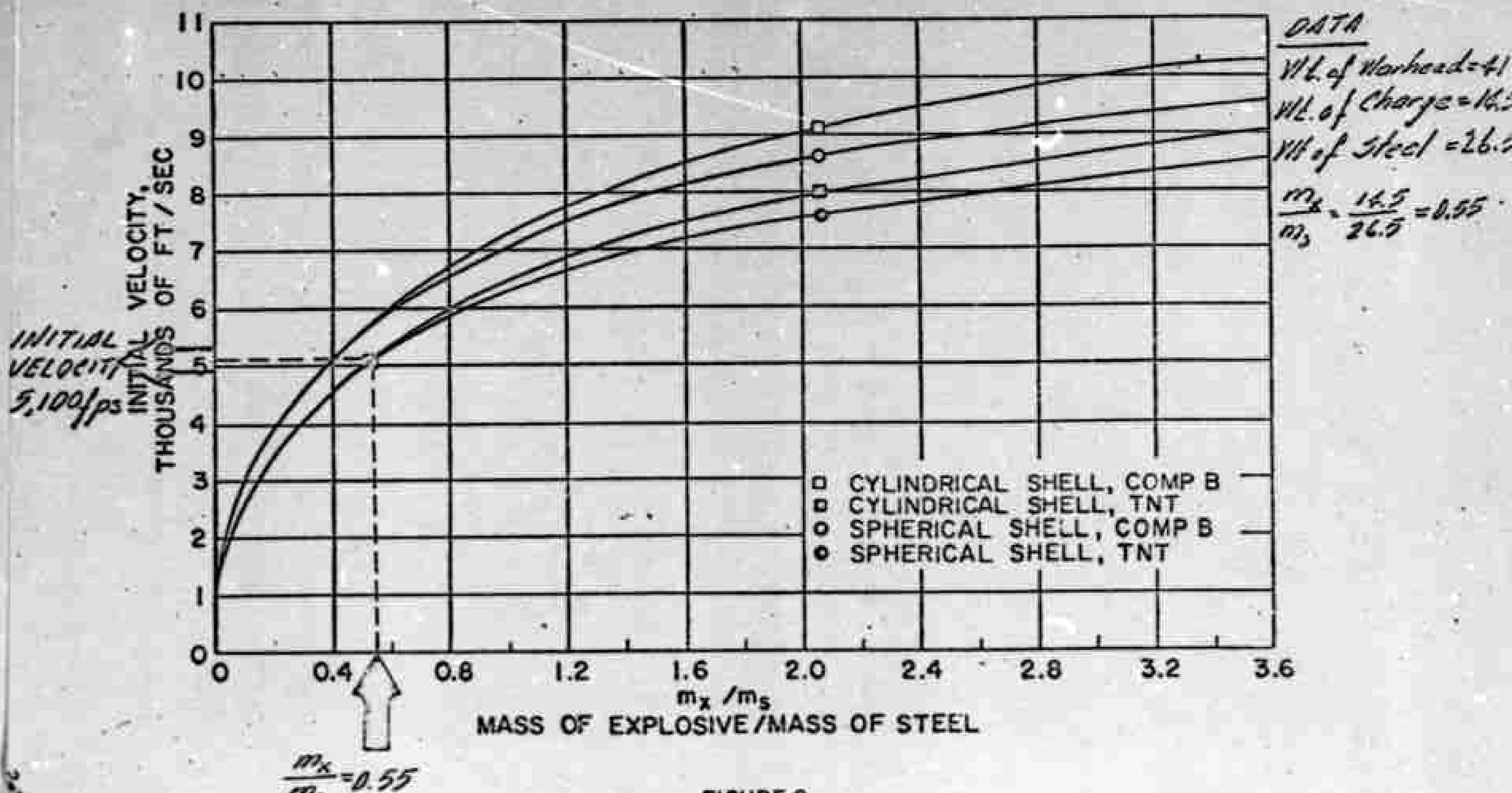


FIGURE 8

10 Jan 69

RATIO OF AREA, TO GRAINS AS