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TERMINAL BALLISTIC DATA

VOLUME III

OFFICE OF THE CHIEF OF ORDNANCE
WASHINGTON, D.C.

BOMBS, ARTILLERY & MORTAR FIRE & ROCKETS

SEPTEMBER 1945

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TO: Commandant
Command & General Staff School
Fort Leavenworth, Kansas

1. Forwarded herewith are copies of Volume III (Bombs, Artillery & Mortar Fire & Rockets) to be added to your present sets of Terminal Ballistic Data which included Volume I (Bombing) and Volume II (Artillery Fire).

2. This volume includes additional data which have been accumulated on terminal ballistics, and revises and expands in scope data already presented in the first two volumes of the "Terminal Ballistic Data" series. The revisions were made in view of the new and more complete data which are now available.

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FOR THE CHIEF OF ORDNANCE:

W. A. WEAVER
Colonel, Ordnance Department
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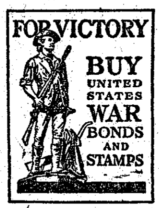

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TERMINAL BALLISTIC DATA

Volume III
Bombs, Artillery, Mortar Fire & Rockets

OFFICE OF THE CHIEF OF ORDNANCE
WASHINGTON, D.C.

September 1945

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INTRODUCTION

This volume reports additional data which have been accumulated on terminal ballistics, and revises and expands in scope data already presented in the first two volumes of the "Terminal Ballistic Data" series. The revisions were required in view of the new and more complete data which are now available.

Listed below are the portions of Volumes I and II which are superseded by this volume.

Superseded Material	*Superseded By*
Volume I, Part 2	Volume III, Parts 2 and 3
Volume I, Part 3, Pages 64 to 72 inclusive. (Bomb fragment patterns at Pages 73 to 115 inclusive, *are not* superseded.)	Volume III, Part 1
Volume II, Part 1, Pages 1 to 29 inclusive. (Vulnerability of German Tanks at Pages 31 to 52 inclusive *have not* been superseded but will be included in the revision of the pocket-size booklet "Vulnerability Tests of German Tanks Pz Kw III, IV, and VI" dated 15 March 1944.	Volume III, Part 11
Volume II, Part 3 Pages 126 to 139 inclusive. (Shell fragment patterns at Pages 140 to 173 *have not* been superseded.)	Volume III, Part 8

Comments, suggestions as to changes, and data acquired from field experience in the use of this book are invited. Additions and revisions will be made in the future as may be deemed necessary.

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Volume III, Part 1

BOMB FRAGMENT DAMAGE

(THIS PART SUPERSEDES VOLUME I, PART 3, PAGES 64 TO 72. PAGES 73 TO 115 ARE NOT SUPERSEDED.)

1. TABLES OF FRAGMENT DAMAGE.

These tables give the number B of effective hits per square foot of target area at a given distance r from the burst. The numbers B are averages for different directions[1] from the burst. They are properly applied only to a considerable number of bursts with random orientation of the bomb axis relative to the target.

2. DAMAGE PATTERNS.

As distinguished from damage tables, the damage patterns represent typical individual cases and vary with the remaining velocity of the bomb, angle of fall, and the height of burst. *Both damage tables and damage patterns presuppose a graze or air burst with no shielding of the target.* The user of the data given here must make due allowance for target shielding and the penetration of the bomb into the ground before burst. The amount of this penetration will depend upon the remaining velocity, the angle of fall of the bomb, the nature of the soil, and the bomb and the fuze. In the fragment damage patterns, shadings of different types indicate regions of decreasing density of hits. The regions distinguished are those where there is at least one hit per 1, 4, 10, or 25 square feet of area. These units of area are understood as normal to the fragment trajectories. **Unshaded regions entering near the burst do not indicate that there are no effective hits in these regions, but merely that the density of effective hits is less than that belonging to the nearest shaded area.**

The white centers of the fragment patterns are used to indicate the origin of the polar system above which the missile bursts. In general these areas suffer the highest type of fragment damage as well as blast damage.

3. TYPES OF DAMAGE.

The types of damage considered are casualties, and normal perforation of mild steel of 1/8 inch, 1/4 inch, and 1/2 inch thickness. A casualty is taken as caused by a hit with at least 58 foot-pounds of energy. It is incapacitation and not necessarily death. Damage comprising perforation of 1/8 inch mild steel is considered effective against airplanes on the ground. Damage in which there is perforation of 1/4 inch or 1/2 inch mild steel is effective against trucks, light armored vehicles, railway rolling stock, and targets of similar resistant nature.

4. SAFETY LIMITS.

The fragment damage tables are useful in determining the distance from a burst at which a soldier stands a given chance of being wounded by a fragment. Suppose, for example, that a soldier is required to take a 1–1,000 chance of being wounded by a fragment from a 20 pound bomb. Suppose that the soldier is in open terrain in such a position that a 2 square foot area of his body is exposed to fragments coming directly from the bomb. Accordingly, the number of casualty producing fragments, per square foot, to which the soldier is exposed is $1/1{,}000 \times 1/2 = 0.0005$ and by Table 5 this fragment density occurs at a little more than 300 feet from the bomb. Thus on the *average* the soldier should be at a distance at least somewhat greater than 300 feet from the bomb.

If account is to be taken of the most dangerous directions from the bomb, the *average densities B of effective fragments as given in the tables* should be multiplied by a factor of about six and then used as in the above example.

In the case of a man in an airplane wearing standard flyer's body armor, a fragment capable of piercing the plane fuselage, the body armor, and then wounding a man, would be capable of perforating approximately 1/8 inch mild steel. Safety limits relative to hits of this type may be found by using the tables for perforations of 1/8 inch mild steel in the manner indicated in the above example.

5. THE CHOICE OF BOMBS.

Tables 1, 2, 3, and 4[2] which follow this discussion will be found useful in making a choice of bomb against unshielded targets according to the type of fragment damage desired. At low or medium altitudes the 20 pound Fragmentation Bomb, AN-M41 or AN-M41A1, is to be preferred against personnel or when only light damage is desired. For low altitude bombing, as noted in Table 1, the parachute on the 23 pound Fragmentation Bomb, AN-M40 or AN-M40A1, greatly improves the effect of the nonparachute Bomb, AN-M41, which except for having fins instead of a parachute is identical with the AN-M40 Bomb. When released from high altitudes, the 20 pound Fragmentation Bomb, AN-M41 or AN-M41A1, is reduced in

[1] Restricting these directions to side wall directions in the case of bombs.

[2] The ratios in Tables 1, 2 and 3 have been revised over those appearing in Volume I, Part 3, to make an allowance of ±2° in the angle of fall on account of the yaw of the bomb and the variation in the slope of the ground.

power. The bombs should be used in accordance with the type of damage required consulting Tables 1, 2, 3, 4, 21 and 22.

The 90 pound Fragmentation Bomb, M82(T9), may be used in clusters of six and when so used will be particularly effective, if the required damage is at most equivalent to perforation of ¼ inch mild steel. For heavier damage, the 260 pound Fragmentation Bomb, AN-M81 (T10), or the 500 pound GP Bomb, AN-M64 or AN-M64A1, may be used.

The altitudes of release given for bombs assume a true air speed of 250 miles per hour.

GROUND BURSTS

6. THE REQUIRED BOMB DENSITY.

Let a target be given in terms of square feet units of area 100 feet x 100 feet (i.e. multiples of 100 feet x 100 feet). Let it be required to wound 50 percent of the enemy personnel (4.5 square feet of area) on the given area or to damage 50 percent of materiel target elements (2 square feet of area) vulnerable to fragments of a given perforative type. Tables 21 and 22 give the number D of bombs of a given type required per unit of area (100 feet x 100 feet).

To obtain the desired effect it is necessary to distribute the bombs over an area somewhat larger than the given target area. The fringe of additional area around the given target area has a width W given in Tables 21 and 22. This enlarged area should receive D bombs per unit of area.

Unless the edge of the target area is very well defined and of marked importance it will usually be more profitable to confine the D bombs per unit area to the given target area A rather than use the enlarged area. In such cases points within A at a distance at least W from the edge of A will receive the desired fragment effect.

The calculations are based on a random[3] distribution of bombs over the enlarged area with an expected bomb density D. The manner of achieving this bomb distribution will depend on the C.E.P., the plane formation, and the timing of the bomb releases and will not be discussed here, except to remark that the total number of bombs which must be dropped to obtain the bomb density D on the enlarged area A, will *considerably exceed* D times the number of units of area (100 feet x 100 feet) in A. This is due to the errors in bombing.

Example. Let the target area be 500 feet x 1,000 feet and suppose it is desired to wound 60 percent of enemy personnel on the area using 20 pound fragmentation bombs released at an altitude of 20,000 feet. Suppose that the terrain is flat and unshielded.

Solution. The width W of the additional fringe of area is 65 feet according to Table 21. Thus the enlarged area is 630 feet x 1,130 feet and contains 71 units of area. For each of these units 0.73 bombs are required in accordance with Table 21. When the percent of wounded is to be 60 instead of 50, a multiplicative factor of 1.32 is called for as given in Table 21. Thus the number of bombs which should be distributed over the enlarged area is 0.73 x 71 x 1.32 = 69. The number to be dropped must be properly increased to take account of probable errors in bombing.

In the case of enemy *materiel* each target is supposed divided into a number of elements each 2 square feet in area and vulnerable to a hit of a given perforative type, i.e., perforations of ⅛ inch, ¼ inch, or ½ inch mild steel. The tables give the number D of bombs per unit area required to effectively damage 50 percent of these target elements. For example, an enemy vehicle may present eight of these target elements vulnerable to hits capable of perforating ⅛ inch mild steel. If the bomb density is D per unit area as given in Table 22, four of the eight target elements may be expected to be effectively damaged. As in the case of casualties, the distribution of bombs with the density D must be made over an area somewhat larger than the given target area. The width W of this additional fringe of area is given in the tables.

If the percent p of target elements which it is desired to effectively damage is not 50 percent, it is sufficient to multiply the bomb density given in Table 22 by a factor F given in the same table to obtain the correct bomb density D.

Shielding. The bomb densities D are calculated for flat unshielded terrain and, in the case of personnel, for men who are standing. For prone men or for terrain which is rolling or shielded, the bomb densities should be multiplied by appropriate factors. Estimates for some of the more important cases are given following Tables 21 for casualties and Table 22 for materiel targets.

Blast. Blast is effective against personnel in the open for relatively small distances, in every case for distances considerably less than those at which a casualty is certain to be caused by fragments (see page 53).

AIR BURSTS

7. GENERAL.

Against personnel in medium foxholes or on rough terrain, or against other moderately shielded targets, an air burst of the 500 pound GP bomb, AN-M64 or AN-M64A1, or the 260 pound Fragmentation Bomb, AN-M81 (T10), is recommended. A height of burst from 35 to 60 feet would be effective, with the higher burst counteracting the greater shielding.

Released from an altitude of 15,000 feet or more, the 20 pound Frag-

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[3]Any two bursts are independent in position.

mentation Bomb, AN-M41 or AN-M41A1 with impact type fuze, is diminished in fragment damage not only from the effects illustrated in the damage patterns (Vol. I, Part 3, pages 74 and 75), but also because the bomb penetrates the soil to some extent before bursting. From these altitudes an air burst of the 500 pound GP Bomb, AN-M64 or AN-M64A1, or the 260 pound Fragmentation Bomb, AN-M81 (T10), will be highly effective.

8. THE OPTIMUM HEIGHT OF AIR BURSTS.

The optimum height of burst of a bomb depends upon the type of shielding of the targets to be attacked. In the complete absence of shielding, both by the terrain and by other targets, and on open level ground the optimum height of burst is just off the ground; to raise the height of burst still higher would cause a loss of effect approximately as follows:

Height of burst	Percent loss in targets effectively damaged
30 ft	5-15%
50 ft	25-50%
100 ft	90-80%

Types of shielding. Air bursts are recommended against men in foxholes or open trenches and against personnel shielded by rough terrain. The type of shielding labelled "10° foxholes" is believed to be that most commonly encountered and will correspond to the shielding afforded men in foxholes when the men are somewhat below the level of the ground,[4] or to the shielding afforded prone men by rough terrain. The term "10° foxhole" arose from its definition as a foxhole in which an occupant will on the average be unharmed by fragments with an angle of fall less than 10 degrees.

Hastily dug in positions on level ground will correspond to "0° foxholes," as will trenches in which the heads of men are even with the ground.

The optimum heights of burst against personnel in the absence of dispersion in the height of burst may be read from Figures 1 to 10.[5] From these figures one reads the number of casualties against the height of burst assuming that there is one man in each foxhole and that the foxholes are ten feet apart. In those cases where a fuze for regulating the height of burst is available and causes a known dispersion in the height of burst, it is possible to use Figures 1 to 10 to determine the *mean height* to which the burst should be adjusted, as is done in the case of time fire with shell. This mean optimum height in the case of dispersion is in general larger than the optimum heights read from the figures.

[4]See illustration, page 3.
[5]The terminal velocities for which these curves are drawn are based on a true air speed of 400 miles per hour. For the angles of fall indicated on Figures 1 to 10 the curves will not be materially changed if the true air speed is reduced to as low as 250 miles per hour.

As the type of shielding runs from the weak zero degree shielding to the strong 30 degree shielding, the optimum heights of burst run approximately as follows:

Bomb	Optimum height of burst No dispersion
20 lb Bomb AN-M41 or AN-M41A1	20 ft-30 ft
90 lb Bomb M82 (T9)	30 ft-50 ft
100 lb Bomb AN-M30 or AN-M30A1	30 ft-50 ft
260 lb Bomb AN-M81 (T10)	35 ft-70 ft
500 lb Bomb AN-M64 or AN-M64A1	30 ft-60 ft

This optimum height is greater the greater the shielding. In the case of heavy shielding, the low angles of fall (around 45 degrees) are superior to the high angles of fall (around 75 degrees). For average shielding the angles of fall (45 degrees–75 degrees) do not affect the result to any considerable degree. Computations show that a tail initiation of the burst would more than double the effect in the case of low shielding and high angle of fall.

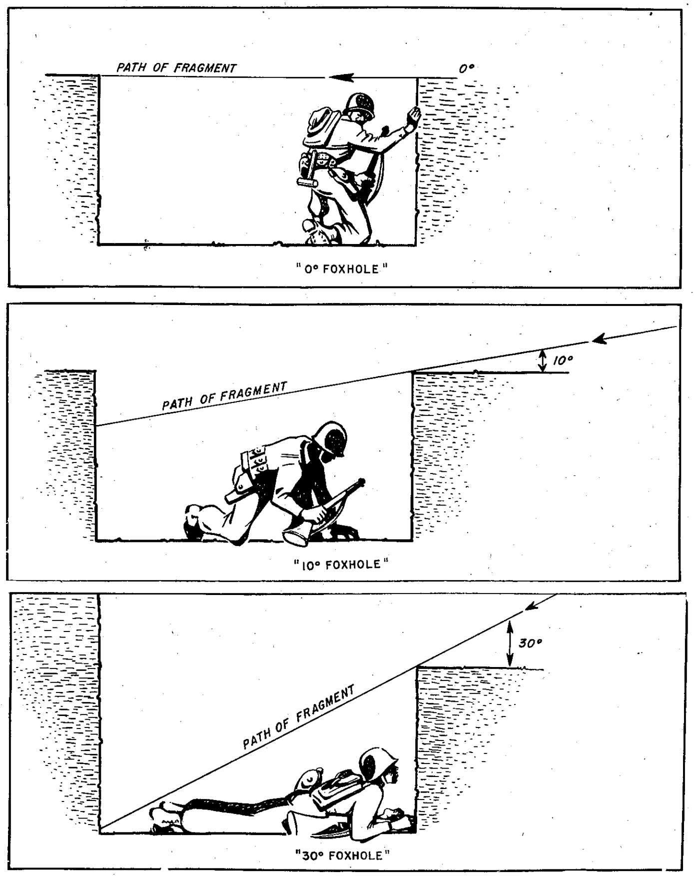


TABLE 1
LOW ALTITUDE BOMBING

The choice of bombs for fragment effect for *low altitude bombing* may be made with the aid of the following table giving the ratio of the number of effective hits for the two sets of bombs listed at the left. The number of bombs compared in each case are those which can be carried in the same station in the bomb bay.

Bombs Compared	Casualties	⅛ in. Mild Steel Perf.	¼ in. Mild Steel Perf.	½ in. Mild Steel Perf.
Six 20 lb bombs* / One 100 lb bomb	1.83	2.38	0.94	
Six 20 lb bombs* / One 260 lb bomb	1.03	0.96	0.52	
One 100 lb bomb / One 260 lb bomb	0.56	0.40	0.55	
Twenty 20 lb bombs* / Six 90 lb bombs	1.05	1.07	0.69	
Twenty 20 lb bombs* / One 500 lb bomb	1.91	2.05	1.12	
Six 90 lb bombs / One 500 lb bomb	1.81	1.92	1.45	0.28
Two 100 lb bombs / One 500 lb bomb	0.79	0.65	0.67	
Two 260 lb bombs / One 500 lb bomb	1.42	1.61	1.21	0.85

20 lb Fragmentation Bomb, AN-M41 or AN-M41A1, TNT Loading.
90 lb Fragmentation Bomb, M82 (T9), RDX Comp B Loading.
100 lb GP Bomb, AN-M30 or AN-M30A1, Amatol Loading.
260 lb Fragmentation Bomb, AN-M81 (T10), RDX Comp B Loading.
500 lb GP Bomb, AN-M64 or AN-M64A1, Amatol Loading.

A fragment with at least 58 ft-lb of energy is considered as "causing" a casualty. Other measures of damage are normal perforations of mild steel at various thicknesses.

The above table applies in the strict sense to attacks on unshielded targets with ground bursts and with relatively low altitudes of release.

*Replacing the 20 lb fragmentation bomb, AN-M41, by the 23 lb fragmentation bomb, AN-M40, with parachute greatly increases the value of this fragment bomb released at low altitudes.

TABLE 2

ALTITUDE OF BOMB RELEASE, 10,000 FT

The choice of bombs for fragment effect may be made with the aid of the following table giving the ratio of the number of effective hits for the two sets of bombs listed at the left. The number of bombs compared in each case are those which can be carried in the same station in the bomb bay.

Bombs Compared	Casualties	1/8 in. Mild Steel Perf.	1/4 in. Mild Steel Perf.	1/2 in. Mild Steel Perf.
Six 20 lb bombs / One 100 lb bomb	3.00	2.48		
Six 20 lb bombs / One 260 lb bomb	1.41	0.88		
One 100 lb bomb / One 260 lb bomb	0.47	0.35	0.49	
Twenty 20 lb bombs / Six 90 lb bombs	1.05	0.81		
Twenty 20 lb bombs / One 500 lb bomb	2.88	2.13		
Six 90 lb bombs / One 500 lb bomb	2.74	2.64	1.80	
Two 100 lb bombs / One 500 lb bomb	0.78	0.66	0.68	
Two 260 lb bombs / One 500 lb bomb	1.65	1.87	1.39	0.98

20 lb Fragmentation Bomb, AN-M41 or AN-M41A1, TNT Loading.
90 lb Fragmentation Bomb, M82 (T9), RDX Comp B Loading.
100 lb GP Bomb, AN-M30 or AN-M30A1, Amatol Loading.
260 lb Fragmentation Bomb, AN-M81 (T10), RDX Comp B Loading.
500 lb GP Bomb, AN-M64 or AN-M64A1, Amatol Loading.

A fragment with at least 58 ft-lb of energy is considered as "causing" a casualty. Other measures of damage are normal perforations of mild steel at various thicknesses.

The above table applies in the strict sense to attacks on unshielded targets with ground bursts.

TABLE 3

ALTITUDE OF BOMB RELEASE, 20,000 FT

The choice of bombs for fragment effect may be made with the aid of the following table giving the ratio of the number of effective hits for the first two sets of bombs listed at the left. The number of bombs compared in each case are those which can be carried in the same station in the bomb bay.

Bombs Compared	Casualties	1/8 in. Mild Steel Perf.	1/4 in. Mild Steel Perf.	1/2 in. Mild Steel Perf.
Six 20 lb bombs / One 100 lb bomb	1.67	1.19		
Six 20 lb bombs / One 260 lb bomb	0.68	0.40		
One 100 lb bomb / One 260 lb bomb	0.41	0.33	0.47	
Twenty 20 lb bombs / Six 90 lb bombs	0.79	0.66		
Twenty 20 lb bombs / One 500 lb bomb	1.86	1.38		
Six 90 lb bombs / One 500 lb bomb	2.34	2.09	1.32	
Two 100 lb bombs / One 500 lb bomb	0.85	0.71	0.74	
Two 260 lb bombs / One 500 lb bomb	2.09	2.14	1.58	1.13

20 lb Fragmentation Bomb, AN-M41 or AN-M41A1, TNT Loading.
90 lb Fragmentation Bomb, M82 (T9), RDX Comp B Loading.
100 lb GP Bomb, AN-M30 or AN-M30A1, Amatol Loading.
260 lb Fragmentation Bomb, AN-M81 (T10), RDX Comp B Loading.
500 lb GP Bomb, AN-M64 or AN-M64A1, Amatol Loading.

A fragment with at least 58 ft-lb of energy is considered as "causing" a casualty. Other measures of damage are normal perforations of mild steel at various thicknesses.

The above table applies in the strict sense to attacks on unshielded targets with ground bursts.

TABLE 4

ALTITUDE OF BOMB RELEASE, 30,000 FT

The choice of bombs for fragment effect may be made with the aid of the following table giving the ratio of the number of effective hits for the two sets of bombs listed at the left. The number of bombs compared in each case are those which can be carried in the same station in the bomb bay.

Bombs Compared	Casualties	1/8 in. Mild Steel Perf.	1/4 in. Mild Steel Perf.	1/2 in. Mild Steel Perf.
Six 20 lb bombs / One 100 lb bomb	1.05	0.79		
Six 20 lb bombs / One 260 lb bomb	0.51	0.35		
One 100 lb bomb / One 260 lb bomb	0.48	0.44	0.61	
Twenty 20 lb bombs / Six 90 lb bombs	1.08	0.65		
Twenty 20 lb bombs / One 500 lb bomb	1.46	0.99		
Six 90 lb bombs / One 500 lb bomb	1.36	1.51	0.98	
Two 100 lb bombs / One 500 lb bomb	0.93	0.75	0.78	
Two 260 lb bombs / One 500 lb bomb	1.91	1.70	1.27	0.91

20 lb Fragmentation Bomb, AN-M41 or AN-M41A1, TNT Loading.
90 lb Fragmentation Bomb, M82 (T9), RDX Comp B Loading.
100 lb GP Bomb, AN-M30 or AN-M30A1, Amatol Loading.
260 lb Fragmentation Bomb, AN-M81 (T10), RDX Comp B Loading.
500 lb GP Bomb, AN-M64 or AN-M64A1, Amatol Loading.

A fragment with at least 58 ft-lb of energy is considered as "causing" a casualty. Other measures of damage are normal perforations of mild steel at various thicknesses.

The above table applies in the strict sense to attacks on unshielded targets with ground bursts.