A FUNCTION OF GRAIN WEIGHT FOR RANDOM STEEL FRAGMENTS

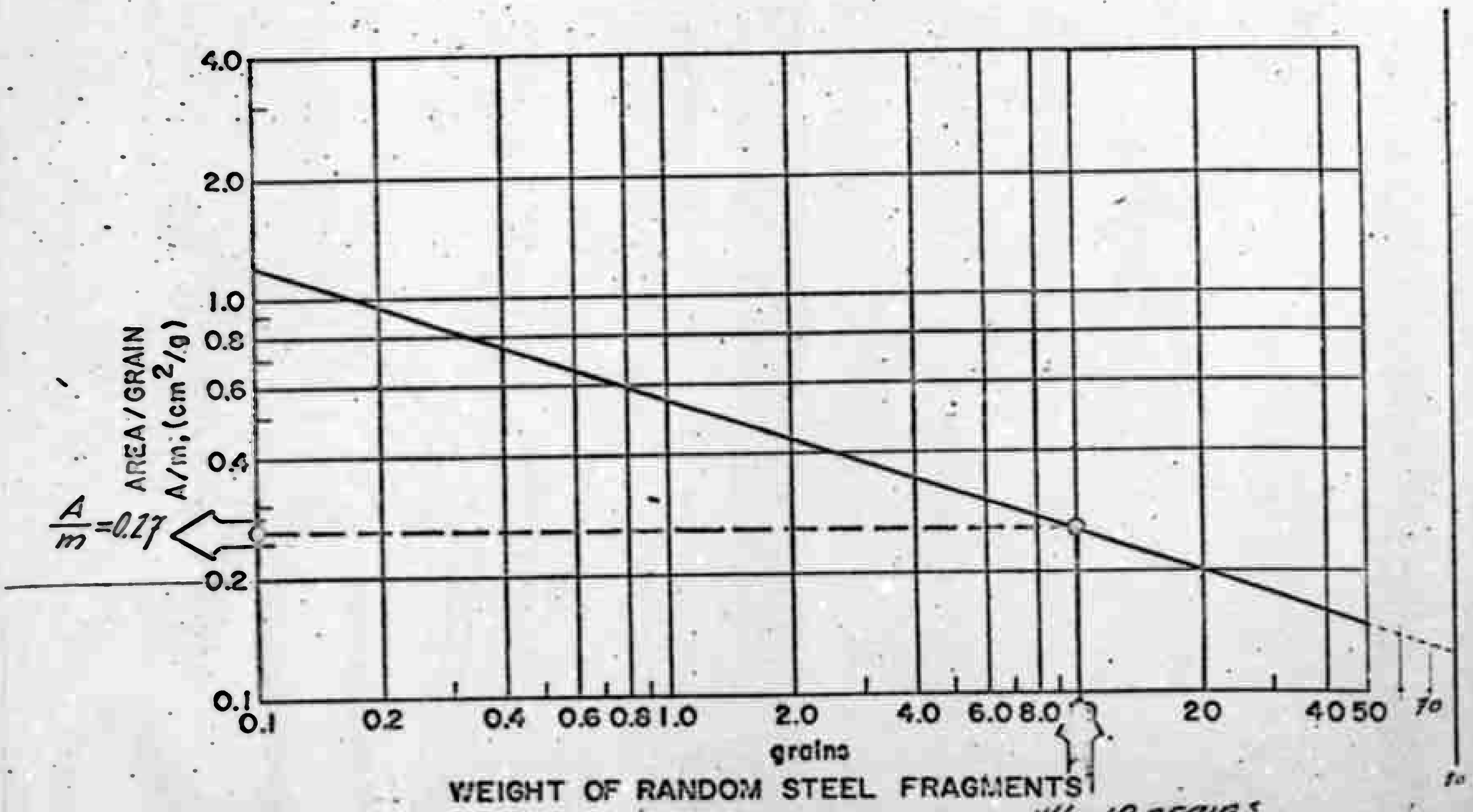


FIGURE 9

REF 24

10 Jan '69

RATIO V/V_O AS A FUNCTION OF DISTANCE TRAVELED BY FRAGMENTS

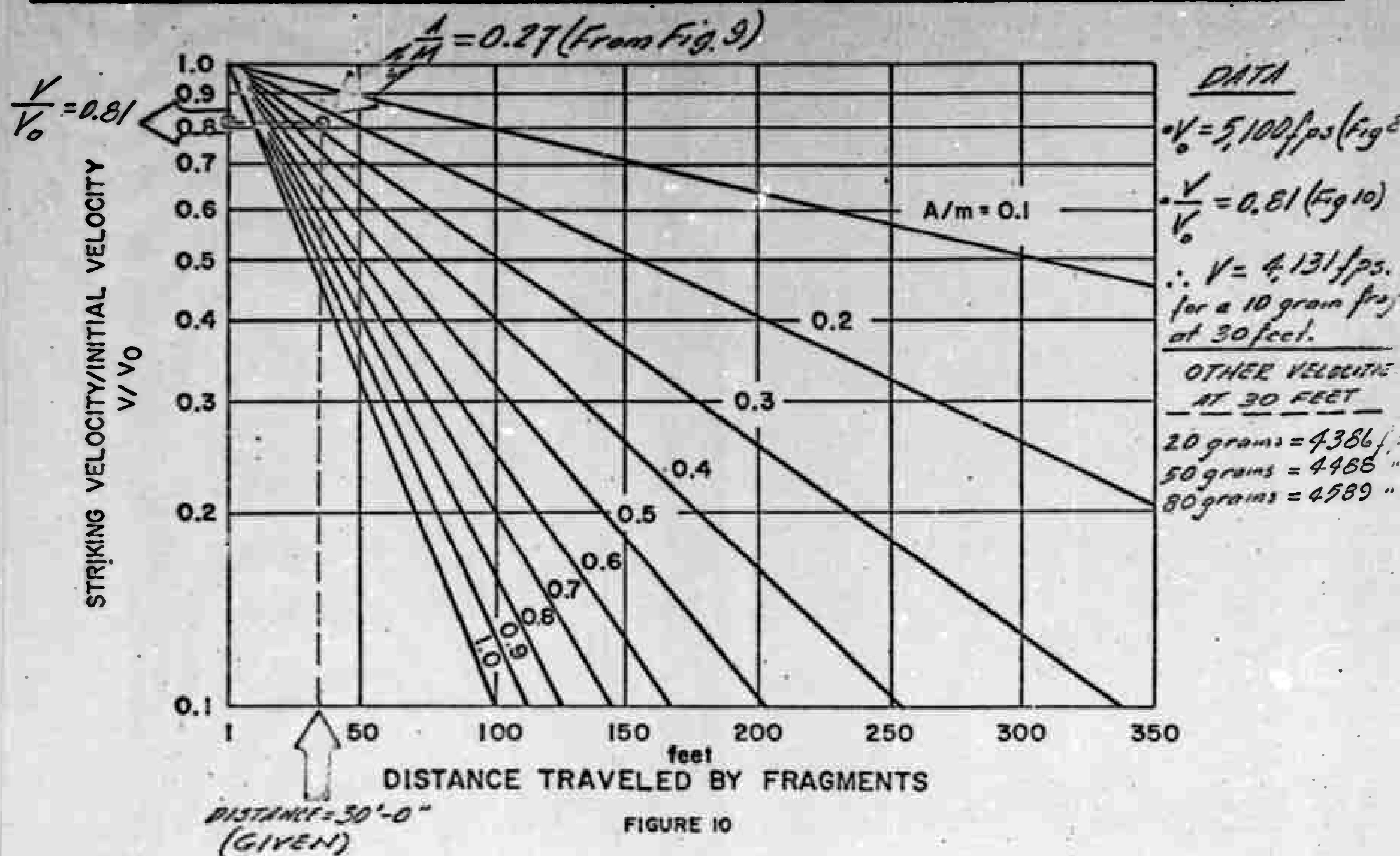
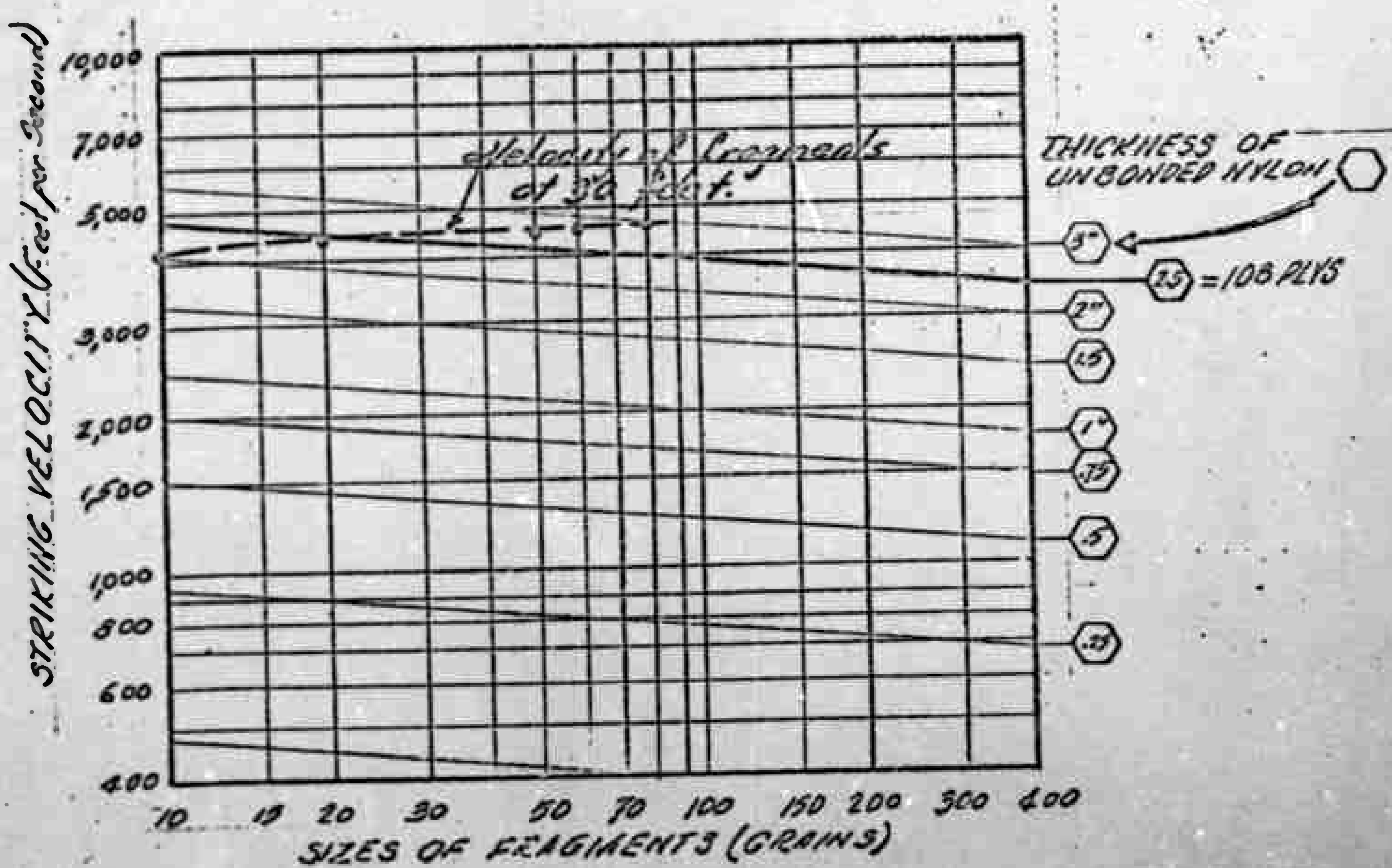