20 LB FRAGMENTATION BOMB, AN-M41 OR AN-M41A1

TNT Loading

INITIAL FRAGMENT VELOCITY 2,810 F/S

TABLE 5

CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,180	0.386	0.0075	2,810
30	1,090	0.158	0.011	2,320
40	1,000	0.0817	0.016	1,930
60	952	0.0345	0.028	1,460
80	895	0.0183	0.042	1,190
100	829	0.0108	0.055	1,040
150	677	0.0039	0.085	836
200	576	0.0019	0.111	731
300	377	0.0006	0.170	591
400	202	0.0002	0.243	502

TABLE 6

PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	930	0.304	0.032	2,810
30	875	0.127	0.045	2,470
40	799	0.0652	0.060	2,230
60	617	0.0224	0.102	1,880
80	399	0.0081	0.161	1,660
100	229	0.0030	0.230	1,470
120	106	0.0010	0.308	1,340
140	31	0.0002	0.397	1,240
160	10	0.0001	0.493	1,170

90 LB FRAGMENTATION BOMB, M82 (T9)

RDX Comp B Loading

INITIAL FRAGMENT VELOCITY 3,100 F/S

TABLE 7
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
40	4,520	0.369	0.014	2,060
50	4,240	0.221	0.019	1,770
60	3,980	0.144	0.024	1,575
80	3,490	0.0712	0.036	1,280
100	2,880	0.0376	0.050	1,090
150	2,000	0.0116	0.080	862
200	1,770	0.0058	0.105	753
300	1,400	0.0020	0.160	610
400	1,040	0.0009	0.230	509
600	646	0.0002	0.405	383
800	413	0.0001	0.632	307

TABLE 8
PERFORATION OF ⅛ IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	3,980	1.30	0.024	3,100
30	3,510	0.510	0.034	2,720
40	3,010	0.245	0.048	2,410
60	1,980	0.0716	0.082	2,010
80	1,620	0.0331	0.125	1,790
100	1,290	0.0168	0.180	1,590
120	975	0.0088	0.250	1,430
140	760	0.0051	0.330	1,310
170	580	0.0026	0.465	1,190
200	435	0.0014	0.605	1,100
300	149	0.0002	1.12	952

TABLE 9
PERFORATION OF ¼ IN. MILD STEEL

r	N	B	m	v
20	1,220	0.398	0.192	3,100
30	1,040	0.151	0.230	2,900
40	896	0.0731	0.275	2,720
60	681	0.0247	0.380	2,420
80	540	0.0110	0.500	2,200
100	395	0.0052	0.650	2,020
120	285	0.0026	0.815	1,870
140	193	0.0013	0.992	1,750
170	83	0.0004	1.36	1,610
200	18	0.0001	1.74	1,490

100 LB GP BOMB, AN-M30 OR AN-M30A1

Amatol Loading

INITIAL FRAGMENT VELOCITY 7,320 F/S

TABLE 10
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
70	4,286	0.114	0.009	2,570
80	3,943	0.0804	0.011	2,320
100	3,310	0.0432	0.017	1,870
120	3,040	0.0276	0.024	1,570
140	2,730	0.0182	0.033	1,340
170	2,300	0.0104	0.047	1,130
200	1,880	0.0061	0.062	980
300	1,080	0.0016	0.107	746
500	519	0.0003	0.214	531
700	232	0.0001	0.357	411

TABLE 11
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
40	4,120	0.336	0.009	4,350
50	3,480	0.182	0.012	4,060
60	3,330	0.121	0.016	3,670
80	3,040	0.0620	0.024	3,100
100	2,620	0.0342	0.037	2,650
120	2,150	0.0195	0.052	2,350
140	1,670	0.0111	0.071	2,110
170	1,090	0.0049	0.105	1,870
200	758	0.0025	0.150	1,700
400	58	0.0001	0.68	1,070

TABLE 12
PERFORATION OF 1/4 IN. MILD STEEL

r	N	B	m	v
20	3,070	1.00	0.022	7,320
30	2,830	0.411	0.029	6,390
40	2,560	0.209	0.039	5,660
60	1,950	0.0707	0.060	4,760
80	1,370	0.0279	0.086	4,140
100	990	0.0129	0.115	3,780
120	758	0.0069	0.150	3,470
140	594	0.0040	0.191	3,110
170	393	0.0018	0.265	2,760
200	239	0.0008	0.352	2,490
300	55	0.0001	0.750	1,930

260 LB FRAGMENTATION BOMB, AN-M81 (T10)

RDX Comp B Loading

INITIAL FRAGMENT VELOCITY 3,410 F/S

TABLE 13
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
40	6,620	0.540	0.012	2,230
50	6,490	0.339	0.016	1,930
60	6,300	0.228	0.021	1,680
80	5,910	0.120	0.033	1,340
100	5,450	0.0711	0.047	1,130
150	4,540	0.0263	0.076	886
200	3,990	0.0130	0.101	768
300	3,230	0.0047	0.157	616
500	2,190	0.0011	0.301	444
700	1,620	0.0004	0.492	348
1,000	1,090	0.0001	0.887	259

TABLE 14
PERFORATION OF ⅛ IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	6,330	2.070	0.020	3,410
30	6,070	0.880	0.029	2,880
40	5,680	0.463	0.040	2,570
60	4,830	0.175	0.066	2,160
80	4,010	0.0817	0.100	1,890
100	3,330	0.0434	0.149	1,710
150	2,170	0.0126	0.307	1,340
200	1,580	0.0052	0.513	1,160
300	999	0.0014	0.994	967
400	587	0.0005	1.55	863
600	170	0.0001	2.85	742

TABLE 15
PERFORATION OF ¼ IN. MILD STEEL

r	N	B	m	v
20	3,330	1.090	0.149	3,410
30	3,040	0.440	0.176	3,240
40	2,640	0.216	0.225	2,920
60	2,200	0.0798	0.300	2,620
80	1,840	0.0375	0.400	2,380
100	1,580	0.0206	0.515	2,180
150	1,080	0.0063	0.890	1,820
200	685	0.0022	1.38	1,600
250	379	0.0008	2.00	1,420
300	189	0.0003	2.75	1,300

TABLE 16
PERFORATION OF ½ IN. MILD STEEL

r	N	B	m	v
20	868	0.283	1.15	3,410
30	770	0.112	1.27	3,330
40	679	0.0554	1.40	3,200
60	509	0.0185	1.68	2,990
80	379	0.0077	2.01	2,790
100	281	0.0037	2.37	2,640
120	189	0.0017	2.75	2,510
140	117	0.0008	3.16	2,380
170	43	0.0002	3.85	2,230
200	25	0.0001	4.62	2,100

500 LB GP BOMB, AN-M64 OR AN-M64A1

Amatol Loading

INITIAL FRAGMENT VELOCITY 7,390 F/S

TABLE 17

CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
70	14,940	0.398	0.009	2,570
80	13,450	0.274	0.012	2,230
100	11,830	0.154	0.017	1,870
150	8,160	0.0473	0.037	1,270
200	6,100	0.0199	0.061	990
250	4,920	0.0103	0.084	840
300	4,160	0.0060	0.106	750
500	2,340	0.0012	0.214	531
700	1,330	0.0004	0.356	411
1,000	430	0.0001	0.653	302

TABLE 18

PERFORATION OF ⅛ IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
40	14,940	1.22	0.009	4,350
50	13,450	0.702	0.012	4,060
60	12,450	0.451	0.015	3,770
80	10,330	0.211	0.023	3,150
100	8,280	0.108	0.036	2,670
150	5,030	0.0292	0.081	2,020
200	3,160	0.0103	0.148	1,710
300	1,260	0.0018	0.370	1,270
400	410	0.0003	0.680	1,070
600	137	0.0001	1.48	873

TABLE 19

PERFORATION OF ¼ IN. MILD STEEL

r	N	B	m	v
20	10,770	3.51	0.021	7,390
30	9,210	1.34	0.029	6,390
40	8,030	0.655	0.038	5,730
60	6,250	0.227	0.059	4,800
80	4,890	0.0998	0.085	4,160
100	3,920	0.0512	0.114	3,790
150	2,380	0.0138	0.209	2,990
200	1,390	0.0046	0.345	2,510
300	361	0.0005	0.735	1,940
500	100	0.0001	2.12	1,400

TABLE 20

PERFORATION OF ½ IN. MILD STEEL

r	N	B	m	v
20	2,790	0.910	0.17	7,390
30	2,480	0.359	0.20	6,770
40	2,190	0.179	0.23	6,460
60	1,670	0.0605	0.30	5,740
80	1,170	0.0239	0.39	5,180
100	872	0.0114	0.47	4,810
150	349	0.0020	0.74	4,030
200	237	0.0008	1.05	3,550
250	137	0.0003	1.44	3,160
300	116	0.0002	1.86	2,880

TABLE 21

BOMB DENSITIES D PER SQUARE 100 FT x 100 FT

REQUIRED IN AREA BOMBING TO CAUSE 50% CASUALTIES. GROUND BURSTS. INSTANTANEOUS FUZE. FLAT TERRAIN. NO SHIELDING. MEN STANDING.

Bomb	Altitude of Release ft	The Required Bomb Density D	Width* W in F of Fringe
20 lb FRAG, AN-M41 or AN-M41A1	Low 10,000 20,000 30,000	0.70 0.45 0.73 0.98	65
90 lb FRAG, M82 (T9)	Low 10,000 20,000 30,000	0.24 0.17 0.21 0.35	90
100 lb GP, AN-M30 or AN-M30A1	Low 10,000 20,000 30,000	0.25 0.25 0.20 0.17	95
260 lb FRAG, AN-M81 (T10)	Low 10,000 20,000 30,000	0.14 0.12 0.083 0.083	140
500 lb GP, AN-M64 or AN-M64A1	Low 10,000 20,000 30,000	0.099 0.096 0.087 0.079	125

*Width of fringe around target area requiring the burst density D.

To obtain p percent casualties the above value of D should be multiplied by the factor F in the following table:

Percent p	10	20	30	40	50	60	70	80	90
The factor F	0.150	0.322	0.516	0.740	1.00	1.32	1.74	2.32	3.32

In case the target area is not flat or is shielded, or the men are not standing, the above values of D should be multiplied by an appropriate factor. Estimates of this factor are given below for a number of typical cases.

Factor	The Tactical Case
3	Men prone, flat terrain, no shielding.
2	Men standing, rolling terrain, no shielding.
4	Men prone, rolling terrain, country fields.
10- 20	Men firing from trenches.
20-100	Men in foxholes.

The above values of D were calculated for the case of a plane speed of 250 mph.

TABLE 22

BOMB DENSITIES D PER SQUARE 100 FT x 100 FT

REQUIRED IN AREA BOMBING TO CAUSE DAMAGE TO 50% OF MATERIEL TARGET ELEMENTS (2 SQ FT) VULNERABLE TO A FRAGMENT OF GIVEN PERFORATIVE TYPE. GROUND BURSTS. INSTANTANEOUS FUZE. FLAT TERRAIN. NO SHIELDING.

Bomb	Altitude of Release ft	The required bomb density D for the following perforative type			Width* W in ft of fringe		
		1/8 in. Mild Steel Perf	1/4 in. Mild Steel Perf	1/2 in. Mild Steel Perf	1/8 in. Mild Steel Perf	1/4 in. Mild Steel Perf	1/2 in. Mild Steel Perf
20 lb FRAG, AN-M41 or AN-M41A1	Low 10,000 20,000 30,000	2.73 2.61 4.47 5.73			27		
90 lb FRAG, M82 (T9)	Low 10,000 20,000 30,000	0.99 0.73 0.91 1.12	1.91 1.45 1.77 2.14		50	30	
100 lb GP, AN-M30 or AN-M30A1	Low 10,000 20,000 30,000	1.17 1.08 0.89 0.76	1.38 1.27 1.06 0.90		60	45	
260 lb FRAG, AN-M81 (T10)	Low 10,000 20,000 30,000	0.47 0.38 0.30 0.33	0.76 0.63 0.50 0.55	2.41 1.98 1.55 1.74	70	55	30
500 lb GP, AN-M64 or AN-M64A1	Low 10,000 20,000 30,000	0.38 0.36 0.32 0.28	0.46 0.44 0.39 0.35	1.02 0.97 0.88 0.80	80	65	40

*W-Width of fringe around target area requiring the burst density D.

To obtain p percent damage the above value of D should be multiplied by the factor F in the following table:

Percent p	10	20	30	40	50	60	70	80	90
The factor F	0.150	0.322	0.516	0.740	1.00	1.32	1.74	2.32	3.32

In case the target area is not flat or is shielded, the above values of D should be multiplied by an appropriate factor. Estimates of this factor are given below for two typical cases.

Factor	The Tactical Case
2	Rolling terrain, no shielding.
3	Rolling terrain, rough country.

The above values of D were calculated for the case of a plane speed of 250 mph.

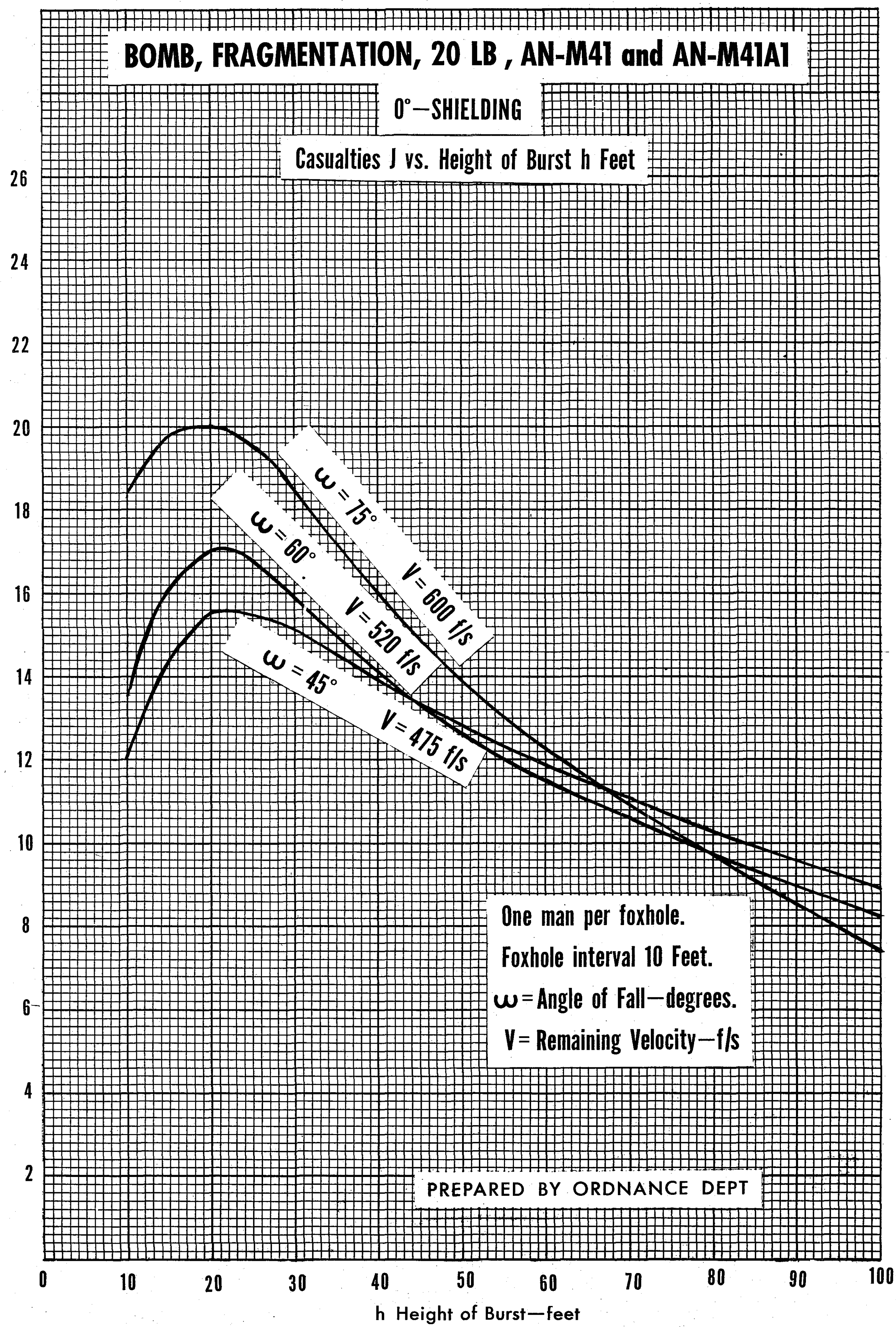

BOMB, FRAGMENTATION, 20 LB, AN-M41 and AN-M41A1
0°—SHIELDING
Casualties J vs. Height of Burst h Feet
26
24
22
20
18
16
J
14
12
10
8
6
4
2
ω = 75° V = 600 f/s
ω = 60° V = 520 f/s
ω = 45° V = 475 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 1

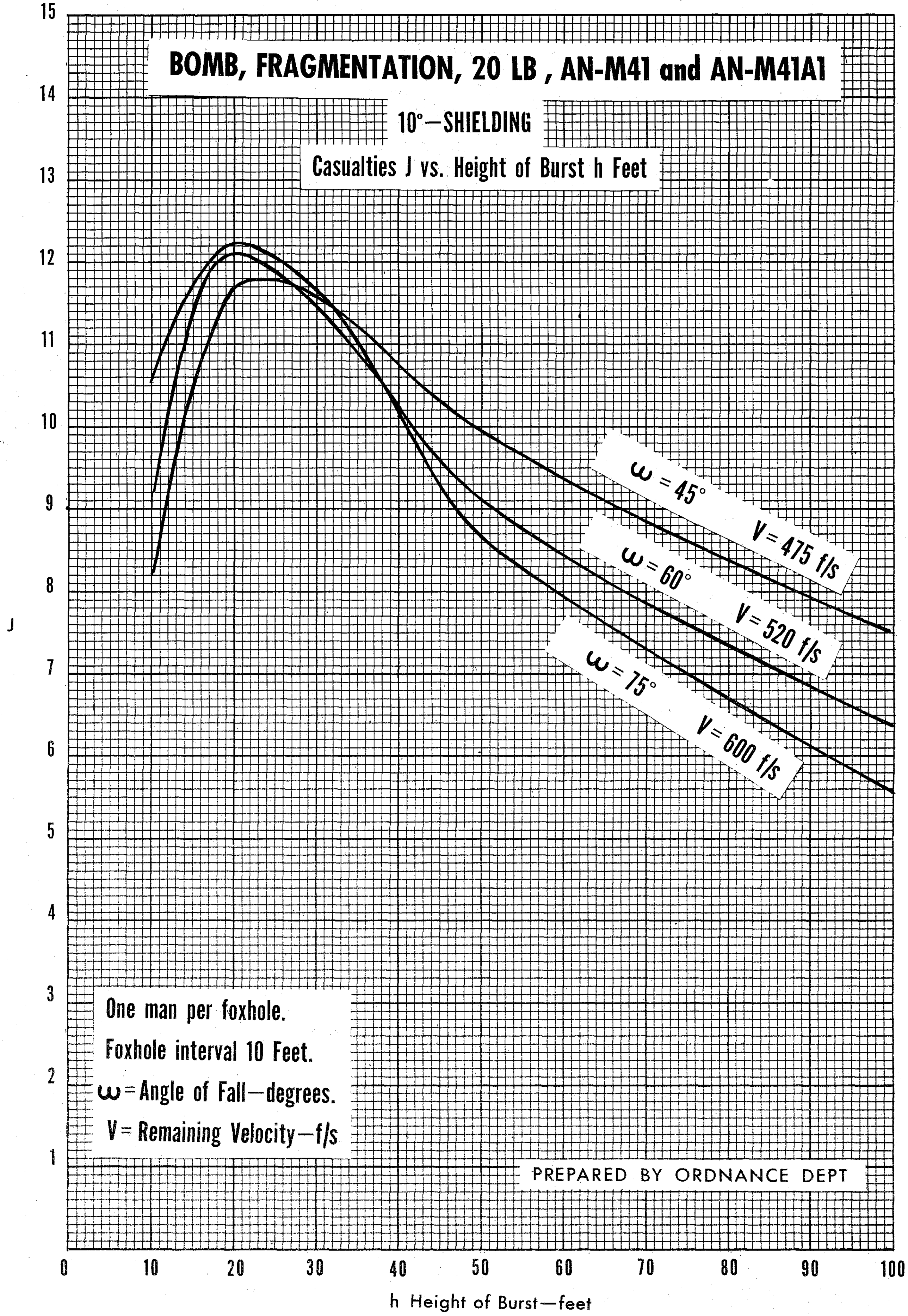

BOMB, FRAGMENTATION, 20 LB , AN-M41 and AN-M41A1
10°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 475 f/s
ω = 60° V = 520 f/s
ω = 75° V = 600 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 10 20 30 40 50 60 70 80 90 100
h Height of Burst—feet

FIGURE 2

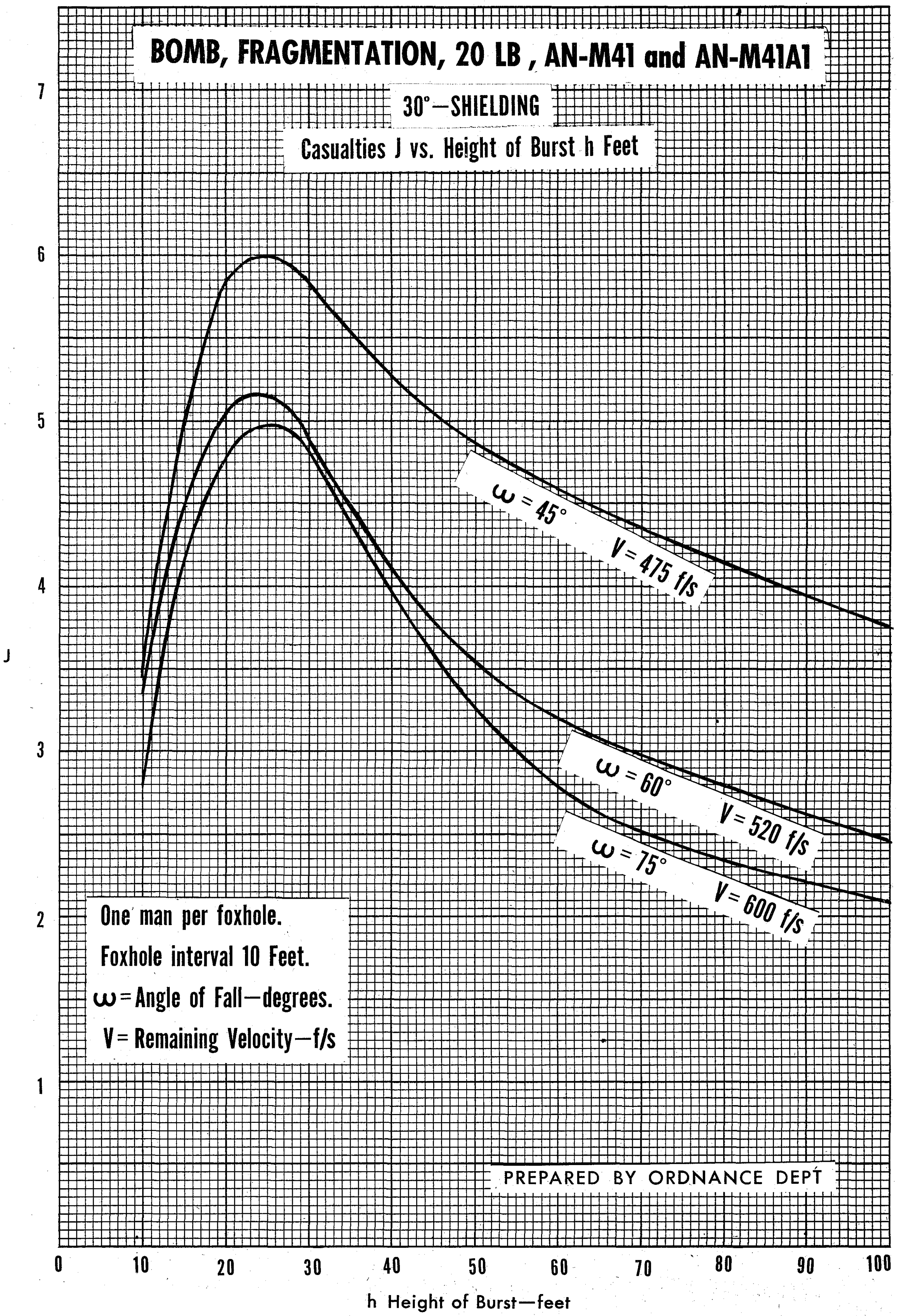

BOMB, FRAGMENTATION, 20 LB, AN-M41 and AN-M41A1
30°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 475 f/s
ω = 60° V = 520 f/s
ω = 75° V = 600 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 3