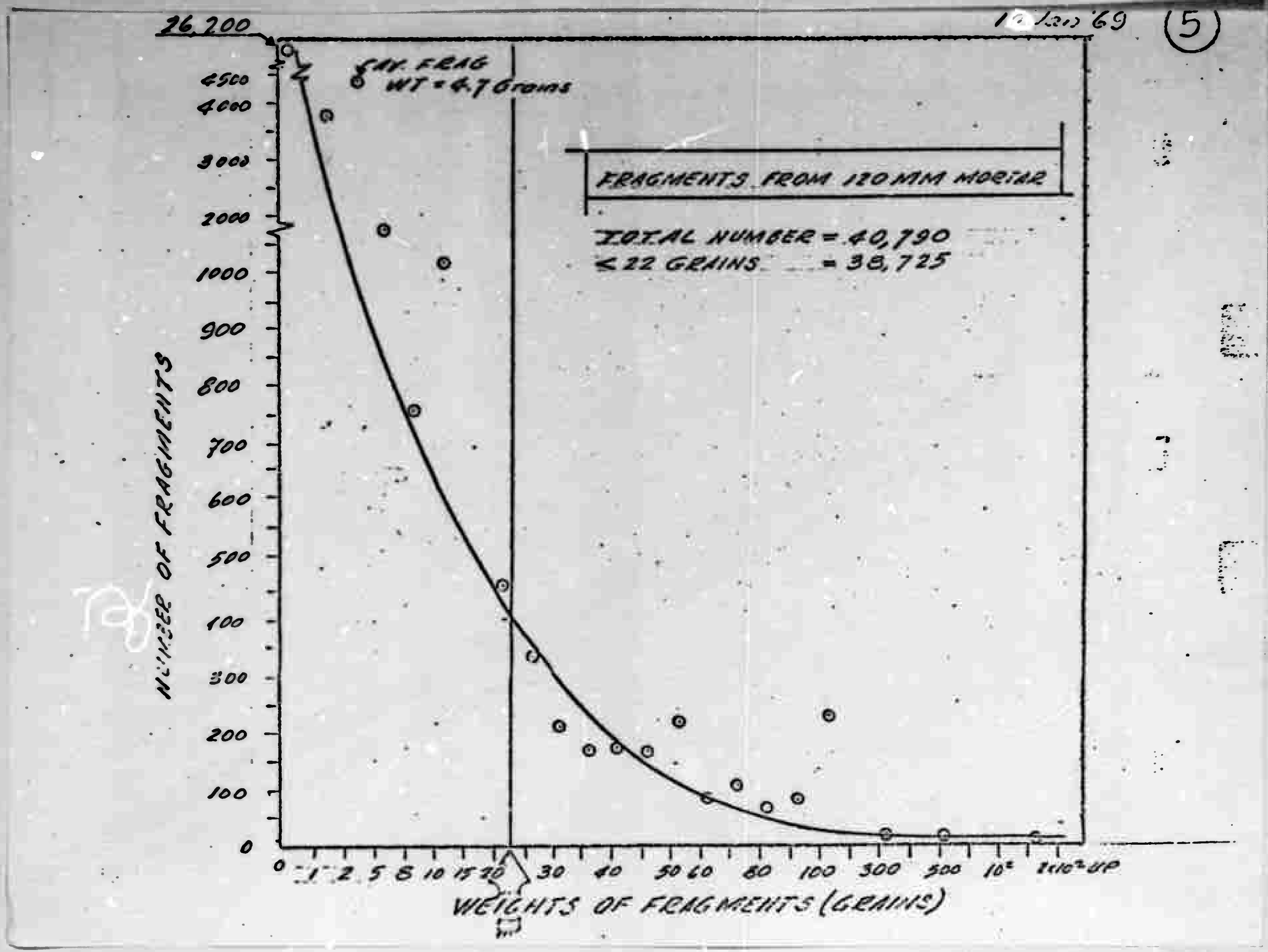
FIGURE 10

REF 24

10 JAN '69

PENETRATION OF UNBONDED NYLON BY COMPACT FRAGMENTS OF STEEL AT 30 FEET





1? Jan '69
5
FRAGMENTS FROM 120MM MORTAR
TOTAL NUMBER = 40,790
< 22 GRAINS = 38,725
AV. FRAG WT = 4.7 Grains
26,200
4500
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
0
NUMBER OF FRAGMENTS
0 .1 .2 .5 5 8 10 15 20 30 40 50 60 80 100 300 500 10² 2x10² UP
WEIGHTS OF FRAGMENTS (GRAINS)

5

January 23, 1969

PROTECTIVE CONSTRUCTION CONCEPTS

Supplemental Note Number 5

SUBJECT: 1,000 Pound General Purpose Bomb vs the Concrete Covered Aircraft Shelter

1. General

The arch type semi-circular aircraft shelter is to be covered with a minimum of 18 inches of concrete. Because this type of aircraft shelter may be placed in general service, it is desirable to conduct a series of tests to ascertain the performance of the shelter in the hostile environment. The purpose of this Supplemental Note is to illuminate the problem by identifying the probable response of the shelter to the 1,000 pound, TNT filled, General Purpose Bomb.

2. Methodology

The methods used for obtaining data concerning penetration and blast are contained in "Protective Construction Concepts" Figures v and iv respectively. Other methods are also described in the development of the "Example" given in paragraph 3 below.