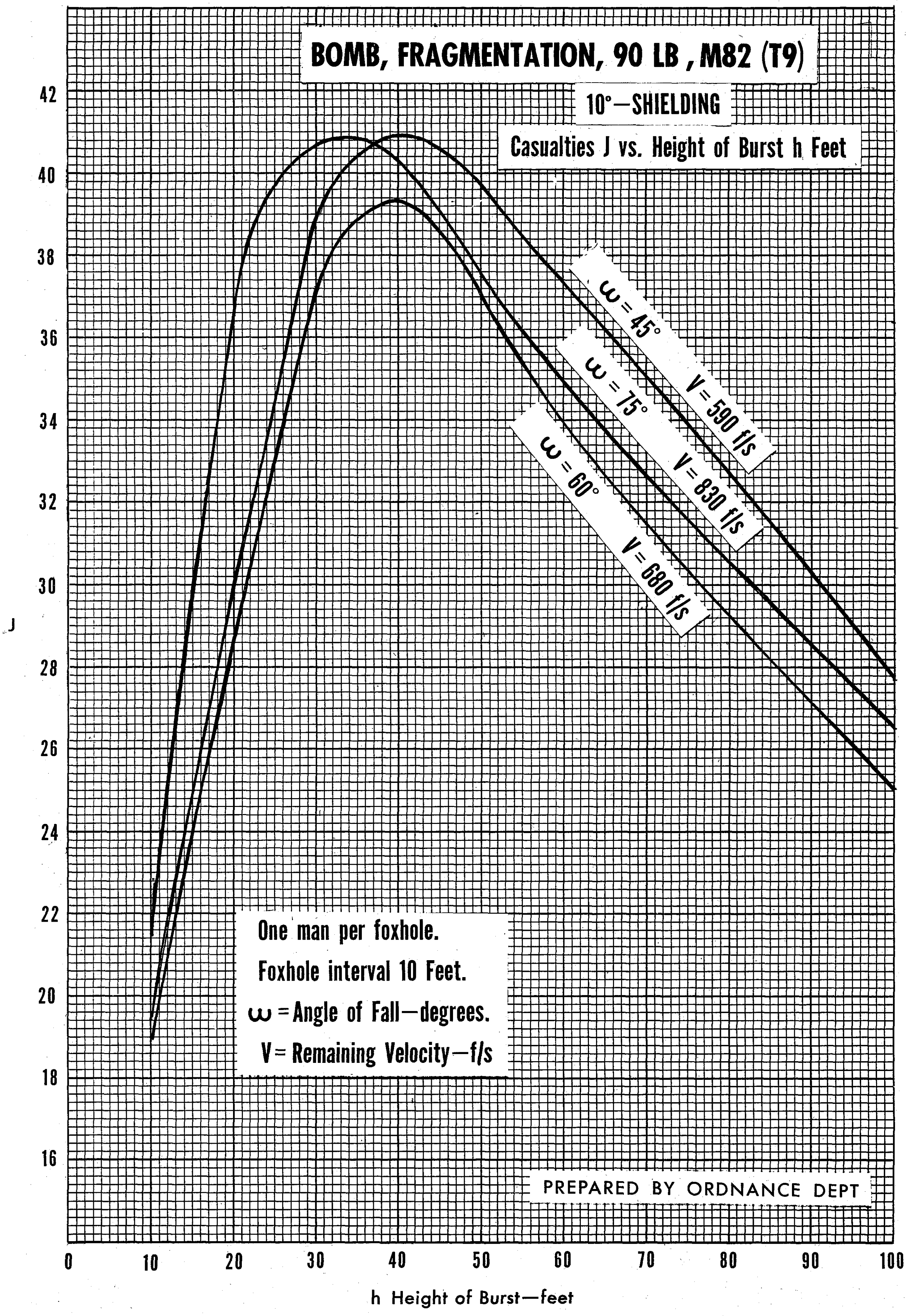

BOMB, FRAGMENTATION, 90 LB , M82 (T9)
10°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 590 f/s
ω = 75° V = 830 f/s
ω = 60° V = 680 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
42
40
38
36
34
32
30
28
26
24
22
20
18
16
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 4

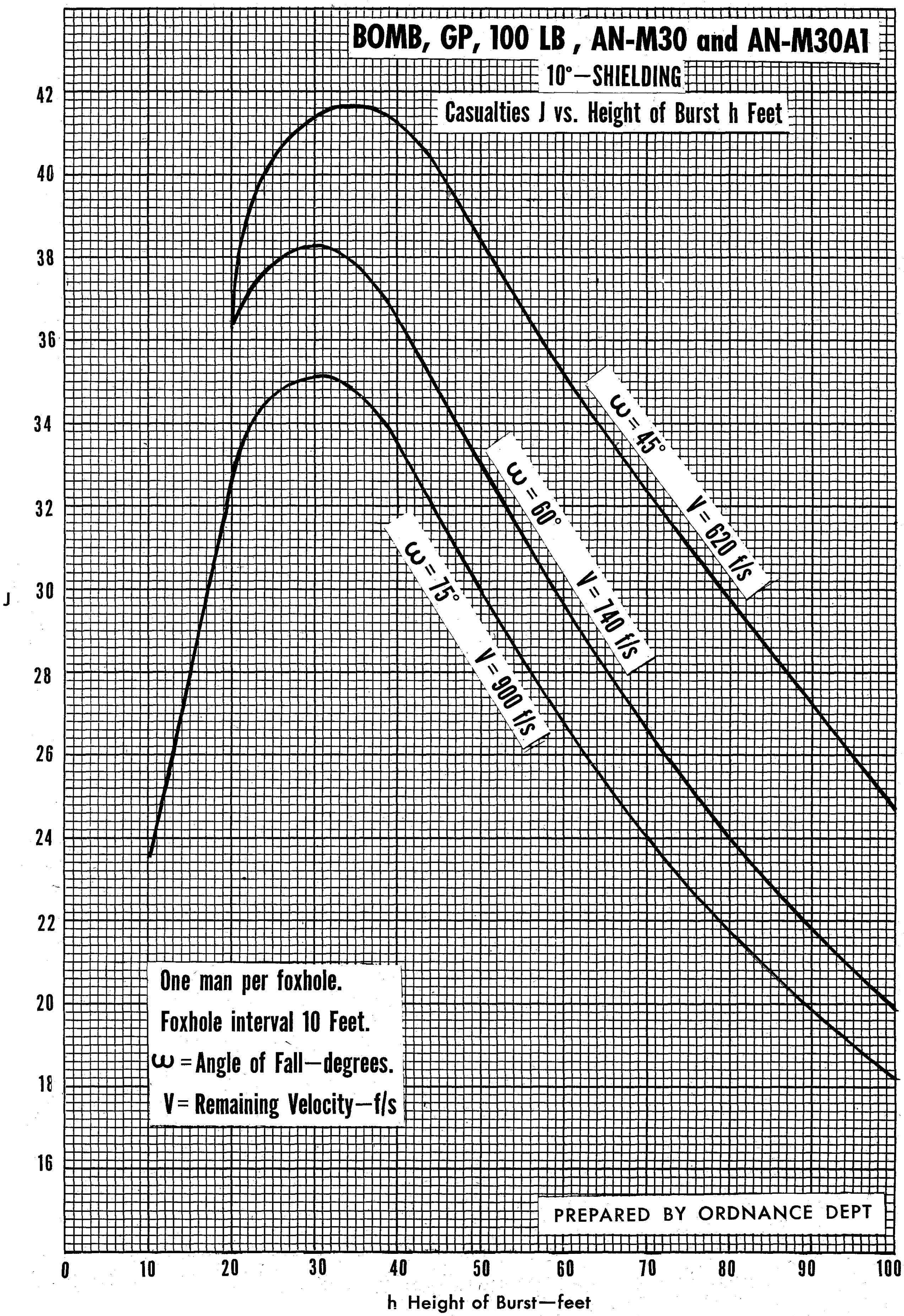

BOMB, GP, 100 LB, AN-M30 and AN-M30A1
10°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 620 f/s
ω = 60° V = 740 f/s
ω = 75° V = 900 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
42
40
38
36
34
32
30
28
26
24
22
20
18
16
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 5

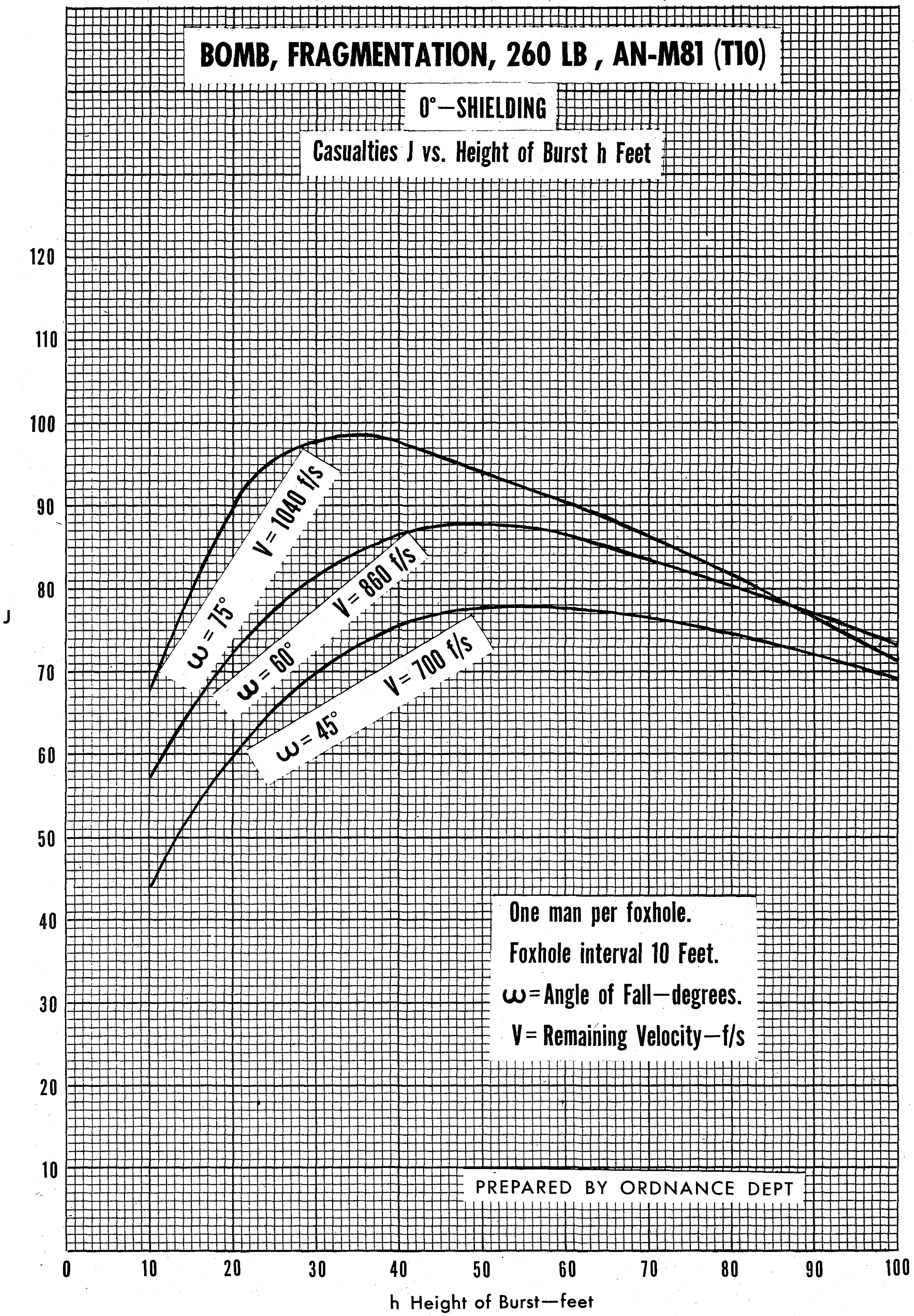

BOMB, FRAGMENTATION, 260 LB, AN-M81 (T10)
0°—SHIELDING
Casualties J vs. Height of Burst h Feet
J
120
110
100
90
80
70
60
50
40
30
20
10
ω = 75° V = 1040 f/s
ω = 60° V = 860 f/s
ω = 45° V = 700 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 6

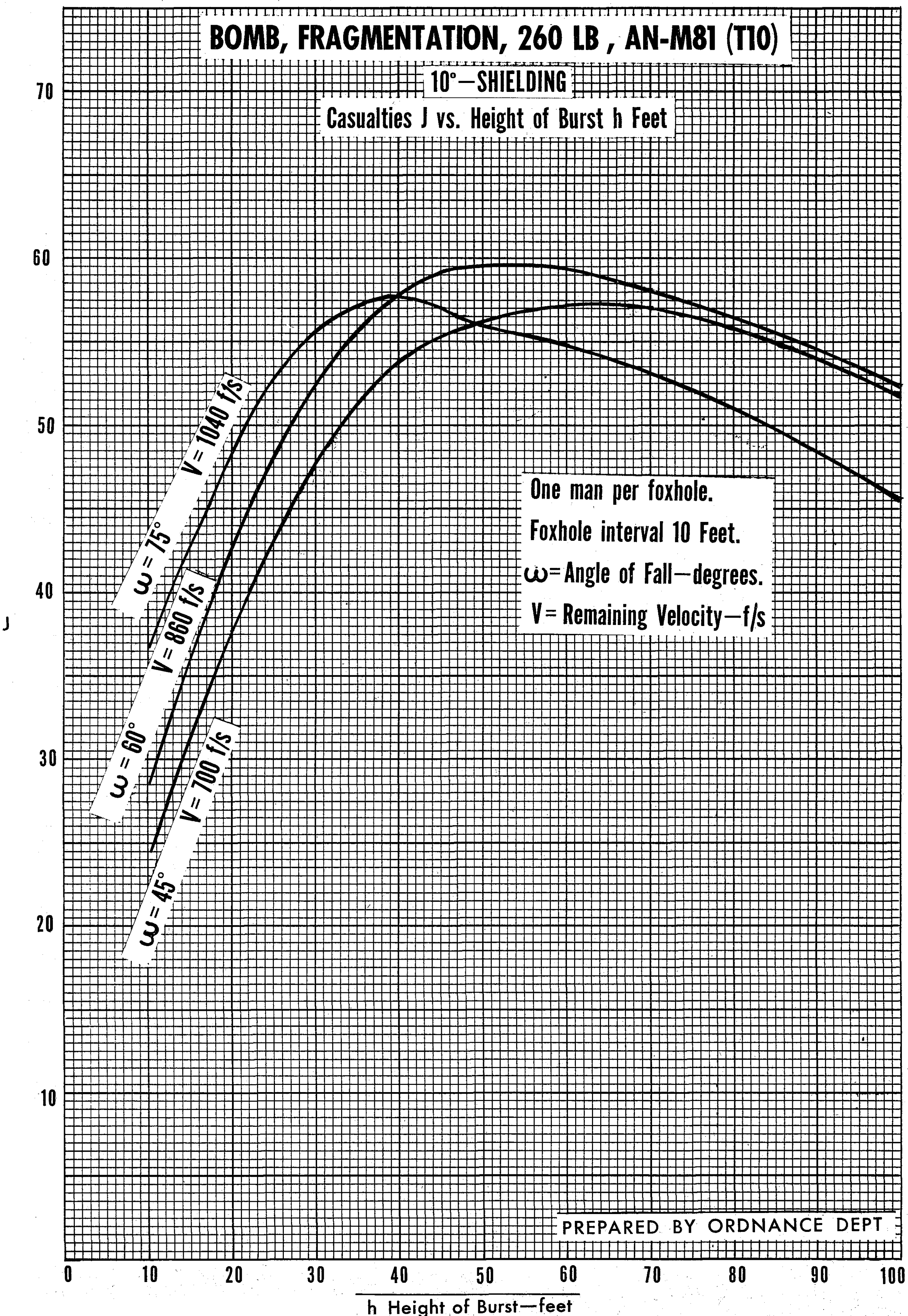

BOMB, FRAGMENTATION, 260 LB, AN-M81 (T10)
10°—SHIELDING
Casualties J vs. Height of Burst h Feet
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
ω = 75°
V = 1040 f/s
ω = 60°
V = 860 f/s
ω = 45°
V = 700 f/s
PREPARED BY ORDNANCE DEPT
J
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 7

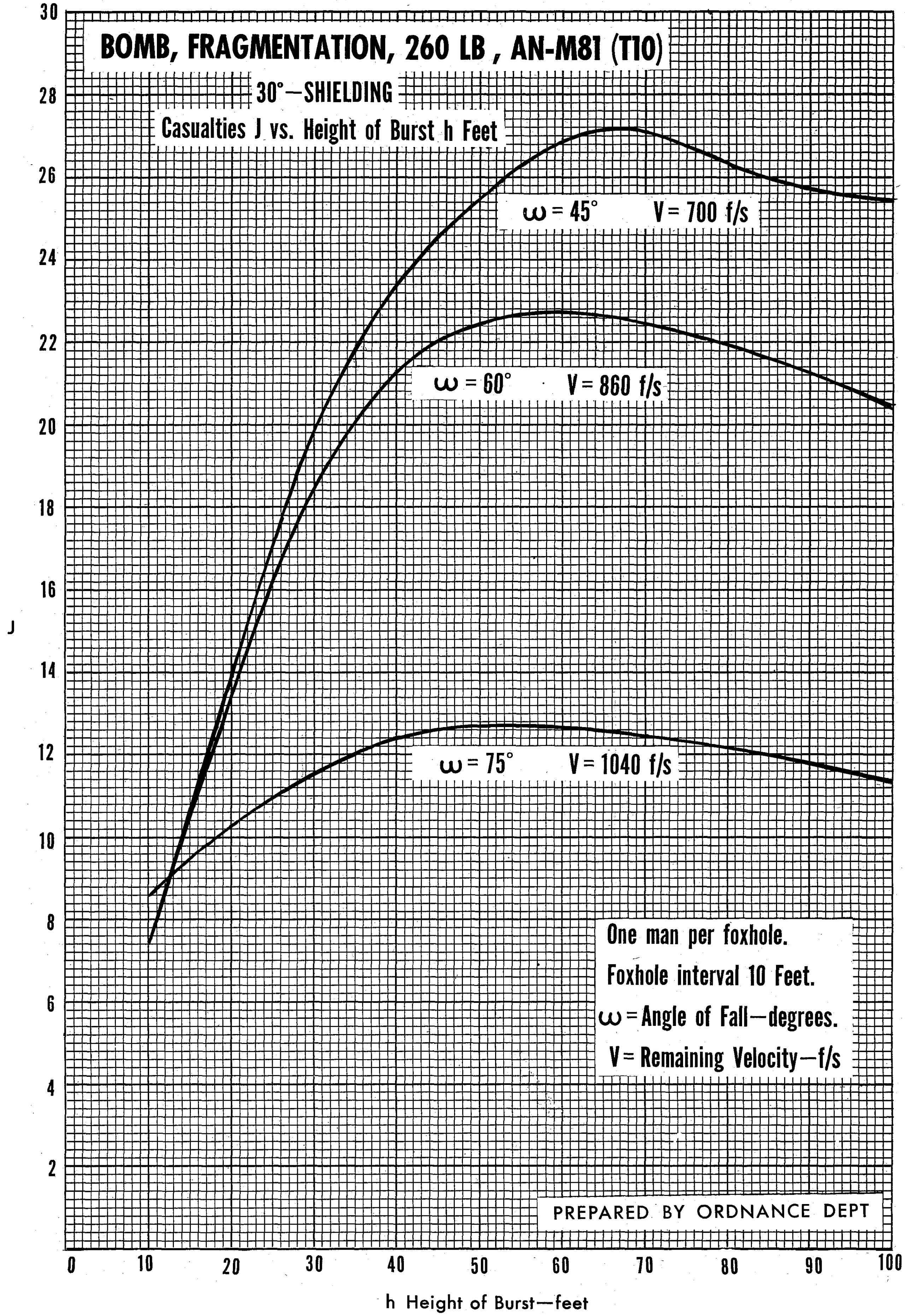
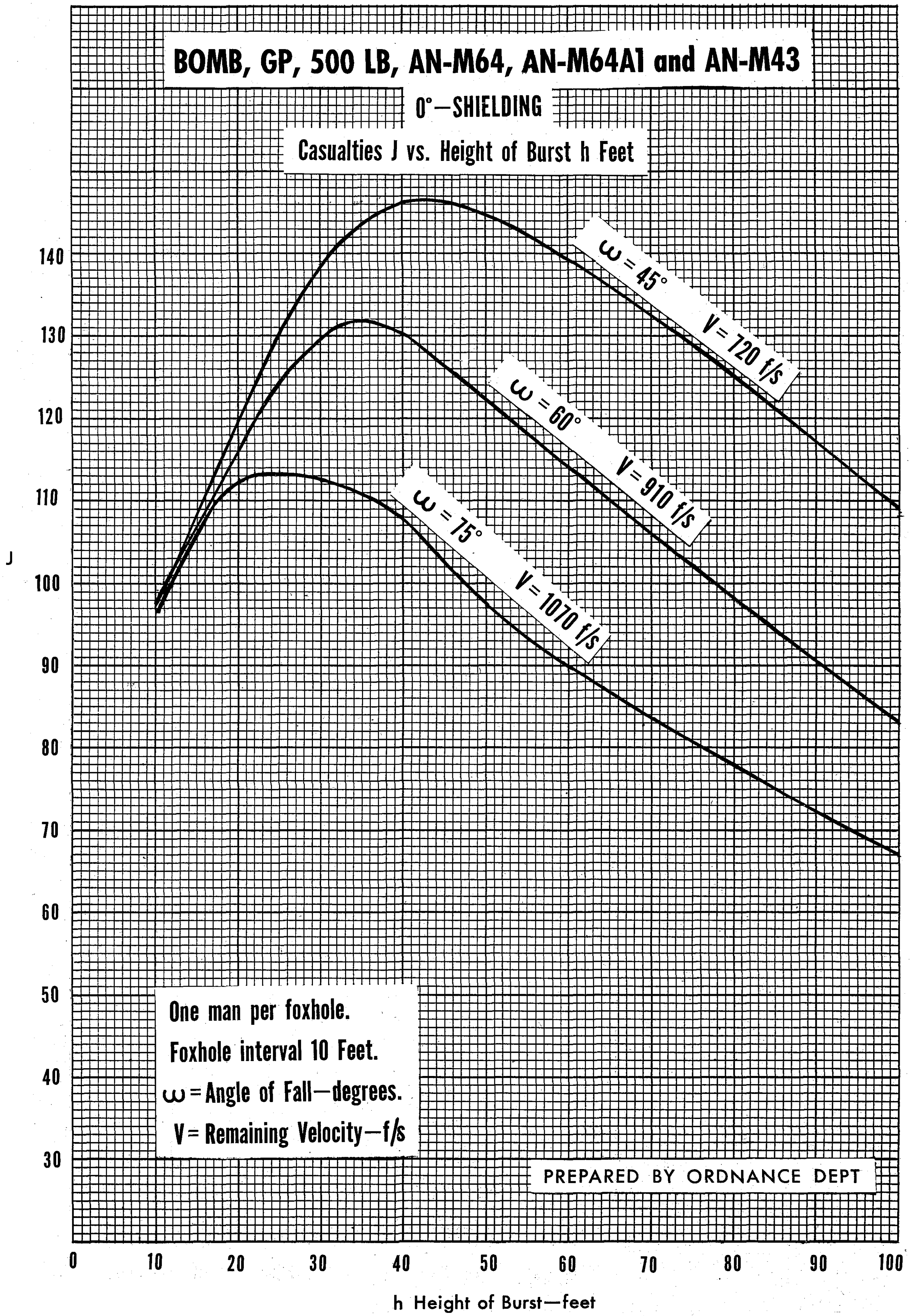

BOMB, FRAGMENTATION, 260 LB , AN-M81 (T10)
30°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 700 f/s
ω = 60° V = 860 f/s
ω = 75° V = 1040 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 8



BOMB, GP, 500 LB, AN-M64, AN-M64A1 and AN-M43
0°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 720 f/s
ω = 60° V = 910 f/s
ω = 75° V = 1070 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
140
130
120
110
100
90
80
70
60
50
40
30
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 9