3. Example - Effects of 1,000 Pound General Purpose Bomb

a. Bomb Characteristics

Total Weight (W) = 990 pounds

Charge Weight (m_x) = 558 pounds of TNT

Cube Root of m_x = 8.2

Charge Weight Ratio = $\frac{m_x}{W}$ = 56

Net Weight of Shell (m_s) = W - m_x = 432 pounds

Ratio $\frac{m_x}{m_s}$ = $\frac{558}{432}$ = 1.29

Impact Velocity = 1,200 feet per second

Outside Diameter of Shell = 18.8 inches

Thickness of Shell = 0.5 inches

b. Weapons Effects

(1) Direct Hit (For methodology see Figure v of "Protective Construction Concepts")

(a) Using Figure 52, "Penetration of Bombs and Projectiles into Soil," on page 4-59 of "Protective Construction Concepts," gives a penetration of about 4.2 feet of 4,000 psi concrete for a 1,000 pound General Purpose Bomb striking at 1,200 feet per second. The reader can also use the chart in Supplemental Note 3, "Relationships between Penetration, Perforation and Scabbing (Spalling) of Concrete," to estimate the penetration.

(b) Since the maximum thickness of the concrete covering the arch-type aircraft shelter is 32 inches (18 inches at top of corrugation and corrugations are 14 inches deep) and the depth of penetration into massive concrete is about 50 inches, perforation will occur. Using the formula for perforation of concrete described in Supplemental Note Number 3, "Relationship between Penetration, Perforation and Scabbing of Concrete," a 1,000 pound General Purpose Bomb striking at 1,200 feet per second would perforate approximately 77 inches of 4,000 psi concrete. The metal liner under the concrete would "petal."

(c) If the bomb was not instantaneously fused and had a delayed fuse which survived the penetration and perforation processes, then explosion would occur inside the structure. This would be a confined blast.

(2) Blast

(a) Inside the Shelter (For methodology see Figure iv of "Protective Construction Concepts")

/1/ The bomb is assumed to have penetrated the shelter unharmed and has come to rest on the ground in the geometric center of the floor of the structure. Upon detonation, the initial shock wave is identical with that obtained in the open. However, when the shock wave strikes the interior surfaces of the structure, it is reflected from all surfaces. The waves continually bounce from the surfaces ("multiple-punch") until the energy is converted to heat or until the structure is destroyed. As a result of the heat generated by wave interaction, the pressure rises in the enclosed structure. The pressure rise due to heat (Δp) can be obtained from the following formula:

$$\Delta p = \frac{8.8\,H}{V}$$

where:

H is the total heat of combustion in Kilocalories

V is the volume of the shelter (enclosure)

TNT has a heat of combustion of 3.6 Kilocalories per gram. There are 453.6 grams in one pound. A 1,000 pound General Purpose Bomb contains 558 pounds of TNT. The aircraft shelter is about 100 feet long and has a 25'-0" radius. Therefore, its volume approximates 98,175 cubic feet. Substituting these data in the above formula yields a pressure rise (Δp) of:

$$\Delta p = \frac{(8.8)(3.6)(453.6)(558)}{98,175} = \frac{8,018,490}{98,175} = 81.68 \text{ psi}$$

This pressure rise assumes that the explosion took place in a volume where the walls were perfectly rigid, non-conductors of heat, without windows or other vents, and that all of the available energy of the explosive is realized in the initial detonation and subsequent after-burning.

The aircraft shelter, however, is partly vented (by virtue of the jet exhaust system and the ballistic nylon curtain closure). Therefore, the explosion will result in peak pressures of relatively long duration because of the limited venting. No data is available on the exact duration of these pressures. For analyzing the response of the arch shelter to the 1,000 pound General Purpose Bomb explosion, the total impulse should be used. This consists of the incident wave, its reflections and the pressures due to the heat of combustion.

Therefore, for the purpose of analysis, the peak mean pressure should be assumed to be of constant magnitude and relatively long duration. The equation for obtaining the peak mean pressure (P_{mo}) is:

$$P_{mo} = 2410 \left(\frac{W}{V}\right)^{0.72}$$

where:

W = Weight of the explosive charge

V = Volume of the structure

$$P_{mo} = 2410 \left(\frac{558}{98,175}\right)^{0.72} = 2410\ (.00568)^{0.72} = 2410\ (.024)$$

$$= 58 \text{ psi}$$

To survive, the arch type shelter should be able to withstand 58 psi internal pressure. The contents of the shelter (aircraft), however, could not survive the blast and the attendant bomb fragments. Therefore, a direct hit by a 1,000 pound General Purpose Bomb on an aircraft shelter with a semi-circular cross section, of the type considered, would defeat the purpose for which the shelter is intended.