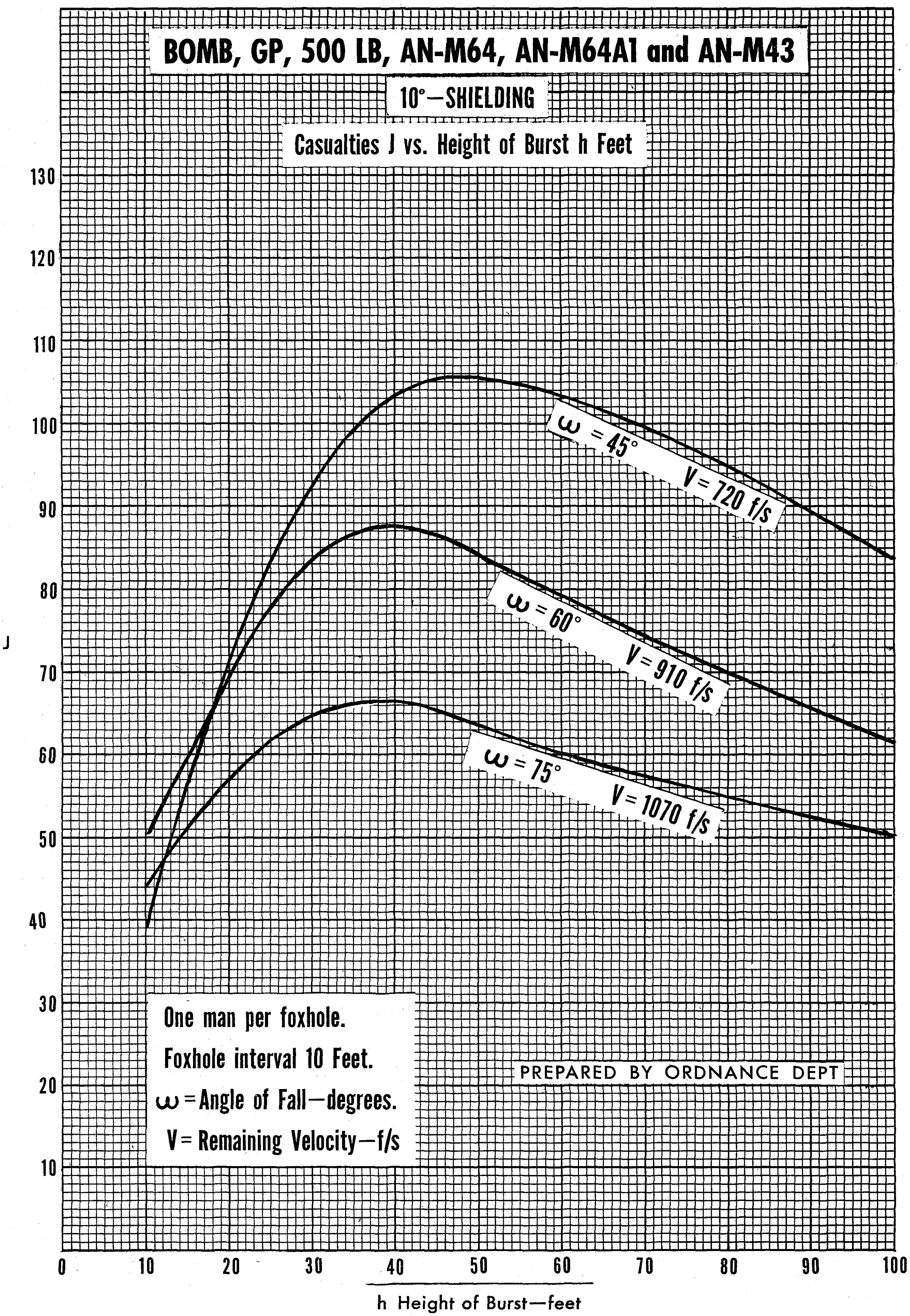

BOMB, GP, 500 LB, AN-M64, AN-M64A1 and AN-M43
10°—SHIELDING
Casualties J vs. Height of Burst h Feet
ω = 45° V = 720 f/s
ω = 60° V = 910 f/s
ω = 75° V = 1070 f/s
One man per foxhole.
Foxhole interval 10 Feet.
ω = Angle of Fall—degrees.
V = Remaining Velocity—f/s
PREPARED BY ORDNANCE DEPT
J
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
h Height of Burst—feet

FIGURE 10

Volume III Part 2
BOMBING OF CONCRETE

(THIS PART SUPERSEDES VOLUME I PART 2, BOMBING OF CONCRETE)

1. GENERAL.

The relatively large dispersion and low striking velocities of bombs prevent the bombing of strongly built concrete fortifications from being generally profitable. Large Armor Piercing (AP) Bombs dropped from considerable altitude are effective in perforating all but the thicker roofs of fortifications, but the general area effect of the many unavoidable misses is negligible. On the other hand, General Purpose (GP) bombs are effective for area bombing of defensive positions but generally ineffective against thick concrete because of bomb case rupture and low penetrative efficiency. Finally, Semi-Armor Piercing (SAP) bombs are specifically designed so as to have the largest possible charge consistent with sufficient structural strength to withstand impact stresses. Thus they ought to possess optimum characteristics against concrete; however, the accompanying data (Tables 23 and 24) show that the range of circumstances in which they are to be preferred to GP bombs is rather narrow.

To evaluate the effort required to hit a specific target the following table may be used: (The smaller numbers are based on good accuracy (15 mil); under operational conditions the larger numbers may be more realistic).

Altitude of plane (ft)		5,000	10,000	20,000	30,000
Number of bombs required to hit a 10 yd x 10 yd target with a probability of	50%	25-250	100-1,000	400- 4,000	1,000-10,000
	90%	80-800	350-3,500	1,300-13,000	3,500-35,000

2. DEFORMATION, RUPTURE AND LOW ORDER DETONATION.

General Purpose bombs with a delay fuze do not withstand impact on thick concrete slabs. Such an impact leads to deformation or breakage of the casing which is generally accompanied by a low order detonation of the explosive filling (Amatol, TNT or RDX Comp B). Breakage is also expected when a delay fuzed GP bomb strikes a strong fortification covered with a layer of earth that is somewhat thinner than the maximum earth penetration (see Vol. III, Part 3). However, when a GP bomb hits a sufficiently thin slab, the slab rather than the bomb is ruptured so that a perforation results without effective damage to the bomb. Estimates of the slab thicknesses that can be thus defeated are shown in Table 23.

Semi-Armor Piercing and Armor Piercing bombs withstand impact on strong concrete without damage that may impair their effective detonation. However, SAP bombs dropped from high altitude (over 15,000 feet) are known to deform appreciably and this may somewhat reduce their penetrative ability.

Hits against heavy concrete columns or beams result in damage impairing the effectiveness of GP but not of SAP or AP bombs.

3. EFFECTS OF DETONATION ON CONCRETE.

The destructive effect achieved by the detonation of AP or SAP bombs that have not succeeded in perforating a concrete slab is small to moderate. General Purpose bombs fitted with an instantaneous nose or, better, with a non-delay tail fuze achieve a substantial effect. The accompanying tabulations (Tables 23, 24 and 25) contain estimates of the total effect of impact and explosion of American bombs on concrete. Since specific data on the quantitative effects of detonation on concrete are scarce and fragmentary, extensive extrapolation was necessary in the preparation of the data.

4. CRATERING IN CONCRETE.

The shallow penetration of GP and SAP bombs that do not succeed in perforating concrete slabs results in wide cracking and spalling of the front face of the slab with formation of a crater. The size of this crater is quite variable. Estimates of the expected depth are shown in the accompanying tables. As a guide to the expected diameter of the crater one may assume that it will be about four times the depth.

When AP bombs succeed in penetrating deeper than 2 or 2½ feet, there is no further increase of the crater depth, but, rather, a bore hole of the diameter of the bomb is formed at the bottom of the crater.

5. BACK FACE EFFECTS—SCABBING.

A shock travels across a concrete slab ahead of a penetrating bomb or of the expanding gases that result from its detonation. As this shock is reflected from the back face of the slab, this face tends to crack with violent ejection of loose pieces of concrete and formation of a back crater. This phenomenon, called "scabbing," actually occurs when the bomb or its detonation products come sufficiently close to the back face and may do serious damage to personnel or light material behind the slab. Special forms of surface steel reinforcement are sometimes used to prevent scabbing. Estimates of the maximum thickness of slab which will be scabbed under various conditions are given in the accompanying tabulations.

Complete perforation is achieved when the front face crater and the scab crater merge. Thicker concrete can therefore be perforated than the depth of penetration in a very thick slab.

Heavily scabbed roofs will show considerable sag even when not blown through.

6. REBOUND.

A bomb that does not perforate a slab tends to rebound. It is not known how long it takes under various conditions for a bomb to penetrate and rebound the small amount necessary to render detonation ineffective against the slab. It seems probable that it will take longer than 0.025 second for a medium or large bomb to rebound this amount, but probably less than 0.1 second. It is practically certain that whenever a fuze delay in excess of 0.1 second is used, that the bomb will rebound sufficient to cause an ineffective detonation.

7. ATTACK ON A VERTICAL WALL.

Minimum altitude attack of vertical walls is generally impractical because of the necessity of using long delay fuzing for safety. Also the penetrating effect would be no better than that attained from 5,000 feet on horizontal roof slabs.

8. EFFECT OF DIRT COVERING UPON CONCRETE.

Dirt covering on the roof or wall of a concrete fortification may cushion the impact of the bomb so as to reduce its penetrating power. Data on the penetration of bombs in various soils are shown at pages 34 to 48 inclusive. A thickness of earth of 20 percent of the maximum underground trajectory of a bomb is expected to reduce its penetrating power in underlying concrete by less than 20 percent. Newly piled dirt is likely to cushion the impact of a bomb even less than wet clay.

9. EFFECT OF UNDERGROUND DETONATION.

The underground detonation of bombs is comparatively effective against the underground portion of concrete fortifications because of the confining effect of the earth. Figures 11 and 12 show what damage can be expected to result to an underground concrete slab by a given bomb detonating at a given distance. The difficulty with this method of attack is that the bomb must be made to detonate within a comparatively narrow region around the target, at a sufficient depth underground. In the case of GP bombs, if the concrete target is hit by the bomb before its velocity is very considerably reduced, rupture of the bomb and consequent failure to detonate effectively would be expected.

TABLE 23

EFFECT OF GENERAL PURPOSE BOMBS ON CONCRETE SLABS

		Fuzing	Bomb				
			100 lb	250 lb	500 lb	1,000 lb	2,000 lb
			AN-M30, AN-M30A1	AN-M57, AN-M57A1	AN-M43, AN-M64, AN-M64A1	AN-M44, AN-M65, AN-M65A1	AN-M34, AN-M66, AN-M66A1
Crater Depth (Ft)		Inst Nose	½	¾	1	1¼	1½
		Non-Delay Tail	1¼	1¾	2¼	2¾	3½
		Delay*	½	¾	1	1¼	1½
Limit Thickness** of slab (ft) that will be	Scabbed	Inst Nose	2¼	3	3¾	4¾	6
		Non-Delay Tail	3¼	4¼	5¼	6¾	8½
		Delay*	1½	2	2¾	3¼	4½
	Blown Through	Inst Nose	1½	1¾	2¼	3	3¾
		Non-Delay Tail	2¼	3	3¾	4¾	6
	Perforated	Delay	1	1¼	1¾	2¼	3

The performance presented in this table is achieved with dive bombing or with bombing from horizontal flight at 5,000 ft altitude. No better performance is expected by bombing from higher altitude due to breakage of the bomb.

*No effect of detonation is included in these data since the bomb is likely to break up prior to fuze operation and/or to detonate low order.

**The effect indicated will occur in all slabs of thickness up to the limit thickness indicated but not for thicker slabs.

TABLE 24

EFFECT OF SEMI-ARMOR PIERCING BOMBS ON CONCRETE SLABS

Bomb			Fuzing	Bombing from Horizontal Flight. True Air Speed 250 mph: 5,000 ft Altitude	10,000 ft Altitude	20,000 ft Altitude	Dive Bombing 60° Dive, 350 mph, 4,000 ft Altitude
500 lb AN-M58, AN-M58A1, AN-M58A2	Crater Depth (Ft)		Inst Nose	3/4			
			Non-Delay Tail	1 3/4	2 1/4	2 3/4	2 1/4
			Delay	1 3/4	2 1/4	3	2 1/4
	Limit Thickness** of Slab (ft) that will be	Scabbed	Inst Nose	3 1/4			
			Non-Delay Tail	4 1/2	5	5 1/2	4 3/4
			Delay	4 1/2	5	5 3/4	5
		Blown Through	Inst Nose	2			
			Non-Delay Tail	3 1/4	3 1/2	4 1/4	3 1/2
			Delay	3 1/4	3 3/4	4 1/2	3 1/2
		Perforated	Delay	2 1/4	3	3 1/2	2 3/4
1,000 lb AN-M59, AN-M59A1	Crater Depth (Ft)		Inst Nose	1			
			Non-Delay Tail	2 1/4	2 3/4	3 1/4	2 1/2
			Delay	2 1/2	3 1/4	4	3
	Limit Thickness** of Slab (ft) that will be	Scabbed	Inst Nose	4			
			Non-Delay Tail	5 3/4	6 1/4	6 3/4	6
			Delay	6	6 1/2	7 1/2	6 1/4
		Blown Through	Inst Nose	2 1/2			
			Non-Delay Tail	4	4 1/2	5	4 1/4
			Delay	4 1/4	5	6	4 3/4
		Perforated	Delay	3	4	5	3 3/4

These data have been computed for strong concrete, of compressive strength 5,000 lb/sq in; they should be increased by 5-15% for medium quality concrete of 3,000 lb/sq in.

It has been assumed that the bomb does not rebound prior to the time of fuze operation. Rebound may occur, however, with a fuze delay of 0.1 sec, in which case the effect of detonation is lost.

**The effect indicated will occur in all slabs of thickness up to the limit thickness indicated but not for thicker slabs.

TABLE 25

EFFECT OF ARMOR PIERCING BOMBS ON CONCRETE SLABS

Bomb			Bombing from Horizontal Flight True Air Speed 250 mph				Dive Bombing 60° Dive, True Air Speed, 350 mph, 4,000 ft Altitude
			5,000 ft Altitude	10,000 ft Altitude	20,000 ft Altitude	30,000 ft Altitude	
1,000 lb AN-Mk 33	Crater Depth (ft)		1½	2½	3¾	4½	2¼
	Limit Thickness** of slab (ft) that will be	Scabbed	4	5¼	7¼	8¼	5¼
		Blown thru	3	4¼	6	6¾	4
		Perforated	2¾	4	5¾	6½	3¾
1,600 lb AN-Mk 1	Crater Depth (ft)		1¾	3¼	5	6¼	2¾
	Limit Thickness** of slab (ft) that will be	Scabbed	5	6¾	9¼	11	6¼
		Blown thru	3¾	5½	7¾	9¼	5
		Perforated	3½	5¼	7½	9	4¾

These data have been computed for strong concrete, of compressive strength 5,000 lb/sq in; they should be increased by 15-30% for medium quality concrete of 3,000 lb/sq in.

It has been assumed that the bomb does not rebound prior to the time of fuze operation (0.08 sec nominal for the AN-MK 228 fuze). In case of rebound the crater depth and the limit thickness of slab scabbed and blown thru should be reduced by about ⅓ ft or ¼ ft.

**The effect indicated will occur in all slabs of thickness up to the limit thickness indicated but not for thicker slabs.

BOMB DAMAGE TO UNDERGROUND CONCRETE SLABS MAXIMUM THICKNESS OF SLAB DAMAGED VS. DISTANCE FROM BOMB BURST

GENERAL PURPOSE BOMBS

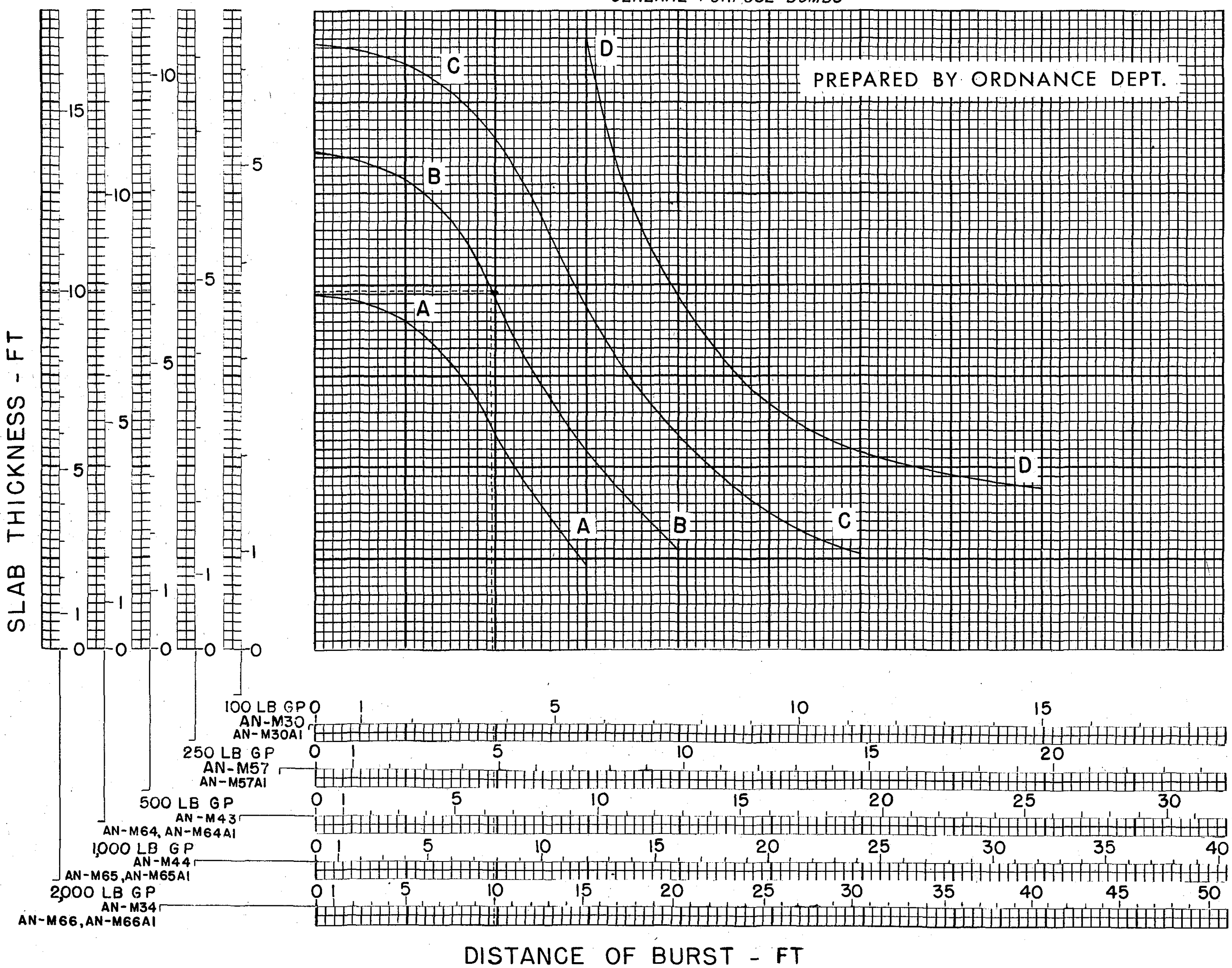


FIGURE 11

Curve A—Breaching of the slab.
Curve B—Heavy damage (Heavy cracks, heavy scabbing).
Curve C—Moderate damage (Medium cracks, slight scabbing).
Curve D—Slight damage (Fine cracks on back face of slab).

The bombs are assumed to detonate at the depth for which maximum crater diameter is obtained (see page 38). The effect is reduced by at least 30% if the depth is only 25% of the assumed depth.

Example—A 10 ft concrete wall will be heavily damaged by a 2,000 lb GP bomb detonating 10 ft away.

BOMB DAMAGE TO UNDERGROUND CONCRETE SLABS
MAXIMUM THICKNESS OF SLAB DAMAGED VS. DISTANCE FROM BOMB BURST
(SEMI-ARMOR PIERCING AND ARMOR PIERCING BOMBS)

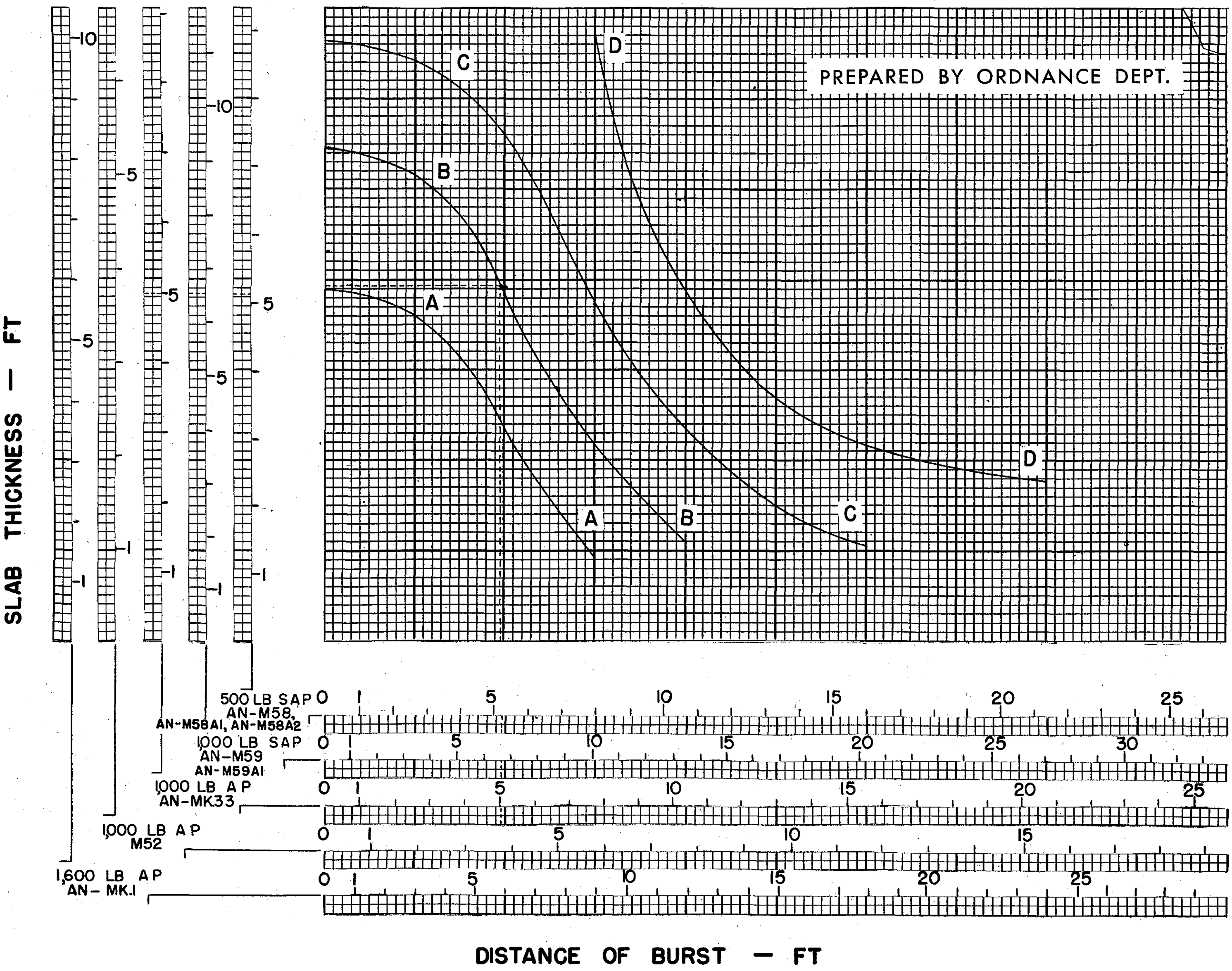


FIGURE 12

Curve A—Breaching of the slab.
Curve B—Heavy damage (Heavy cracks, heavy scabbing).
Curve C—Moderate damage (Medium cracks, slight scabbing).
Curve D—Slight damage (Fine cracks on back face of slab).

The bombs are assumed to detonate at the depth for which maximum crater diameter is obtained (see page 39). The effect is reduced by at least 30% if the depth is only 25% of the assumed depth.

EXAMPLE—A 5 ft concrete wall will be heavily damaged by a 1,000 lb AP (AN-Mk 33) bomb detonating 5 ft away.

Volume III Part 3

EARTH PENETRATION AND CRATER FORMATION BY BOMBS

(THIS PART SUPERSEDES VOLUME I PART 2, PAGES 54, 55, 56, 57, 58 AND 59)

1. GENERAL.

Information on the travel of bombs in earth, on the depths reached at definite fuze settings, and on the size and types of craters produced in different soils is presented in the following tables (26 to 29 inclusive). The underground trajectory may be of importance in considering the attack on fortifications. (See pages 26, 30 and 31.)