(b) Outside the Shelter (For methodology see Figure iv of "Protective Construction Concepts")

/1/ Burst Near or On the Surface

/a/ The positive impulse in air due to detonation of an explosive charge in free air (spherical) is given by:

$$I = E\, e^{s} \left(\frac{m_x^{2/3}}{r}\right)$$

where:

I = Positive impulse, psi-ms

m_x = Weight of explosive

r = Distance from explosion

E = Explosive Factor (TNT = 29)

s = Equivalent cylinder charge/weight ratio

e = 2.718 (base of natural log)

Applying the above formula to the 1,000 pound general purpose bomb, the following positive impulses result.

DISTANCE (r) (feet)	SCALED DISTANCE ($r/W^{1/3}$)	SCALED IMPULSE (psi-ms/$W^{1/3}$)	ABSOLUTE IMPULSE
10	1.22	17.0	140 psi-ms
20	2.44	16.0	131
30	3.66	13.8	113
40	4.88	11.2	92
50	6.09	9.2	75
60	7.31	8.0	65
70	8.53	6.9	56
80	9.76	5.9	48
90	10.90	5.0	41
100	12.19	4.2	34
200	24.4	2.8	23
300	36.6	1.8	15
400	48.8	1.5	12

b It has been found, through extensive testing, that the positive impulses in air due to detonation of an explosive charge resting on the ground (hemispherical) are higher than those given for a free air (spherical) burst by a factor of two (2). The positive impulses associated with the hemispherical TNT surface explosion are:

DISTANCE (r) (feet)	SCALED DISTANCE ($r/W^{1/3}$)	SCALED IMPULSE ($psi\text{-}ms/W^{1/3}$)	ABSOLUTE IMPULSE
10	1.22	22	180 psi-ms
20	2.44	20	164
30	3.66	18.5	152
40	4.88	16	131
50	6.09	14	113
60	7.31	12	98
70	8.53	10.5	86
80	9.76	9.8	80
90	10.90	8.8	72
100	12.19	7.7	63
200	24.4	4.2	34

c. Reaction of the Structure

To assess the damage to the structure as a result of the impulses issued by the 1,000 pound General Purpose Bomb, three levels of damage are established. They are:

(1) Destroyed

(2) Irrepairable (25% Destroyed)

(3) Repairable

The impulses associated with these levels of damage are:

LEVEL	IMPULSE TO ACHIEVE	DISTANCE
Destroyed	90 to 120 psi-ms	~ 27 feet
Irrepairable	55 to 75 psi-ms	~ 60 feet
Repairable	30 to 40 psi-ms	~100 feet

In terms of damage to the concrete of the structure, assuming that the shelter has a uniform concrete thickness of 2'-0", the deflections that can be expected are:

DISTANCE FROM STRUCTURE	DEFLECTIONS OF 2'-0" THICK PANEL OF R/C
7.2 feet	0.1 inches per foot of span
5.4 feet	0.5 inches per foot of span
3.0 feet	1.2 inches per foot of span

The theoretical positive impulse values delineated in paragraph 3b, above, are conservative. Tests to validate the reaction of the shelter to 1,000 pound, General Purpose, TNT-filled bombs should be made by exploding a series of bombs at various distances from the shelter. The first test should be made so that detonation takes place at a distance (70 to 80 feet) which will not theoretically make the shelter irrepairable.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	Headquarters, U.S. Air Force Directorate of Civil Engineering

13. ABSTRACT

This report develops concepts to protect personnel, weapons and equipment from attack from weapons contained in the current threats (surface-to-surface and air-to-surface weapons). This report deals with direct hits and the effects of near misses. ( )

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Passive Protection						
Protective Construction Concepts						
Personnel Shelters						
Weapons Shelters						
Equipment Shelters						
Direct Hits						
Near Misses						
Counters to Enemy Weapons						
Fragment Penetration						
Aircraft Shelters						
Command, Control and Communication Shelters						
POL Shelters						

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