Accidental and irreproducible factors such as the type of earth, differences in the constitution of the earth at the point of impact, stones, etc., have a large influence on the behavior of penetrating bombs.

2. QUALITY OF THE SOIL.

Different soils may be arranged in a rough scale with respect to their resistance to bomb penetration and detonation. Dry sand, because it does not easily transmit and distribute the action of the bomb over a wide region, and because its successive layers have to be crushed with considerable waste of energy, is extremely high in resistance. Conversely, wet clay is extremely low in resistance. The water content tends to distribute the effects of bomb penetration and detonation over wide ranges, so that wet clay can more easily "give in" to a bomb without being crushed. In general, the greater the soil's water content and plasticity, the easier it is penetrated and the more readily can large craters be formed.

Data for three types of soil are given in the accompanying tables. These soils have been labeled as "soft", corresponding to a fairly wet clay; "medium", corresponding, for example to a sandy clay loam or to soft chalk; and "hard pan", corresponding to sand or gravel or mixtures thereof. Some degree of interpolation between these types of soils should be possible.

It appears that the maximum crater diameter does not depend on the quality of the soil to the same extent as does the depth of penetration.

3. SHAPE OF THE UNDERGROUND TRAJECTORIES.

The underground trajectories of bombs are generally J-shaped. A bomb travels straight as long as its yaw[1] remains small, but swerves after its instability (i.e., tendency to tumble) has resulted in a considerable yaw.

[1]Yaw is the deviation of the longitudinal axis of the bomb from the line of flight.

Swerving generally occurs in such a direction to bring the bomb nearer to the ground surface, but it is quite erratic. Bombs frequently swerve to the right or left of their initial trajectory, resulting in considerable lateral offset, sometimes even in a backwards direction with respect to the motion of the bombing plane.

It is reported that American bombs swerve to a considerably lesser extent than similar British or German bombs, that is, the J-shape of their path is less pronounced.

4. TIME OF OPERATION OF FUZES.

The times of operation of the instantaneous nose fuze (AN-M103) and any of the standard tail fuzes with a non-delay detonator have been estimated to be as follows:

Instantaneous Nose	0.0005 second
Non-Delay Tail	0.002 to 0.003 second (depending on size of the bomb)

The time limits for delay elements of the American tail fuzes, with Primer-Detonator M14, are set by acceptance tests as follows:

0.01 second nominal delay:	0.008 to 0.013 second
0.025 second nominal delay:	0.018 to 0.032 second
0.1 second nominal delay:	0.10 to 0.15 second

Variations within these limits may affect the depth of the burst and hence the crater size to a considerable extent.

5. VOLUME OF MATERIAL TO FILL CRATERS.

The amount of material that must be trucked in to refill a bomb crater affects considerably the amount of effort that must be spent in repairing it. This amount of material excludes, of course, the loose material that is already available in the bottom or on the lip of the crater. Also, this amount does not depend only on the apparent volume of the crater, but also on the amount of soil crushed, loosened or displaced in the crater bottom. Crude estimates of the volume of loose soil that must be trucked in for repair are shown in the accompanying tables. (Figures given are based on the assumption that all the available loose and trucked-in soil must be packed hard.) It is also estimated that the manpower requirement for repair may run at about 1½ man-hours per cubic yard of material needed.

6. BOMBING FROM MINIMUM ALTITUDE.

Bombs dropped on level or gently sloping soil from planes flying at minimum altitude, generally ricochet. Such bombs will penetrate steep embankments. If the releasing plane flies very fast, for example at nearly 400 miles per hour, and the embankment has a 45 degree inclination, the penetration path followed will not differ much from that of a bomb dropped from 5,000 feet on level ground. Less penetration will be achieved if the plane is slower or the embankment is not as steep.

7. EARTH SHOCK EFFECT OF UNDERGROUND DETONATION.

A violent shock is propagated earthquake-like through the earth around the point of a bomb explosion.

The demolition of buildings by earth shock is somewhat unpredictable, since it appears to depend, among other things, on whether the building can vibrate in step with the shock waves from the detonated bomb.

Demolition does not appear to extend to buildings at a distance from the point of burst greater than the maximum crater diameter produced by the bomb.

Damage to fixed gun emplacements by the bomb action tilting them effectively seems to be confined to a distance of about ¾ of the maximum crater diameter.

Damage to ceramic service pipes (of earthenware, brick or tile) seems to extend to pipes whose closest approach to the point of detonation is equal to or slightly greater than the maximum crater diameter. Damage to cast iron pipes is likely to occur up to distances from the point of burst of about 0.6 of the maximum crater diameter.

Any trench or duct tends to absorb a ground shock, even though its walls may be damaged. In particular, service pipes laid in ducts are effectively protected, unless included in the crater itself.

Adjacent structures or earthworks will shift the center of the crater off from the point of detonation. The presence of a trench relieves the earth pressure, so that craters will be directed towards that direction. On the contrary, craters are shifted away from embankments or strong structures that withstand the earth shock.

The effect or earth shock on the underground portions of fortifications is discussed at page 26.

8. UNDERFOOTING OF COLUMNS AND STANCHIONS.

Cratering action of bombs may be exploited to remove the ground support from columns or stanchions in industrial structures. It is estimated that this form of attack will be successful whenever the foot of a structural element falls within the crater limits.

Attack of structures by cratering seems to be particularly valuable against the strongest type of factory buildings, namely those with gantry cranes. These structures may be strong enough to withstand the removal of a single column. Consequently, bombs large enough to contain two columns in one crater are recommended.

9. ORIENTATION OF A DETONATING BOMB.

The orientation of a bomb detonating underground and the thickness of the bomb casing do not seem to have much influence on the resulting effects. Only the nature and amount of charge and the position of its center have to be considered.

TABLE 26
EARTH PENETRATION AND CRATER FORMATION

Bomb	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
	ALTITUDE OF RELEASE, 20,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
100 LB GP AN-M30A1, AN-M30	0.0005 (INST)	Soft	−0.17	−0.72	10.0	2.8	3.1	—	−1.7
		Medium	−0.17	−0.72	7.9	3.0	3.4	—	−1.9
		Hard	−0.17	−0.72	6.0	1.6	1.8	—	−2.4
	0.002 (NON-DELAY)	Soft	0.11	0.50	13	3.9	4.8	12	1.2
		Medium	0.11	0.48	11	3.4	3.9	4	1.3
		Hard	0.10	0.46	9.9	2.7	3.3	2	1.5
	0.01	Soft	1.5	6.1	22	6.9	12	46	14
		Medium	1.6	5.6	20	5.1	9.3	30	15
		Hard	1.4	5.1	16	2.6	8	15	17
	0.025	Soft	3.5	12.0	21	2.8	14	24	28
		Medium	3.6	9.6	19	3.0	14	18	25
		Hard	2.9	6.8	16	3.0	10	14	23
	0.10	Soft	4.9	14.0	16	1.3	19	18	32
		Medium	3.8	9.6	19	3.0	14	18	25
		Hard	2.9	6.8	16	3.0	9.9	14	23
250 LB GP AN-M57A1, AN-M57	0.0005 (INST)	Soft	−0.25	−1.0	13	4	3.5	—	−1.8
		Medium	−0.25	−1.0	11	3	3.2	—	−2.0
		Hard	−0.24	− .97	8	2.4	2.2	—	−2.4
	0.0023 (NON-DELAY)	Soft	0.15	0.59	17	5.7	5.1	19	1.0
		Medium	0.14	0.58	15	4.5	4.0	13	1.2
		Hard	0.14	0.55	12	4.1	3.5	10	1.4
	0.01	Soft	1.7	6.7	29	7.8	12	100	12
		Medium	1.6	6.3	25	6.9	11	66	13
		Hard	1.5	6.0	21	5.4	10	35	15
	0.025	Soft	3.8	15	28	4.3	21	60	26
		Medium	4.2	13	25	3.7	18	40	26
		Hard	4.1	9.1	21	2.3	13	33	23
	0.10	Soft	7.1	19	20	1.1	25	40	33
		Medium	5.4	14	24	3.2	19	37	27
		Hard	4.1	9.1	21	2.3	13	32	23
500 LB GP AN-M64A1, AN-M64, AN-M43	0.0005 (INST)	Soft	−0.38	−1.3	16	4.4	5.1	—	−1.8
		Medium	−0.38	−1.3	14	3.2	4.2	—	−2.0
		Hard	−0.38	−1.3	10	2.6	3.1	—	−2.6
	0.0025 (NON-DELAY)	Soft	0.14	0.50	24	9.3	10	48	0.68
		Medium	0.14	0.49	19	5.4	6.4	33	0.76
		Hard	0.13	0.46	15	4.5	5.1	19	0.90
	0.01	Soft	2.0	6.9	35	9.8	14	200	9.4
		Medium	1.9	6.6	31	8.6	12	140	10.0
		Hard	1.8	6.2	26	7.1	11	72	12.0
	0.025	Soft	4.9	17	38	7.0	24	200	23
		Medium	4.8	15	33	6.1	21	120	24
		Hard	5.1	12	26	4.6	17	61	24
	0.10	Soft	10.3	25	22	3.5	33	81	35.0
		Medium	7.7	18	30	3.8	25	100	28.0
		Hard	5.8	13	26	4.3	18	48	25.0

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be *interpolated*.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 20,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB GP AN-M65A1, AN-M65, AN-M44	0.0005 (INST)	Soft	−0.46	−1.6	20	5.8	6.4	—	−1.7
		Medium	−0.46	−1.6	18	4.9	5.7	—	−2.0
		Hard	−0.46	−1.6	11	3.6	3.9	—	−2.5
	0.0027 (NON-DELAY)	Soft	0.14	0.49	27	7.9	8.8	100	0.53
		Medium	0.14	0.48	24	6.9	8.1	64	0.59
		Hard	0.13	0.46	19	6.5	5.5	34	0.71
	0.01	Soft	2.0	7.0	42	12	16	360	7.5
		Medium	1.9	6.7	37	10	15	250	8.3
		Hard	1.8	6.3	31	8.8	12	140	9.7
	0.025	Soft	5.1	18	50	11	27	450	19
		Medium	4.3	15	43	10	23	300	18
		Hard	5.2	13	35	7.7	19	150	20
	0.10	Soft	11.2	28	40	4.2	42	200	30
		Medium	8.4	20	42	6.9	28	220	24
		Hard	6.3	14	35	7.1	20	150	21
2,000 LB GP AN-M66A1, AN-M66, AN-M34	0.0005 (INST)	Soft	−0.63	−2.2	26	7.2	8.2	—	−2.0
		Medium	−0.63	−2.2	21	6.3	6.9	—	−2.2
		Hard	−0.63	−2.2	16	4.1	4.9	—	−2.7
	0.0030 (NON-DELAY)	Soft	0.066	0.23	32	9.4	10	160	0.19
		Medium	0.062	0.22	29	8.2	9.3	100	0.22
		Hard	0.054	0.19	22	6.5	7.4	55	0.23
	0.01	Soft	1.9	6.6	48	13	18	600	5.6
		Medium	1.8	6.4	43	13	16	420	6.3
		Hard	1.8	6.2	37	11	14	240	7.6
	0.025	Soft	5.3	18	61	15	30	900	16
		Medium	4.9	17	54	13	28	600	18
		Hard	4.9	15	44	9.8	23	300	19
	0.10	Soft	15.0	38	42	15	51	350	33
		Medium	12.0	27	50	17	38	320	27
		Hard	8.7	19	47	8	27	290	23

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

	ALTITUDE OF RELEASE, 10,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT								
					CRATER MEASUREMENTS AND TYPE				
Bomb	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
100 LB GP AN-M30A1, AN-M30	0.0005 (INST)	Soft	−0.29	−0.76	9.6	2.7	3.0	—	−1.7
		Medium	−0.29	−0.76	8.2	2.3	2.5	—	−2.0
		Hard	−0.29	−0.76	6.0	2.0	1.8	—	−2.5
	0.002 (NON-DELAY)	Soft	0.087	0.23	12	3.7	4.1	9.0	.53
		Medium	0.076	0.20	11	3.2	3.6	6.0	.53
		Hard	0.070	0.18	8.7	2.6	2.8	3.0	.60
	0.01	Soft	1.8	4.7	21	6.4	9.6	43	11.0
		Medium	1.7	4.4	20	5.2	7.9	29	12.0
		Hard	1.6	3.9	15	4.1	6.8	15	13.0
	0.025	Soft	4.4	9.9	23	2.3	14	42	23.0
		Medium	3.8	7.3	21	4.5	11	30	19.0
		Hard	3.2	5.1	16	3.9	8.1	15	17.0
	0.10	Soft	5.8	11	22	3.7	15	30	25.0
		Medium	4.3	7.6	20	4.3	12	30	20.0
		Hard	3.2	5.1	16	3.9	8.1	15	17.0
250 LB GP AN-M57A1, AN-M57	0.0005 (INST)	Soft	−0.41	−1.0	12	3.5	4.0	—	−1.8
		Medium	−0.41	−1.0	11	3.0	3.4	—	−2.0
		Hard	−0.41	−1.0	8.0	2.2	2.4	—	−2.5
	0.0023 (NON-DELAY)	Soft	0.087	0.22	16	4.7	5.3	20	0.38
		Medium	0.074	0.18	14	4.0	4.5	13	0.36
		Hard	0.075	0.18	11	3.2	3.6	7	0.45
	0.01	Soft	2.0	5.0	27	5.9	10	91	8.7
		Medium	1.9	4.7	24	6.6	9.4	61	9.4
		Hard	1.8	4.4	20	5.5	8.2	33	11.0
	0.025	Soft	4.8	12	31	6.3	17	100	21.0
		Medium	4.9	9.6	26	6.0	14	68	19.0
		Hard	4.2	6.8	21	5.2	11	35	17.0
	0.01	Soft	8.1	15	29	4.3	20	65	26
		Medium	6.1	10	27	5.4	15	68	21
		Hard	4.6	7	21	5.0	11	35	18
500 LB GP AN-M64A1, AN-M64, AN-M43	0.0005 (INST)	Soft	−0.58	−1.4	16	4.4	5.1	—	−1.90
		Medium	−0.58	−1.4	14	3.8	5.0	—	−2.20
		Hard	−0.58	−1.4	9.7	2.8	3.1	—	−2.70
	0.0025 (NON-DELAY)	Soft	0.038	0.089	20	6.0	6.7	40	0.12
		Medium	0.024	0.057	18	5.1	5.8	26	0.089
		Hard	0.016	0.039	14	4.0	4.6	13	0.076
	0.01	Soft	2.1	5.0	33	9.2	12.0	170	6.8
		Medium	2.0	4.8	29	8.3	11.0	118	7.5
		Hard	1.9	4.5	24	6.6	8.7	64	8.8
	0.025	Soft	5.5	13.0	39	9.2	20	220	18.0
		Medium	5.2	11.4	34	8.1	18	150	18.0
		Hard	5.4	8.8	27	6.6	14	74	17.0
	0.10	Soft	11.0	19.4	36	5.0	27	130	26
		Medium	8.2	13.6	34	6.9	20	140	21
		Hard	6.1	9.2	27	6.4	19	74	18

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

	ALTITUDE OF RELEASE, 10,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT								
					CRATER MEASUREMENTS AND TYPE				
Bomb	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB GP AN-M65A1, AN-M65, AN-M44	0.0005 (INST)	Soft	−0.69	−1.6	21	6.5	5.7	—	−1.7
		Medium	−0.69	−1.6	18	6.3	5.5	—	−2.0
		Hard	−0.69	−1.6	13	3.9	3.6	—	−2.5
	0.0027 (NON-DELAY)	Soft	−0.0042	−0.010	25	8.4	7.4	—	−0.011
		Medium	−0.0105	−0.0248	10	7.3	6.5	—	−0.031
		Hard	−0.0187	−0.0442	18	5.2	5.8	—	−0.068
	0.01	Soft	2.2	5.2	38	11	14	300	5.6
		Medium	2.1	5.0	34	9.9	13	210	6.2
		Hard	2.0	4.7	29	8.4	11	120	7.2
	0.025	Soft	5.6	13.2	49	13	22	450	14.0
		Medium	5.2	11.8	42	11	19	300	15.0
		Hard	5.4	9.3	34	8.8	16	150	14.0
	0.10	Soft	11.9	20.9	49	9.3	30	420	22
		Medium	8.8	14.6	43	10	23	300	18
		Hard	6.6	9.9	34	8.8	16	150	15
2,000 LB GP AN-M66A1, AN-M66, AN-M34	0.0005 (INST)	Soft	−0.97	−2.2	26	7.6	8.4	—	−1.9
		Medium	−0.97	−2.2	21	6.6	6.0	—	−2.2
		Hard	−0.97	−2.2	16	4.5	4.8	—	−2.7
	0.0030 (NON-DELAY)	Soft	−0.15	0.33	22	7.0	5.8	—	−2.8
		Medium	−0.15	0.34	17	4.8	5.1	—	−3.3
		Hard	−0.16	0.36	11	2.8	2.8	—	−4.4
	0.01	Soft	2.0	4.6	44	13	15	460	3.9
		Medium	2.0	4.4	39	12	14	300	4.3
		Hard	1.9	4.2	33	9.8	12	190	5.1
	0.025	Soft	6.1	14	58	16	25	850	12
		Medium	5.7	13	52	14	22	560	13
		Hard	5.0	10	41	11	18	300	13
	0.10	Soft	17	28	61	9.9	40	620	24
		Medium	12	20	55	12.0	30	580	20
		Hard	9.3	14	43	11.0	22	300	17

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
	ALTITUDE OF RELEASE, 5,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
100 LB GP AN-M30A1, AN-M30	0.0005 (INST)	Soft	−0.45	−0.76	9.6	2.7	3.0	—	−1.7
		Medium	−0.45	−0.76	8.2	2.3	2.5	—	−2.0
		Hard	−0.45	−0.76	6.0	1.6	1.8	—	−2.5
	0.002 (NON-DELAY)	Soft	−0.021	−0.035	12	3.5	3.9	—	−0.08
		Medium	−0.029	−0.048	10	3.0	3.3	—	−0.13
		Hard	−0.036	−0.060	8.1	2.4	2.7	—	−0.20
	0.01	Soft	2.0	3.3	20	5.6	7.4	37	7.6
		Medium	1.8	3.1	17	4.9	6.6	25	8.2
		Hard	1.8	2.6	15	4.1	6.8	15	13.0
	0.025	Soft	4.9	7.0	23	5.6	11	46	16
		Medium	4.5	5.2	20	5.2	8.9	30	14
		Hard	3.5	3.5	15	4.2	6.3	14	12
	0.10	Soft	6.2	7.6	24	5.5	12	46	18
		Medium	4.6	5.2	20	5.2	8.9	30	14
		Hard	3.5	3.5	15	4.2	6.3	14	12
250 LB GP AN-M57A1, AN-M57	0.0005 (INST)	Soft	−0.62	−0.99	12	3.5	4.0	—	−1.7
		Medium	−0.62	−0.99	11	3.0	3.4	—	−2.0
		Hard	−0.62	−0.99	8.0	2.2	2.4	—	−2.5
	0.0023 (NON-DELAY)	Soft	−0.049	−0.079	15	4.5	5.1	—	−0.14
		Medium	−0.055	−0.088	13	3.8	4.3	—	−0.17
		Hard	−0.063	−0.012	11	3.2	3.6	—	−0.25
	0.01	Soft	2.2	3.4	24	6.9	8.6	71	5.9
		Medium	2.0	3.3	21	6.2	7.9	51	6.6
		Hard	1.9	3.0	18	5.2	7.2	28	7.5
	0.025	Soft	5.2	8.5	30	7.7	14	100	15
		Medium	5.3	6.7	25	6.8	11	67	14
		Hard	4.7	4.7	20	5.4	8.3	34	12
	0.10	Soft	8.6	10	30	7.2	16	100	18
		Medium	6.5	7.1	26	6.7	12	68	14
		Hard	4.8	4.8	20	5.5	8.8	32	12
500 LB GP AN-M64A1, AN-M64, AN-M43	0.005 (INST)	Soft	−0.83	−1.3	16	3.7	4.4	—	−1.8
		Medium	−0.83	−1.3	14	4.2	3.2	—	−2.0
		Hard	−0.83	−1.3	10	3.1	2.6	—	−2.6
	0.0025 (NON-DELAY)	Soft	−0.18	−0.29	20	6.0	6.7	—	−0.39
		Medium	−0.18	−0.30	17	4.8	5.4	—	−0.47
		Hard	−0.20	−0.31	13	3.6	4.1	—	−0.60
	0.01	Soft	2.1	3.3	28	8.4	10	130	4.5
		Medium	2.0	3.2	26	7.6	12	92	5.0
		Hard	1.8	2.9	21	6.1	7.6	50	5.7
	0.025	Soft	5.7	9.1	37	10	16	220	12
		Medium	5.1	8.2	33	8.9	14	150	12
		Hard	5.7	6.0	26	7.0	11	71	12
	0.10	Soft	11.2	13.5	39	8.9	21	220	18
		Medium	8.3	9.3	34	8.6	15	150	14
		Hard	6.1	6.2	26	7.1	11	72	12

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

	ALTITUDE OF RELEASE, 5,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT								
					CRATER MEASUREMENTS AND TYPE				
Bomb	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB GP AN-M65A1, AN-M65, AN-M44	0.0005 (INST)	Soft	−1.0	−1.6	21	6.5	5.7	—	−1.7
		Medium	−1.0	−1.6	18	6.3	5.5	—	−2.0
		Hard	−1.0	−1.6	13	3.9	3.6	—	−2.5
	0.0027 (NON-DELAY)	Soft	−0.25	−0.40	24	7.0	7.9	—	−0.43
		Medium	−0.26	−0.41	21	6.0	6.9	—	−0.51
		Hard	−0.26	−0.42	16	4.9	5.5	—	−0.65
	0.01	Soft	2.0	3.2	34	10	12	230	3.4
		Medium	1.9	3.0	30	8.9	10	150	3.7
		Hard	1.9	2.8	25	7.2	8.8	85	4.3
	0.025	Soft	5.8	9.2	45	13	18	400	9.9
		Medium	5.6	8.4	40	11	16	280	10.0
		Hard	5.4	6.2	32	8.8	12	140	9.5
	0.10	Soft	12.0	14.5	48	13	23	450	16
		Medium	8.9	10.0	41	11	18	300	12
		Hard	6.6	6.6	32	8.8	13	140	10
2,000 LB GP AN-M66A1, AN-M66, AN-M34	0.0005 (INST)	Soft	−1.3	−2.1	26	7.6	8.4	—	−1.8
		Medium	−1.3	−2.1	21	6.6	6.0	—	−2.1
		Hard	−1.3	−2.1	16	4.5	4.8	—	−2.6
	0.0030 (NON-DELAY)	Soft	−0.46	−0.74	29	9.9	8.8	—	−0.63
		Medium	−0.47	−0.75	25	7.4	8.2	—	−0.73
		Hard	−0.49	−0.78	20	5.7	6.5	—	−0.96
	0.01	Soft	1.8	2.8	40	12	12	350	2.4
		Medium	1.7	2.7	35	10	12	230	2.6
		Hard	1.6	2.6	29	8.6	10	140	3.2
	0.025	Soft	6.0	9.5	53	15	20	740	8.1
		Medium	5.5	8.8	47	13	17	500	8.6
		Hard	5.5	5.5	34	10	13	300	6.7
	0.10	Soft	17	20	62	15	32	900	17
		Medium	12	14	52	14	24	570	14
		Hard	9.1	9.2	40	11	17	290	13

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
		ALTITUDE OF RELEASE, 4,000 Ft—AIRSPEED, 350 mph—60° DIVE			CRATER MEASUREMENTS AND TYPE				
100 LB GP AN-M30A1, AN-M30	0.0005 (INST)	Soft	−0.29	−0.79	10	2.7	3.0	—	−1.8
		Medium	−0.29	−0.79	7.9	2.3	2.6	—	−2.1
		Hard	−0.29	−0.80	5.7	1.6	1.8	—	−2.7
	0.002 (NON-DELAY)	Soft	0.03	0.09	12	3.5	4.0	8.2	0.21
		Medium	0.03	0.08	10	3.0	3.4	5.4	0.21
		Hard	0.02	0.07	8	2.4	2.7	2.7	0.23
	0.01	Soft	1.6	4.5	21	5.9	8.7	42	10
		Medium	1.4	4.0	18	5.1	7.6	28	11
		Hard	1.5	3.5	15	4.2	6.3	14	12
	0.025	Soft	3.8	9.0	23	4.8	13	46	21
		Medium	3.8	6.8	20	4.6	11	30	18
		Hard	3.0	4.7	16	4.0	7.6	15	16
	0.10	Soft	5.2	10	23	4.2	14	41	23
		Medium	3.9	6.9	20	4.6	11	30	18
		Hard	3.0	4.7	16	4.0	7.6	15	16
250 LB GP AN-M57A1, AN-M57	0.0005 (INST)	Soft	−0.29	−0.78	13	3.9	4.3	—	1.4
		Medium	−0.29	−0.78	11	3.7	3.1	—	1.6
		Hard	−0.29	−0.78	8.6	2.4	2.7	—	2.0
	0.0023 (NON-DELAY)	Soft	0.12	0.32	16	4.9	5.4	22	0.56
		Medium	0.12	0.31	14	4.2	4.8	15	0.62
		Hard	0.11	0.30	12	3.4	3.8	8.5	0.75
	0.01	Soft	1.7	4.6	26	7.4	10	86	8.0
		Medium	1.6	4.3	23	6.4	8.9	59	8.7
		Hard	1.6	3.9	19	5.4	7.6	32	9.8
	0.025	Soft	4.1	11	30	7.0	16	105	18
		Medium	4.3	8.6	26	6.4	13	69	17
		Hard	4.0	6.2	21	5.3	10	35	16
	0.10	Soft	7.0	13	30	5.5	19	98	23
		Medium	5.3	9.2	26	6.0	14	68	18
		Hard	4.0	6.2	21	5.3	10	35	16
500 LB GP AN-M64A1, AN-M64, AN-M43	0.0005 (INST)	Soft	−0.55	−1.4	16	4.6	4.9	—	−1.9
		Medium	−0.55	−1.4	13	4.4	3.8	—	−2.2
		Hard	−0.55	−1.4	9.9	3.1	2.8	—	−2.7
	0.0025 (NON-DELAY)	Soft	−0.07	−0.18	20	5.1	5.8	—	−0.24
		Medium	−0.07	−0.19	17	4.7	5.4	—	−0.30
		Hard	−0.08	−0.20	13	4.5	3.8	—	−0.39
	0.01	Soft	1.6	4.2	30	8.1	11	150	5.7
		Medium	1.5	4.0	27	7.8	9.9	100	6.2
		Hard	1.4	3.7	22	6.6	8.4	58	7.2
	0.025	Soft	4.3	11	38	9.9	18	220	15
		Medium	4.2	9.8	33	8.6	16	150	15
		Hard	4.8	7.9	27	6.9	13	74	16
	0.10	Soft	9.1	17	39	7.0	24	200	23
		Medium	6.9	12	34	7.7	18	150	18
		Hard	5.2	8	27	6.9	13	74	16

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 26 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 4,000 Ft—AIRSPEED, 350 mph—60° DIVE				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB GP AN-M65A1, AN-M65, AN-M44	0.0005 (INST)	Soft	−0.65	−1.7	20	5.8	6.5	—	−1.8
		Medium	−0.65	−1.7	17	4.8	5.6	—	−2.1
		Hard	−0.65	−1.7	13	3.5	4.0	—	−2.6
	0.0027 (NON-DELAY)	Soft	−0.11	−0.29	25	6.4	7.2	88	0.31
		Medium	−0.12	−0.31	21	6.1	6.9	58	0.38
		Hard	−0.12	−0.32	23	11.0	12.0	32	0.49
	0.01	Soft	1.5	4.0	35	10	13	250	4.3
		Medium	1.5	3.8	32	9.3	11	170	4.7
		Hard	1.4	3.6	27	7.8	9.8	100	5.5
	0.025	Soft	4.3	13.2	48	13	22	450	14
		Medium	4.1	10	40	11	18	290	12
		Hard	4.4	8.0	33	9.0	14	150	12
	0.10	Soft	9.8	18	52	11	27	450	20
		Medium	7.4	13	42	11	21	300	16
		Hard	5.5	8.6	33	9	15	150	13
2,000 LB GP AN-M66A1, AN-M66, AN-M34	0.0005 (INST)	Soft	−0.83	−2.3	26	7.2	8.2	—	−2.0
		Medium	−0.84	−2.3	21	6.0	6.6	—	−2.2
		Hard	−0.84	−2.3	16	4.5	4.9	—	−2.8
	0.0030 (NON-DELAY)	Soft	−0.25	−0.68	29	8.8	9.9	—	−0.58
		Medium	−0.25	−0.69	26	7.3	8.2	—	−0.68
		Hard	−0.26	−0.71	20	5.9	6.7	—	−0.87
	0.01	Soft	1.3	3.6	41	12	15	400	3.1
		Medium	1.3	3.5	37	11	13	270	3.4
		Hard	1.2	3.3	31	9	11	160	4.0
	0.025	Soft	4.2	12	56	16	22	800	9.8
		Medium	3.9	11	50	14	20	540	10
		Hard	4.1	9.3	40	11	17	290	11
	0.10	Soft	13	25	63	12	37	880	21
		Medium	9.7	17	54	13	28	580	17
		Hard	7.3	12	42	11	20	300	14

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 27
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 20,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT								
					CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
500 LB SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (INST)	Soft	−0.38	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.38	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.38	−1.4	7.3	1.9	1.8	—	−3.3
	0.0027 (NON-DELAY)	Soft	0.18	0.65	17	4.9	4.3	44	1.0
		Medium	0.17	0.64	15	4.9	4.4	25	1.2
		Hard	0.16	0.61	12	4.0	3.5	14	1.4
	0.01	Soft	1.9	7.0	31	8.5	13	120	11
		Medium	1.8	6.8	27	7.4	12	83	13
		Hard	1.7	6.5	22	5.8	11	44	15
	0.025	Soft	4.8	18.0	28	3.2	24	60	29
		Medium	4.4	16	22	2.1	22	37	31
		Hard	4.9	14	16	1.3	18	18	32
	0.10	Soft	12	31	—	—	39	30	51
		Medium	9	22	4.8	—	28	20	41
		Hard	6.8	15	12.0	—	19	16	35
1,000 LB SAP AN-M59A1, AN-M59	0.0005 (INST)	Soft	−0.51	−1.8	19	4.6	5.0	—	−2.3
		Medium	−0.51	−1.8	13	3.0	3.4	—	−2.7
		Hard	−0.51	−1.8	9.2	2.4	2.9	—	−3.3
	0.0030 (NON-DELAY)	Soft	0.20	0.68	22	6.7	7.4	60	0.88
		Medium	0.19	0.66	20	6.6	5.9	43	0.98
		Hard	0.18	0.63	16	4.9	5.4	24	1.20
	0.01	Soft	2.1	7.2	37	10	14	230	9.3
		Medium	2.0	7.0	33	9.1	14	160	10
		Hard	1.9	6.7	27	7.4	12	85	12
	0.025	Soft	5.5	19	40	6.6	27	170	25
		Medium	5.1	18	32	5.1	25	97	26
		Hard	4.2	14	26	4.0	20	50	26
	0.10	Soft	15	38	—	—	48	60	50
		Medium	12	27	7.7	—	35	40	40
		Hard	8.6	19	16.7	5.9	24	32	34

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 27 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 10,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
500 LB SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (INST)	Soft	−0.58	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.58	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.58	−1.4	7.3	1.9	1.8	—	−3.3
	0.0027 (NON-DELAY)	Soft	−0.067	−0.16	16	4.8	5.4	—	−0.26
		Medium	−0.060	−0.15	15	4.4	4.9	—	−0.28
		Hard	−0.053	−0.13	12	4.0	3.5	—	−0.30
	0.01	Soft	2.1	5.1	28	8.0	11	110	8.3
		Medium	2.0	5.0	25	7.1	9.9	77	9.3
		Hard	1.9	4.7	21	5.9	8.8	42	11.0
	0.025	Soft	5.5	14	33	6.2	20	123	22
		Medium	5.1	12	28	5.1	18	75	23
		Hard	5.8	10	22	3.6	35	35	24
	0.10	Soft	13	24	10	—	31	—	38
		Medium	9.7	16	22	2.1	22	—	31
		Hard	7.4	11	21	3.2	16	25	26
1,000 LB SAP AN-M59A1, AN-M59	0.0005 (INST)	Soft	−0.58	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.58	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.58	−1.4	7.3	1.9	1.8	—	−3.3
	0.0030 (NON-DELAY)	Soft	−0.067	−0.16	16	4.8	5.4	—	−0.26
		Medium	−0.060	−0.15	15	4.4	4.9	—	−0.28
		Hard	−0.053	−0.13	12	4.0	3.5	—	−0.30
	0.01	Soft	2.1	5.0	33	9.6	12	190	6.4
		Medium	2.0	4.8	30	8.6	11	170	7.1
		Hard	2.0	4.6	25	7.0	9.7	76	8.5
	0.025	Soft	6.0	14	41	9.4	22	260	18
		Medium	5.6	13	36	8.1	20	170	19
		Hard	5.6	11	29	5.9	17	88	21
	0.10	Soft	16	28	18	—	37	80	37
		Medium	12	20	30	3.4	27	78	30
		Hard	8.9	14	28	4.3	19	55	25

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 27 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 5,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
500 LB SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (INST)	Soft	−0.87	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.87	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.87	−1.4	7.3	1.9	1.8	—	−3.3
	0.0027 (NON-DELAY)	Soft	−0.14	−0.22	16	4.7	5.2	—	−0.38
		Medium	−0.17	−0.26	13	4.5	5.0	—	−0.48
		Hard	−0.18	−0.29	11	3.2	3.5	—	−0.67
	0.01	Soft	2.1	3.4	25	7.4	9.2	86	5.5
		Medium	1.7	2.8	21	6.4	7.8	54	5.2
		Hard	1.5	2.4	18	4.8	6.0	28	5.6
	0.025	Soft	6.0	9.6	32	8.1	15	130	16
		Medium	5.6	8.8	28	7.0	14	84	16
		Hard	5.7	6.9	23	5.5	11	45	16
	0.10	Soft	14	16	30	4.3	23	72	27
		Medium	10	11	29	5.9	17	86	21
		Hard	7.5	7.6	23	5.5	12	45	18
1,000 LB SAP AN-M59A1, AN-M59	0.0005 (INST)	Soft	−0.87	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.87	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.87	−1.4	7.3	1.9	1.8	—	−3.3
	0.0030 (NON-DELAY)	Soft	−0.14	−0.22	16	4.7	5.2	—	−0.38
		Medium	−0.17	−0.26	13	4.5	5.0	—	−0.48
		Hard	−0.18	−0.29	11	3.2	3.5	—	−0.67
	0.01	Soft	2.0	3.2	29	8.7	10	140	4.1
		Medium	1.9	3.1	26	7.8	9.4	98	4.6
		Hard	1.9	3.0	22	6.4	8.1	58	5.6
	0.025	Soft	6.1	9.8	39	11	17	250	13
		Medium	5.7	12	36	8.4	19	170	18
		Hard	4.3	6.5	28	7.4	12	85	12
	0.10	Soft	16	19	40	6.2	28	160	25
		Medium	12	14	36	7.7	20	170	20
		Hard	8.9	9	29	7.0	14	88	17

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 27 (Continued)
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 4,000 Ft—AIRSPEED, 350 mph—60° DIVE				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
500 LB SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (INST)	Soft	−0.58	−1.5	12	2.7	3.0	—	−2.4
		Medium	−0.58	−1.5	10	2.8	2.9	—	−2.8
		Hard	−0.58	−1.5	8.8	2.4	2.6	—	−3.5
	0.0027 (NON-DELAY)	Soft	−0.05	−0.12	17	4.9	5.5	23	−0.20
		Medium	−0.05	−0.13	15	4.3	4.8	15	−0.24
		Hard	−0.06	−0.14	12	3.5	4.0	8.7	−0.32
	0.01	Soft	1.6	4.2	27	7.7	9.8	100	6.8
		Medium	1.5	4.0	24	7.0	9.1	69	7.5
		Hard	1.5	3.8	20	5.6	7.7	39	8.8
	0.025	Soft	4.4	12	33	7.5	18	130	19
		Medium	4.2	11	29	6.2	16	78	20
		Hard	4.5	8.6	23	4.9	13	40	20
	0.10	Soft	11	20	21	1.2	27	50	33
		Medium	8.3	14	26	3.7	20	48	26
		Hard	6.2	9.6	23	4.3	14	42	22
1,000 LB SAP AN-M59A1, AN-M59	0.0005 (INST)	Soft	−0.73	−1.9	15	4.2	4.6	—	−2.4
		Medium	−0.73	−1.9	13	3.4	3.7	—	−2.8
		Hard	−0.73	−1.9	3.5	2.7	2.4	—	−3.5
	0.0030 (NON-DELAY)	Soft	−0.11	−0.30	20	6.5	7.3	—	−0.39
		Medium	−0.12	−0.31	18	5.7	6.4	—	−0.46
		Hard	−0.12	−0.33	14	4.0	4.6	—	−0.61
	0.01	Soft	1.5	4.0	31	9.3	11	170	5.2
		Medium	1.5	3.8	28	8.1	10	115	5.6
		Hard	1.4	3.6	23	6.8	14	66	6.7
	0.025	Soft	4.5	12	40	10	19	260	15
		Medium	4.2	11	38	9.1	18	170	16
		Hard	4.4	9.4	29	6.8	15	88	17
	0.10	Soft	13	24	31	3.1	32	110	31
		Medium	9.8	17	34	5.4	24	110	25
		Hard	7.4	12	30	5.9	17	87	21

*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TABLE 28
EARTH PENETRATION AND CRATER FORMATION

Bomb	ALTITUDE OF RELEASE, 20,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB		Soft	18	50	—	—	—	10	113
AP	0.08	Medium	16	38	—	—	—	8	99
AN-MK 33		Hard	13	26	—	—	—	5	78
1,600 LB		Soft	18	55	—	—	—	4	80
AP	0.08	Medium	18	44	—	—	—	3	74
AN-MK 1		Hard	15	31	—	—	—	1	65

Bomb	ALTITUDE OF RELEASE, 10,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB		Soft	19	37	—	—	—	10	83
AP	0.08	Medium	17	28	—	—	—	8	72
AN-MK 33		Hard	13	19	—	—	—	5	57
1,600 LB		Soft	19	41	—	—	4	4	59
AP	0.08	Medium	19	32	—	—	3	3	53
AN-MK 1		Hard	15	22	—	—	2.8	1	46

Bomb	ALTITUDE OF RELEASE, 5,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB		Soft	19	—	—	—	—	10	58
AP	0.08	Medium	16	—	—	—	—	8	48
AN-MK 33		Hard	15	—	—	—	—	5	45
1,600 LB		Soft	19	27	11	—	34	4	39
AP	0.08	Medium	18	22	15	—	28	3	36
AN-MK 1		Hard	15	15	19	1.9	20	2.6	31

Bomb	ALTITUDE OF RELEASE, 4,000 Ft—AIRSPEED, 250 mph—LEVEL FLIGHT				CRATER MEASUREMENTS AND TYPE				
	Fuze Delay	Type of Earth	Displacement Feet****	Depth Penetrated Feet****	Diameter Feet	Apparent Depth Feet***	Actual Depth Feet***	Volume for Refill Cu Ft*	Crater Type**
1,000 LB		Soft	14	31	—	—	—	10	70
AP	0.08	Medium	14	23	—	—	—	8	59
AN-MK 33		Hard	10	16	—	—	20	5	48
1,600 LB		Soft	14	36	—	—	—	4	53
AP	0.08	Medium	14	27	1.2	—	34	3	45
AN-MK 1		Hard	12	19	8.8	—	24	1	39

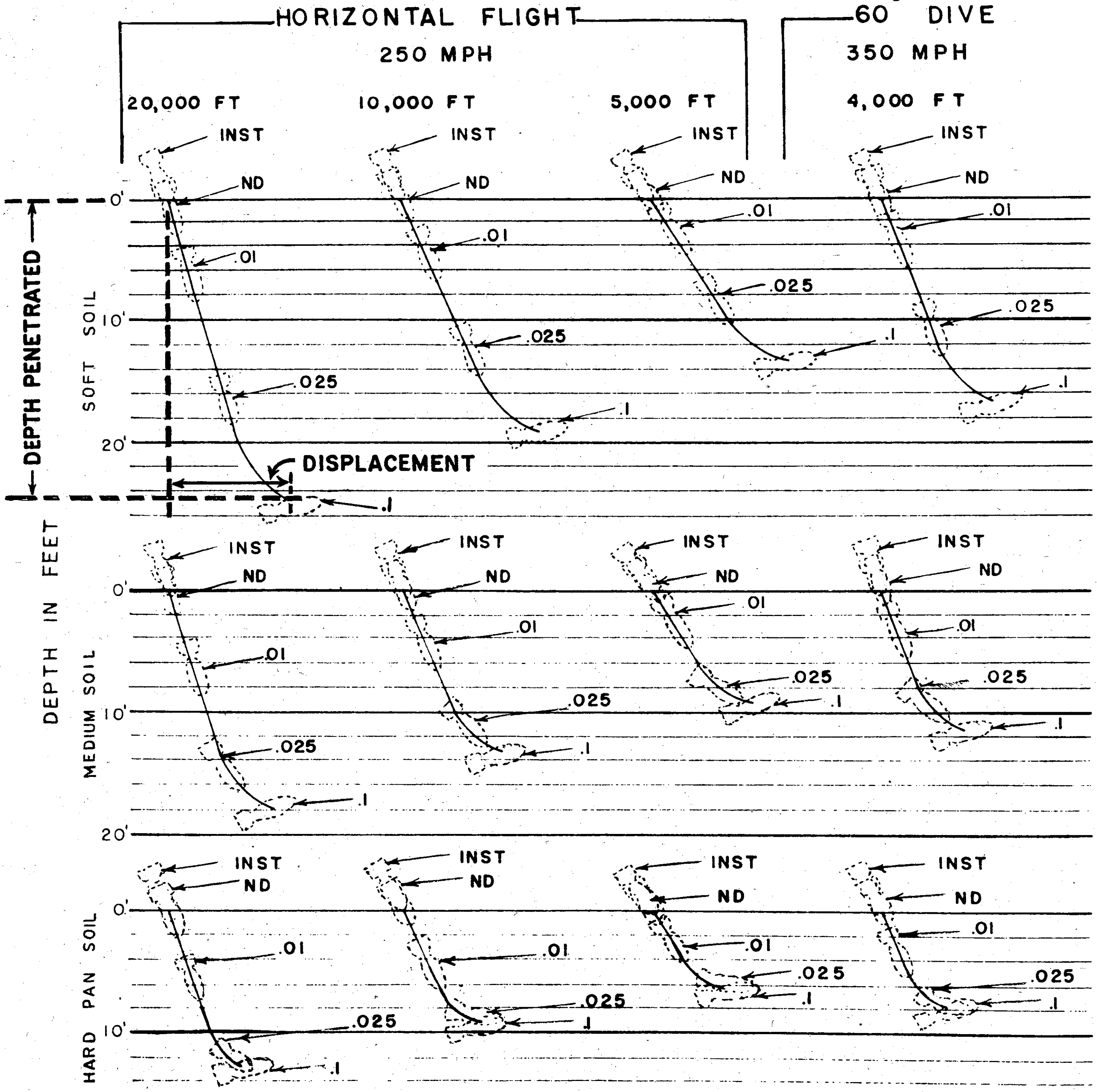
*Volume of refill is the cubic feet of earth that it is necessary to cart in to fill the crater. This volume assumes that all loose earth in the crater has been tamped into the crater.

**Crater type refers to values given in Table 29b. Values other than those indicated in table must be interpolated.

***Apparent and actual depths are illustrated in Table 29b.

****Displacement and depth penetrated are illustrated in Table 29a.

TYPICAL PENETRATION
PATHS OF 500 LB. GP BOMBS



BOMBS ARE SHOWN AT EXPECTED POINT OF DETONATION FOR VARIOUS FUZINGS

TABLE 29a

ESTIMATED CRATER SIZE AND SHAPE

1000 LB. TNT CHARGES IN AVERAGE SOIL

SCALE 1CM = 10FEET

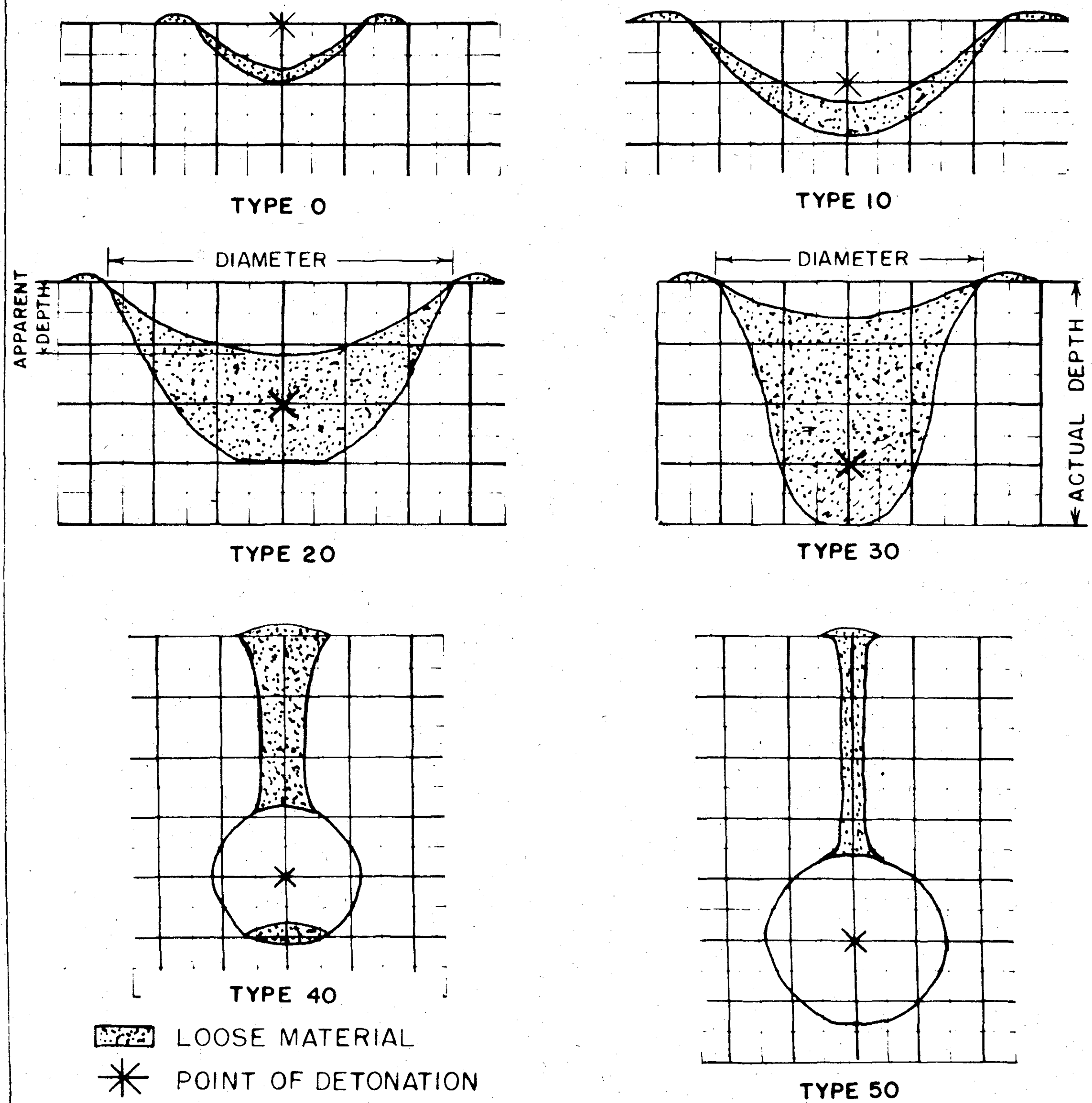


TABLE 29b

Volume III Part 4

ARMOR PENETRATION BY BOMBS

1. GENERAL.

The relatively large dispersion and low striking velocity of bombs prevent the direct attack of armored targets *for perforation* from being generally profitable, except for targets of unusual importance or size. However, large Armor Piercing (AP) bombs dropped from high altitudes can perforate the armored decks of battleships of current construction. Also, the detonation of large high capacity bombs may tear armor plate of considerable thickness.

2. DEFORMATION, RUPTURE AND LOW-ORDER DETONATION.

General Purpose (GP) and Semi-Armor Piercing (SAP) bombs with delay fuze do not withstand impact on heavy armor. Such an impact leads to deformation and breakage of the casing, which is generally accompanied or preceded by a low order detonation of the explosive filling (Amatol, TNT or RDX Comp B). However, when a GP or SAP bomb hits a sufficiently thin armor plate, the plate rather than the bomb is deformed and ruptured so that a perforation results without effective damage to the bomb. Estimates of the plate thicknesses that can be thus defeated are shown in Table 30. SAP bombs perform better than GP bombs of equal weight.

Armor Piercing bombs with standard Explosive D filling withstand impact on all but the heaviest armor without appreciable deformation or danger of low order detonation. The expected performance of AP bombs is shown in Figure 13. Notice that use of the 1,000 pound and 1,600 pound bombs against armor thicker than seven and eight inches respectively is not recommended, because of the danger of deformation.

3. EFFECTS OF DETONATION ON ARMOR.

General Purpose, and to some extent Semi-Armor Piercing, bombs provided with a quick fuze achieve considerable effect when hitting armor plate of moderate thickness which would withstand the impact of the same bombs with delay fuze. Estimates of the plate thicknesses that can be thus punched through, letting fragments and some of the detonation gases pass through the plate, are shown in Table 30. It is realized, however, that no substantial demolition can be thus effected on heavy structures behind the defeated plate in contrast to the effect of a delay fuzed perforating bomb that would burst behind the plate.

The detonation of uncased or lightly cased charges of TNT laid on armor produces penetrations greater than those from corresponding weights of explosive in bombs dropped on armored targets. The compactness of the charge and its proximity to the armor increases penetration. The following rule appears to hold approximately: W pounds of TNT pierces up to $\sqrt[3]{W}$ inches of armor.

4. QUALITY OF ARMOR.

The data given here refers to Homogeneous Armor which is also commonly referred to as "Special Treatment Steel" or "Class B" or "Machinable Quality" armor. One inch thickness of this armor is roughly equivalent to 0.6–0.7 inch "Class A" or "Face Hardened" armor, to 0.9–1.0 inch of "Homogeneous Hard" armor, and to 1¼ inches of mild steel.

TABLE 30
ARMOR PERFORATION GP AND SAP BOMBS

Bomb	Maximum Thickness of Plate Perforated With Delay Fuze Without Break-up or Low Order Detonation[1] (in.)	Maximum Thickness of Plate Punched Through By Detonation With Quick Fuze[2] (in.)
100 lb GP AN-M30 and AN-M30A1	1.0	1.8
250 lb GP AN-M57 and AN-M57A1	1.3	2.3
500 lb GP AN-M43, AN-M64 and AN-M64A1	1.5	3.0
1,000 lb GP AN-M44, AN-M65 and AN-M65A1	1.7	3.8
2,000 lb GP AN-M34, AN-M66 and AN-M66A1	2.0	4.8
500 lb SAP AN-M58, AN-M58A1 and AN-M58A2	2.0	2.0 EST
1,000 lb SAP AN-M59 and AN-M59A1	2.5	2.5 EST

[1]The perforations shown in this column can be obtained under the following conditions:

(a) Against horizontal plate:
Level Bombing: about 5,000 ft altitude or more.
Dive Bombing at 60° dive, 350 mph air speed, any altitude.

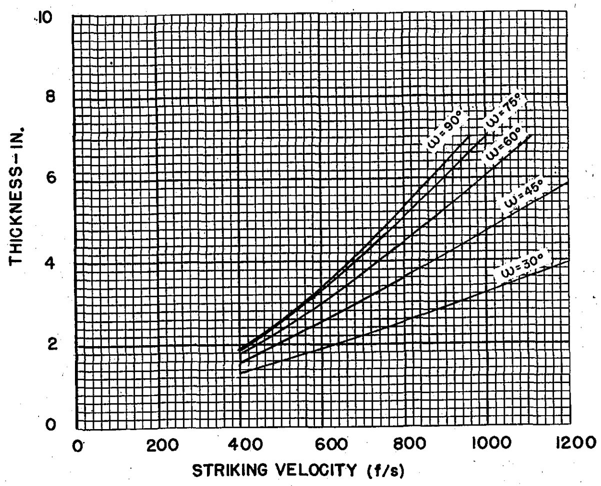
(b) Against vertical plate:
Minimum Altitude Bombing: 400 mph air speed.
About 30% loss of thickness perforated can be expected for level bombing from 1,500 ft or for minimum altitude bombing at 300 mph air speed.
No increase of thickness perforated above the figures shown in table can be obtained by increasing the striking velocity, since with thicker plate break-up and/or low order detonation would probably occur.

[2]The figures shown refer to use of an instantaneous nose fuze. Use of a non-delay tail fuze should increase the thickness punched through, possibly by 20%.

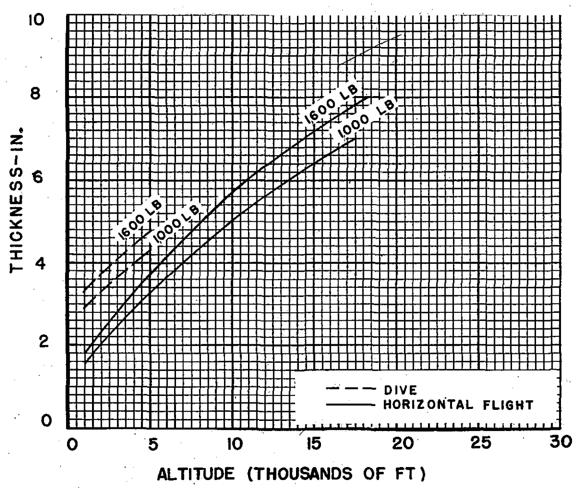
ARMOR PENETRATION BY AP BOMBS

THICKNESS OF PLATE PERFORATED
VS. STRIKING VELOCITY
FOR VARIOUS OBLIQUITIES
(ω= ANGLE OF FALL)

1,000-LB A P
AN- MK. 33



THICKNESS OF PLATE PERFORATED
VS. ALTITUDE OF RELEASE
BOMBING FROM HORIZONTAL FLIGHT 250 M PH
DIVE BOMBING, 60° DIVE, 350 M PH



1,600-LB A P
AN-MK.I

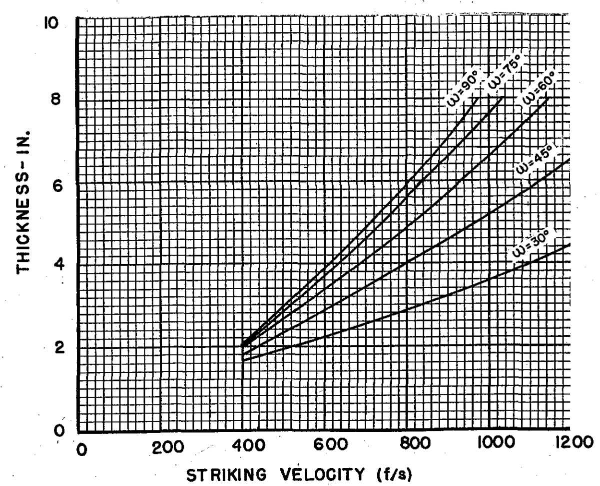


FIGURE 13

1. The graphs on the left side serve to determine the maximum thickness perforated under any condition of impact. If the armor plate is not horizontal, the angle formed by the trajectory with the plate should be entered instead of the angle of fall.
2. The graph on the right side serves to determine the maximum thickness of horizontal plate perforated under typical conditions of bomb release.
3. The bomb 1,000 lb AP AN–M52 is somewhat heavier than the AN–Mk. 33 and hence it performs slightly (about 4%) better under equal conditions of impact. However, its explosive charge is smaller and its exterior ballistics poorer.

Volume III Part 5
BOMB FUZE FUNCTIONING ON THIN ROOFS

1. GENERAL.

The nose fuze in bombs will presumably be initiated by all roofs, but the tail fuze in bombs is inertia activated and will not function on the thinnest roofs. The effective thickness of roof necessary depends only on the weight per square foot. The following table (Table 31) gives, for various bombs and altitudes of release, the thinnest roof which will cause functioning of most of the bombs dropped when using any of the AN-M100, AN-M101 or AN-M102 series fuzes.

Values are given for the General Purpose (GP) bombs, and also for Semi-Armor Piercing (SAP) bombs. For the latter category (SAP) the use of such a table will be to determine whether the fuze will be initiated on the roof or the cellar, when bombs strike protected cellars that are covered by thin roofed buildings. In this case heed should be given that thinner roofs than those tabulated will still initiate the fuze of a considerable fraction of the bombs. Only roofs one-third of the thickness tabulated or less will pass most of the dropped bombs without initiation of the fuze.

Roof and floor thicknesses are not to be added in estimating fuze action. That is, if the bomb must pass many layers of floors (spaced more than five feet apart) and no single one of the layers would initiate the fuze, then the multiple layers will in general not initiate the fuze.

TABLE 31

THICKNESS OF ROOF NECESSARY TO CAUSE FUNCTIONING OF THE TAIL FUZES AN-M100A1, AN-M100A2, AN-M101A1, AN-M101A2, AN-M102A1 OR AN-M102A2

Altitude from which bomb is dropped	Bomb / Roofing	GP, 100 lb AN-M30 AN-M30A1 GP, 250 lb AN-M57 AN-M57A1	GP, 500 lb AN-M64 AN-M64A1 AN-M43 GP, 1,000 lb AN-M65 AN-M65A1 AN-M44	GP, 2,000 lb AN-M66 AN-M66A1 AN-M34 SAP, 500 lb AN-M58 AN-M58A1 AN-M58A2 SAP, 1,000 lb AN-M59 AN-M59A1
5,000 ft	(a) lb/sq ft	3	4.5	6
	(b) in. concrete	1/4	3/8	1/2
	(c) in. metal	1/12	1/8	1/6
	(d) gage metal	14	11	9
10,000 ft	(a) lb/sq ft	2.5	3.5	4.5
	(b) in. concrete	1/4	1/3	3/8
	(c) in. metal	1/15	1/10	1/8
	(d) gage metal	16	13	11
20,000 ft	(a) lb/sq ft	2	3	4
	(b) in. concrete	1/6	1/4	1/3
	(c) in. metal	1/20	1/12	1/10
	(d) gage metal	18	14	12

(a) Weight in pounds per square foot
(b) Thickness in inches if roof is concrete
(c) Thickness in inches if roof is sheet metal (steel)
(d) U. S. Standard Gage of sheet metal roof

Volume III Part 6
BLAST

1. GENERAL.

The hot gases ejected by a detonating bomb sweep out and compress the surrounding air and throw that compressed body of air against adjacent layers of air. In this way a belt is formed within which the air has high pressure and high outward velocity. This belt is limited by an extremely sharp front (less than one thousandth of an inch) called the "shock front" in which the pressure rises abruptly.

The shock front travels away from the point of detonation with an extremely high initial velocity (3,000 feet per second at 60 feet from a 4,000 pound Light Case (LC) bomb where the pressure jump is 100 pounds per square inch). The velocity then decreases rapidly towards the velocity of sound (about 1,100 feet per second) as the shock front travels on and the pressure jump decreases.

The excess pressure prevailing at a point in the air after the arrival of the shock front decreases and vanishes in a short time (about 0.04 second at 400 feet from a 4,000 pound Light Case (LC) bomb; about 0.006 second at 50 feet from a 100-pound General Purpose (GP) bomb) and is followed by minor disturbances which often include a partial vacuum. The entire disturbance produced in air by the detonation of a bomb is called "blast."

2. PEAK PRESSURE.

The "peak pressure", that is the highest excess pressure which is attained right at the shock front, gives a measure of the maximum force exerted against a structure by the blast (Pressure times area = force). Figures 17 and 18 show the peak blast pressure *vs.* the distance from the point of burst, for various bombs. The peak pressure required to produce certain specific effects is also shown.

The numbers in Figures 17 and 18 refer to the hydrostatic pressure, which is that measured on a surface which is "side on" to the blast (i.e. parallel to the direction of travel). Larger pressures (up to eight fold) would be measured on surfaces at a right angle to the direction of travel due to the impact of the blast. (Figure 15.)

3. DEMOLITION OF A WALL—IMPULSE.

A blast cannot quickly travel around anything as large as the wall of a house; therefore the pressure difference established by the blast on the outer and inner faces of such a wall persists until the blast has subsided. As a result of the great inertia of walls, the deformation produced by the blast seldom attains the point of collapse before the blast has subsided; the wall keeps on deforming further after that time, again a result of its inertia, which now tends to overcome the structural strength. The eventual attainment of a deformation leading to collapse will depend on the velocity acquired by the wall under the impact of the blast. This velocity depends in turn not only on the blast pressure but also on its duration, specifically, on its measurable impulse which is the average pressure multiplied by the duration, (i.e., the integral of pressure over time).

4. RADII AND AREAS OF EFFECTIVENESS.

The damage caused by various types of bombs in German load bearing wall construction can actually be correlated with the blast impulse measured at various distances from the bomb. Therefore, the known impulse *vs.* distance relation for any type of bomb can be used to estimate the distance at which a bomb would cause a certain degree of damage. Radii and areas of blast effectiveness for bombs have been obtained in this way and are shown in Table 32 and Figure 14.

Data for bombs and fuzes are included in Table 32 which do not correspond to a normal tactical employment, because these data also serve to indicate the comparative blast effectiveness of different bombs on targets other than German load bearing wall construction.

Data for the effectiveness of bombs on Japanese light construction are not yet available. However, it has been estimated that the areas of effectiveness may be at least five times greater than the corresponding areas for German construction.

5. EFFECTS OF CONFINEMENT.

The presence of obstacles that prevent the travel of blast in some direction may increase the effect of blast in other directions.

A blast traveling along a tunnel, a corridor, a trench and in the case of large bombs, even along a street, is effectively confined, so that its intensity decreases much more slowly than in the open.

When a bomb detonates inside a house, demolition of the walls may occur even if the distance to the walls exceeds the radius of demolition for the same wall and for the same type of bomb bursting in the open. This is due to a variety of effects, among which is the "multiple punch" effect created by the blasts hitting on a wall in quick succession after having been reflected by other walls. For this reason, separate radii and areas of demolition are given in Table 32 for bombs bursting inside and outside of buildings. If the effect of a blast is intensified on one side of a wall by its confining action, it is reduced by the same token on the opposite side of the wall by its screening action (see Figure 16).

RADII OF EFFECTIVENESS OF GP BOMBS

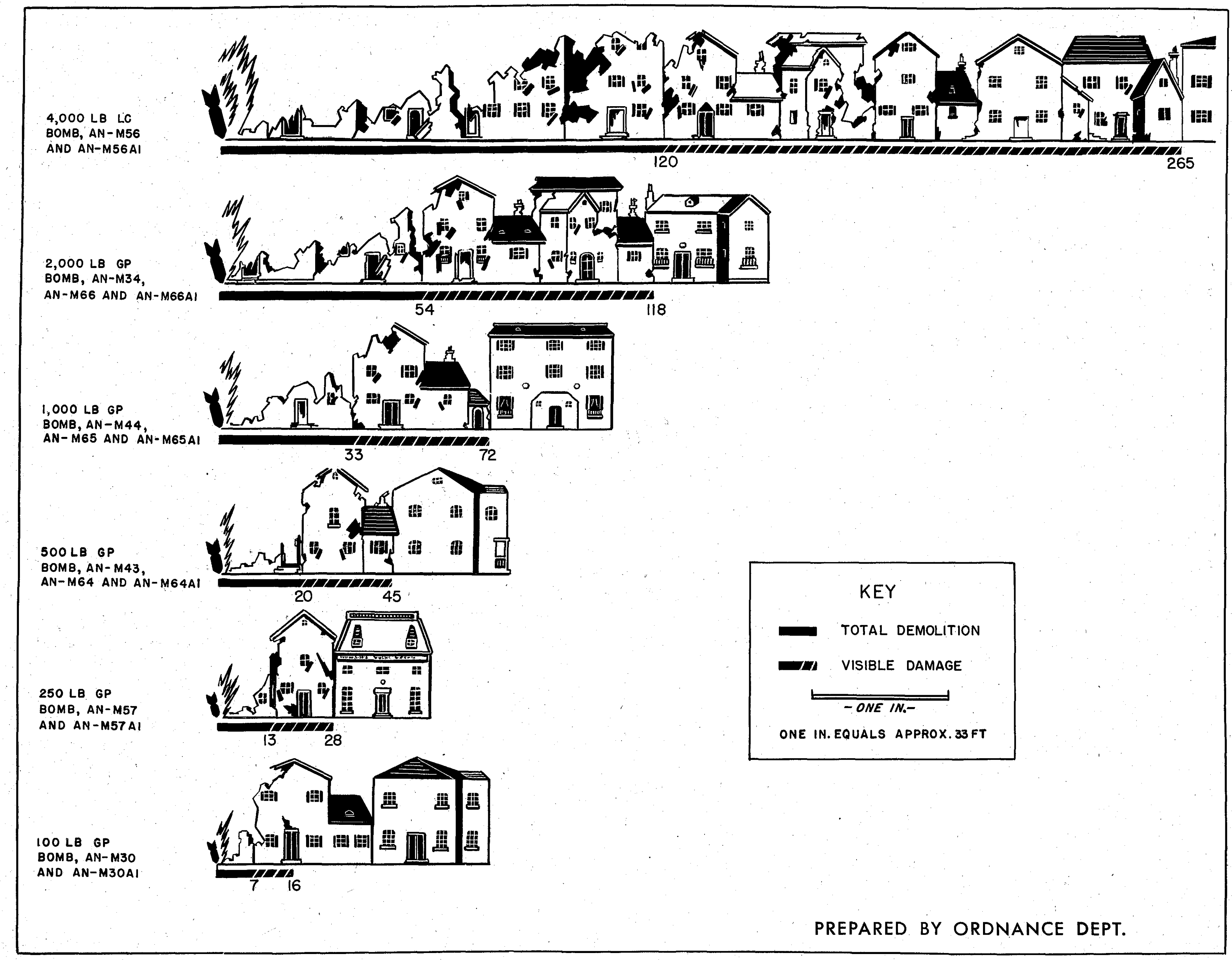


FIGURE 14

6. PROTECTION FROM BLAST.

A wall effectively reduces blast pressure and impulse on objects close to it if it is about 10 feet by 10 feet or larger and it is of sufficient strength to withstand the blast.

Foxholes, slit trenches or ditches reduce the blast pressure by about 50 percent in the range where serious injury can occur to persons.

A simple right-angle bend in a tunnel reduces the blast pressure about 50 percent. A system of four such bends reduces it to about 15 percent.

7. EFFECT OF THE TYPE OF EXPLOSIVE.

The data in Table 32 and Figures 14 to 18 inclusive refer to TNT fillings. Corrective factors to obtain data for other explosives are given in Table 33.

8. EFFECT OF CHARGE/WEIGHT RATIO.

The action of the explosive of a bomb detonating in air imparts a great speed to the bomb casing. The casing breaks up into fragments. Later the action produces an air blast. The lighter the casing, the less energy it takes to accelerate it. Therefore, a high charge/weight ratio increases the effect of detonation in air in a twofold manner; (1) it will reduce the fraction of energy taken up by fragments, and (2) it will increase the weight of charge included in a bomb of given weight. The LC bombs are best among present bombs from the stand-point of blast effectiveness.

9. EFFECT OF BLAST ON INDUSTRIAL STRUCTURES.

The demolition of industrial structures, which are generally steel framed, cannot be analyzed in the same comparatively simple terms as the demolition of buildings with load bearing walls.

It has been estimated that the factory area whose structure is effectively damaged by a direct hit with the 500 pound GP Bomb AN-M64 with a 0.01 second fuze delay averages about 400–450 square yards (1,600–1,800 square yards per ton). A considerable reduction of damage is experienced if the same bomb is fuzed 0.025 second delay, because its detonation then occurs far below the roof structure.

The area of factory structure damaged by various other GP bombs is not very different, when expressed in square yards per ton of bombs.

No direct evidence is available on the effectiveness of the U. S. 4,000 pound LC bomb on factory structures, but Allied experience indicates that the damage by this type of bomb is greater than that of all GP bombs, when expressed in square yards per ton of bomb load.

FIGURE 15

DEPENDENCE OF BLAST PRESSURE ON THE ORIENTATION OF THE SURFACE ON WHICH IT IS MEASURED

1. The peak pressure on the surface (A) parallel to the direction of travel of the blast, at 20 ft from the point of burst of a 2,000 lb GP bomb is about 580 lb/sq in.

2. The peak pressure on the surface B at right angle to the direction of travel of the blast, at 20 ft from the point of burst of a 2,000 lb GP bomb is about 4,100 lb/sq in., that is, more than 7 times the pressure at A.

3. The peak pressure on the surface C parallel to the direction of travel of the blast, at 200 ft from the point of burst of a 2,000 lb GP bomb is about 2.7 lb/sq in.

4. The peak pressure on the surface D at right angle to the direction of travel of the blast, at 200 ft from the point of burst of a 2,000 lb GP bomb is about 5.8 lb/sq in., that is, little more than 2 times the pressure on C.

5. The ratio of the peak pressure on pairs of surfaces oriented like A and B, or C and D decreases with increasing distance from the burst. It is equal to 8 at very short distances from the burst, and equal to 2 at very great distance. The pressure on a surface oblique to the direction of travel of the burst is intermediate between the pressure on surfaces parallel and at right angles to the same direction.

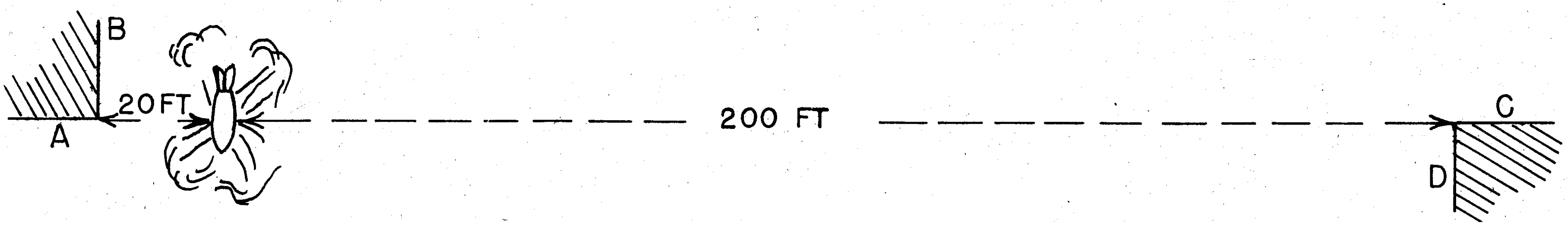


FIGURE 16

DEMOLITION OF BUILDINGS WITH LOAD BEARING WALLS BY DIRECT HITS OF DELAY-FUZED GP BOMBS.

Circles represent mean radii of demolition of:

(1) 250 lb GP (22 Ft)
(2) 500 lb GP (35 Ft)
(3) 1,000 lb GP (55 Ft)

Bombs detonating inside houses, as given in Table 32, for buildings of German construction with load bearing walls.

A series of duplex houses, each unit measuring 30 ft x 45 ft is shown at the left of a street, a 50 ft deep block is shown on the right. Cross hatched areas indicate extent of probable demolition.

Notice that:

(a) The area within the circles increases faster than the weight of the bomb.
(b) With increasing weight of the bomb, the radius of effectiveness exceeds the dimensions of the buildings, resulting in a loss of effectiveness.
(c) The larger bombs are more efficient against the larger buildings, the smaller against smaller buildings.
(d) Demolition does not extend to buildings other than the one directly hit (upper left corner.)

Near misses by delay-fuzed bombs produce cratering and earth shock effect (see page 32).

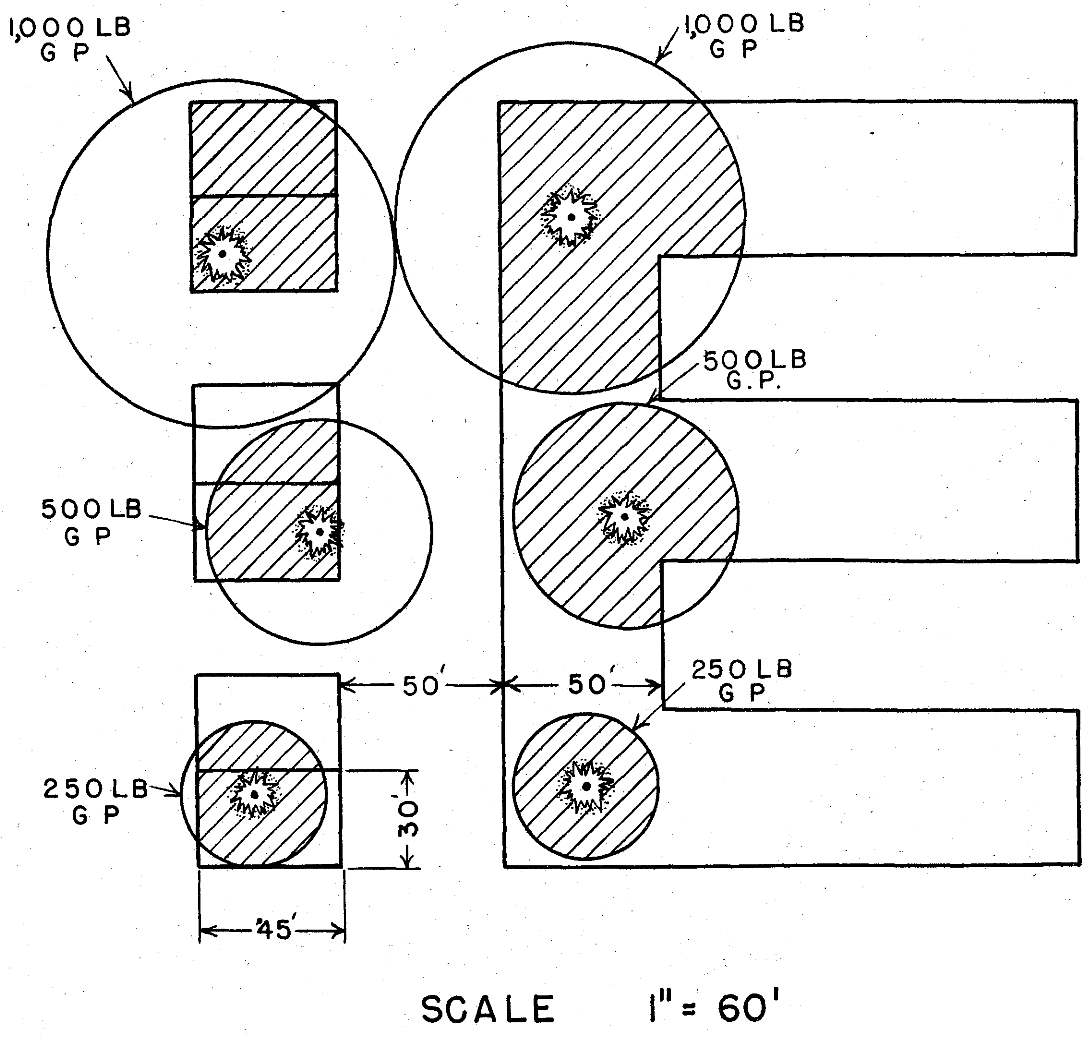


TABLE 32

RADII AND AREAS OF EFFECTIVENESS
APPROXIMATE VALUES FOR TYPICAL GERMAN BUILDINGS WITH LOAD BEARING WALLS
(TNT LOADING)

	Detonation outside Building on ground or roof (Bomb must be fuzed instantaneous)						Detonation inside building (Direct penetration hit only) (Bombs must be fuzed delay)	
	Demolition			Visible Damage			Demolition	
Bomb	Mean Radius (ft)	Maximum Radius (ft)	Mean Area (sq yd)	Mean Radius (ft)	Maximum Radius (ft)	Mean Area (sq yd)	Mean Radius (ft)	Mean Area (sq yd)
4,000 lb LC AN-M56 or AN-M56A1	120	150	5,000	265	(330)	24,000	(200)††	(14,000)*††
2,000 lb GP AN-M34, AN-M66 or AN-M66A1	54	66	1,000	118	(150)	4,900	(90)††	(2,900)*††
1,000 lb GP AN-M44, AN-M65 or AN-M65A1	(33)	(40)	(375)	(72)	(90)	(1,800)	55	1,000*
500 lb GP AN-M43, AN-M64 or AN-M64A1	(20)†	(25)†	(150)†	(45)	(56)	(700)	35	400*
250 lb GP AN-M57 or AN-M57A1	(13)†	(15)†	(60)†	(28)	(35)	(275)	22	160
100 lb GP AN-M30 or AN-M30A1	(7)†	(9)†	(17)†	(16)†	(20)†	(90)†	12	50
1,000 lb SAP AN-M59 or AN-M59A1	(18)†	(22)†	(110)†	(39)	(48)	(500)	30	300
500 lb SAP AN-M58, AN-M58A1 or AN-M58A2	(11)†	(13)†	(40)†	(24)	(30)	(200)	18	100
1,600 lb AP AN-Mk. 1	(12)†	(14)†	(50)†	(26)	(32)	(240)	(20)	(150)
1,000 lb AP AN-Mk. 33	(9)†	(11)†	(28)†	(20)†	(25)†	(140)†	(15)	(80)
260 lb Frag AN-M81 (T10)	(3)†	(4)†	(3)†	(7)†	(9)†	(17)†	(5)†	(9)†

See text for significance of these data. Figures in parentheses do not correspond to normal or advisable tactical employment of the bomb in question, and are shown mainly for purpose of comparison. Starred figures should be scaled down in keeping with limited size of buildings. This table purports only to represent the results of mathematical extrapolation of rules that have been established for medium and large bombs, and is mainly intended as a guide to the relative effectiveness of different bombs. However figures marked with a † are believed to be lower than the actual damage due to the neglect of fragment damage and some other effects. The figures marked †† are probably greater than the real damage due to the effect of building design and other neglected effects.

TABLE 33

CORRECTIVE FACTORS
CORRELATING THE BLAST EFFECTIVENESS OF VARIOUS EXPLOSIVE FILLINGS
(TNT-100)

Explosive	Peak Pressure (At Equal Distance)	Radius of Effectiveness Load Bearing Wall Construction	Area of Effectiveness Load Bearing Wall Construction
Torpex (RDX/TNT/AL, 42/40/18)	122½	125	160
HBX (RDX/TNT/AL/Wax, 40/38/17/5)	117½	120	150
Minol (NH_4NO_3/TNT/AL, 40/40/20)	115	117½	130
Tritonal (TNT/AL, 80/20)	112½	117½	140
DBX (NH_4NO_3/RDX/TNT/AL, 21/21/40/18)	112½	112½	130
RDX Comp B (RDX/TNT, 60/40)	110	110	120
Ednatol (Halite/TNT, 57/43)	105	105	110
TNT	100	100	100
Picratol (Expl. D/TNT, 52/48)	100	100	100
Amatex (NH_4NO_3/RDX/TNT, 43/9/48)	100	97½	95
Amatol (NH_4NO_3/TNT, 50/50)	95	87½	80

PEAK BLAST PRESSURE VS. DISTANCE FROM BOMB BURST

(TNT LOADING – GP AND OTHER BOMBS)

PREPARED BY ORDNANCE DEPT

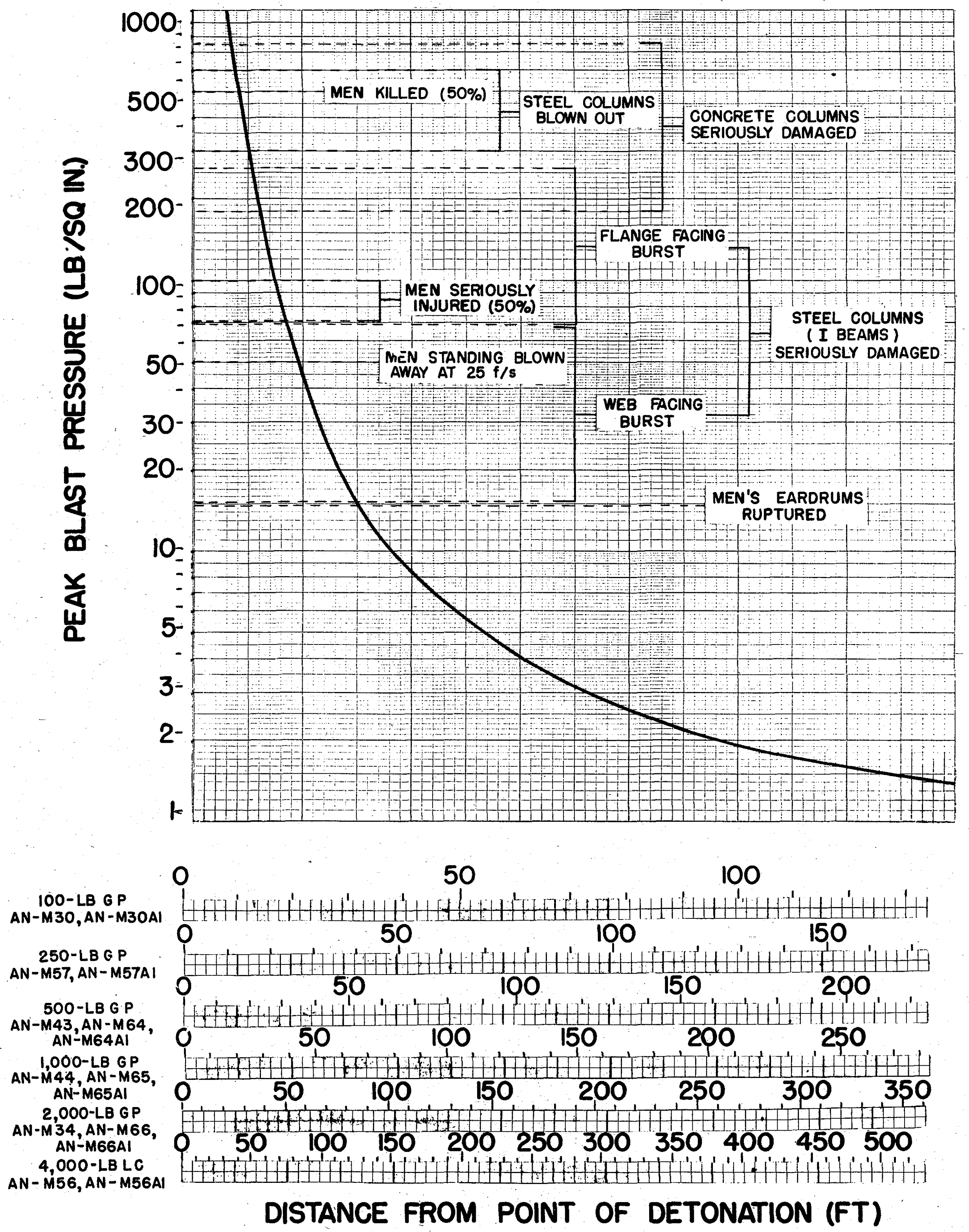


FIGURE 17

PEAK BLAST PRESSURE VS. DISTANCE FROM BOMB BURST

(TNT LOADING - S A P AND OTHER BOMBS)

PREPARED BY ORDNANCE DEPT

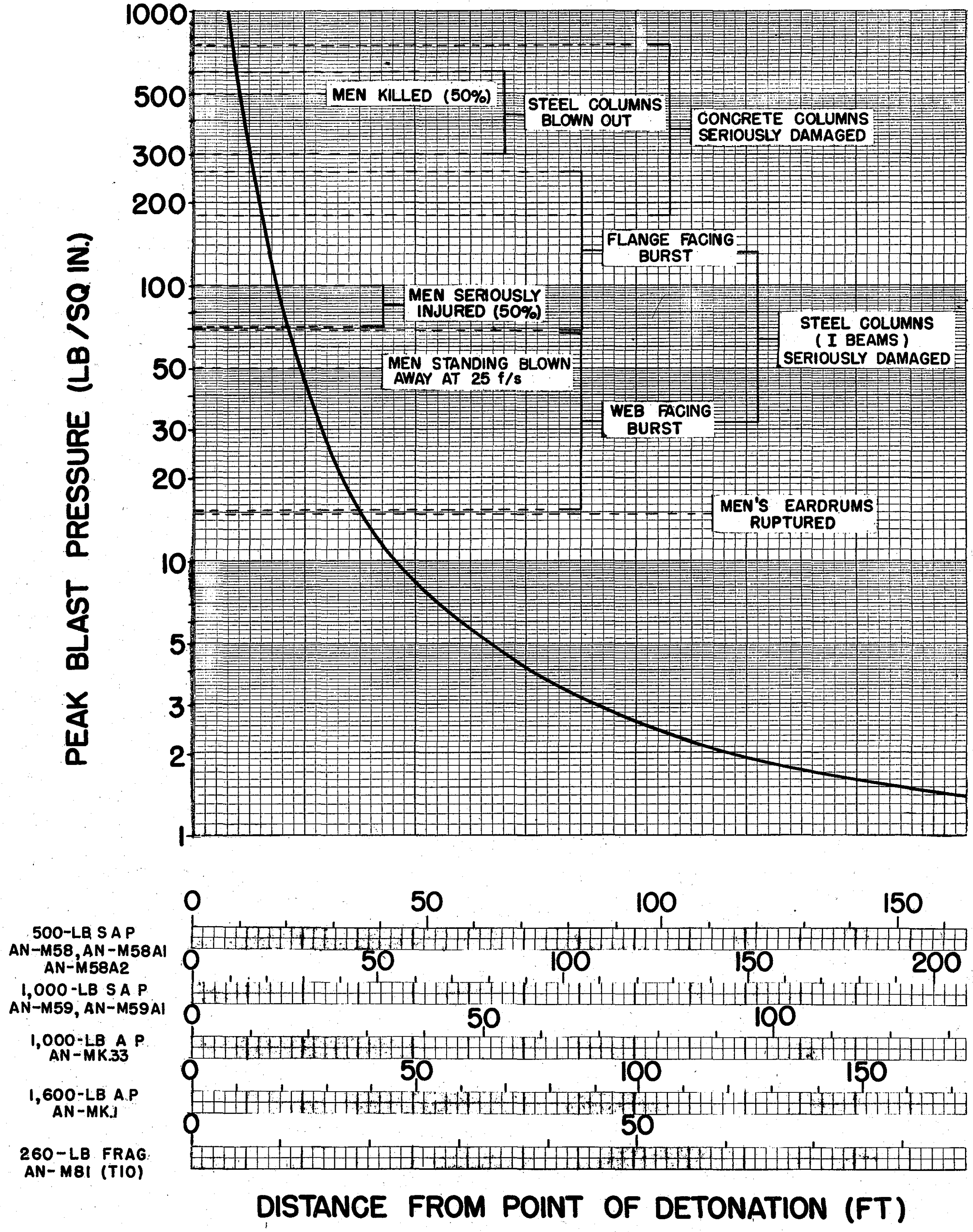


FIGURE 18

Volume III Part 7

LOW ALTITUDE BOMBING TRAJECTORIES

LEVEL, DIVE, AND CLIMB BOMBING

1. DIVE BOMBING TRAJECTORIES.

The following chart (Figure 20) gives the
(a) Angle of Fall
(b) Striking Velocity
(c) Time of Flight
of a bomb dropped from a dive. The chart is based on vacuum trajectories, and neglects air resistance. It will be accurate for low altitude release, and more accurate for heavy than light bombs.[1]

Enter the chart with
(1) The plane speed
(2) Altitude of release
(3) Angle of dive

At the top the plane speed must be entered in miles per hour or feet per second. The circles are those of the plane speed shown at the top. On the circle of correct plane speed, at the angle of dive, is the *initial point*. Vertically above and below this initial point are identical horizontal scales giving the *horizontal component* of the bomb velocity, which remains constant. At the left, on the level of the initial point, the scale gives the *initial vertical component* of the bomb velocity.

Use the *curve of fall* on the right, starting at the *initial vertical component* (the level of the initial point) and follow down the curve as far as the *altitude of release*, shown at the top. The level of this curve, read on the extreme left, is the *final vertical component* of bomb velocity. The point on this level directly under the *initial point* is the *final point*. The circle on which this point lies gives the *striking velocity*. The angle of this point is the *angle of fall*.

The *time of fall* is given in the lower right corner as the number of seconds. The correct time is that corresponding to the straight slanting line (scaled 1 to 12 seconds) intersecting the *curve of fall* at the correct *altitude of release*.

The *range* is the *time of flight* multiplied by the *horizontal* component of velocity.

For ease in using this chart, Figure 19 gives the location of each of the above italics terms.

Example of Bombing from a Dive:

A bomb released at 4,000 feet altitude from a plane diving at 60 degrees and 350 miles per hour, will fall at an angle of 69 degrees and with a striking velocity of 720 feet per second. Its range will be 255 feet per second x 7 seconds = 1,800 feet.

---

[1]For level bombing at 300 miles per hour from 4,000 feet the values obtained from the chart are in error as follows:

100 pound GP bomb:
- Angle of fall 4 degrees too low
- Striking velocity 17 percent too high
- Range 9 percent too long

1,600 pound AP bomb:
- Angle of fall 2 degrees too low
- Striking velocity 5 percent too high
- Range 2 percent too long

The errors for dive bombing trajectories from the same altitude are less.

2. BOMBING FROM LEVEL FLIGHT.

The procedure is the same as for dive bombing except that the angle of dive is zero. The *initial point* lies on the upper edge of the chart, and the *horizontal component* of velocity is then the plane speed. The *curve of fall* to be used is that at the extreme right. The *time of flight* is read from the figures along this curve.

3. BOMBING FROM A CLIMB.

The graph may also be used for bombing from a climb. It is necessary to enter the chart with the angle of climb, plane speed, and altitude of release, as is the case for dive bombing. The trajectory of the bomb, when released from a climb, can be considered to consist of two parts; first, a climb over the apex and descent to the same altitude as the point of release, and then the fall from the altitude of release. At the end of the first portion, when the bomb has returned to the release altitude, it is moving with the release velocity, and with an angle of fall equal to the original angle of climb. From then on the trajectory is the *same as if released from a dive with the same plane speed as the actual plane speed, same altitude of release as the actual, but with angle of dive equal to the actual angle of climb*. The final *striking velocity* and *angle of fall* of the bomb *is the same as for* the corresponding *dive*, but the time of flight is longer by the time required to climb over and down from the apex in the initial part of the bomb trajectory. This latter time is just twice the time which would have been required to attain the initial vertical component of velocity of the bomb if it had been dropped from level flight. These times are marked on the curve on the extreme right.

The directions for obtaining data for climb bombing are then as follows:
(1) Use actual plane speed.
(2) Use actual altitude of release.
(3) Use angle of dive equal to the actual angle of climb.
  (a) Read the angle of fall as usual for the case of dive.
  (b) Read the striking velocity of the bomb as usual for the case of dive.
  (c) Obtain the time of flight by adding the time taken from the case of dive to the time required by the bomb to go over the apex. To obtain the latter time proceed as follows: Use the initial vertical velocity from the dive and follow at this level along the chart to the curve on the extreme right. Take the number of seconds marked on that curve at this velocity, and multiply by two.
  (d) The range will be, as always, the true time of flight times the initial horizontal component of the plane speed.

Example of Bombing from a Climb:

A bomb released at 3,000 feet altitude from a plane climbing at 20 degrees and 310 miles per hour, will fall at an angle of 47 degrees and with a striking velocity of 625 feet per second. Its range will be 420 feet per second x 19.8 seconds = 8,316 feet. Time of flight was 10 seconds + 2 x 4.7 seconds = 19.8 seconds.

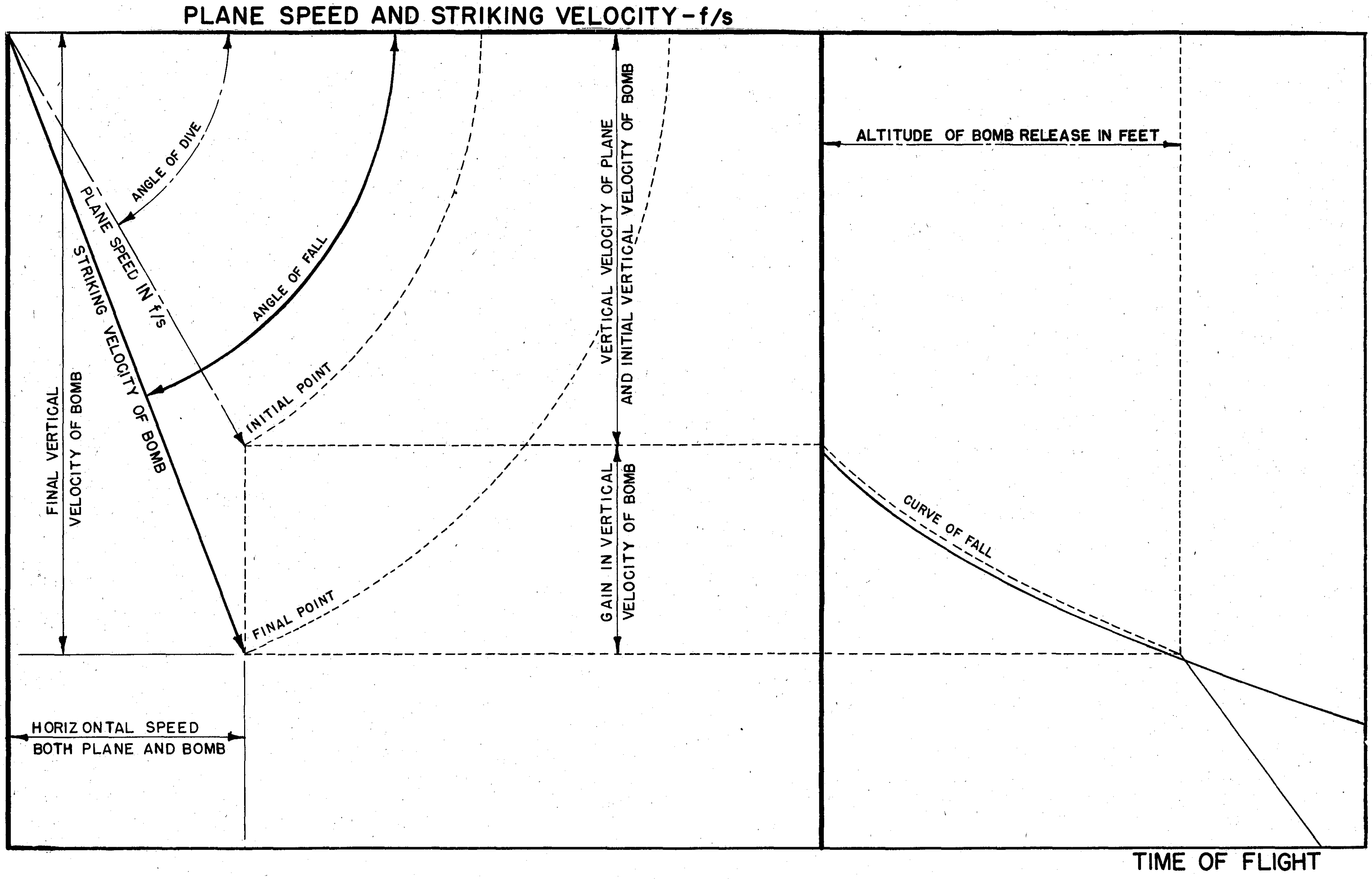

PLANE SPEED AND STRIKING VELOCITY - f/s
ANGLE OF DIVE
PLANE SPEED IN f/s
ANGLE OF FALL
STRIKING VELOCITY OF BOMB
FINAL VERTICAL VELOCITY OF BOMB
INITIAL POINT
FINAL POINT
VERTICAL VELOCITY OF PLANE AND INITIAL VERTICAL VELOCITY OF BOMB
GAIN IN VERTICAL VELOCITY OF BOMB
ALTITUDE OF BOMB RELEASE IN FEET
CURVE OF FALL
HORIZONTAL SPEED BOTH PLANE AND BOMB
TIME OF FLIGHT

FIGURE 19

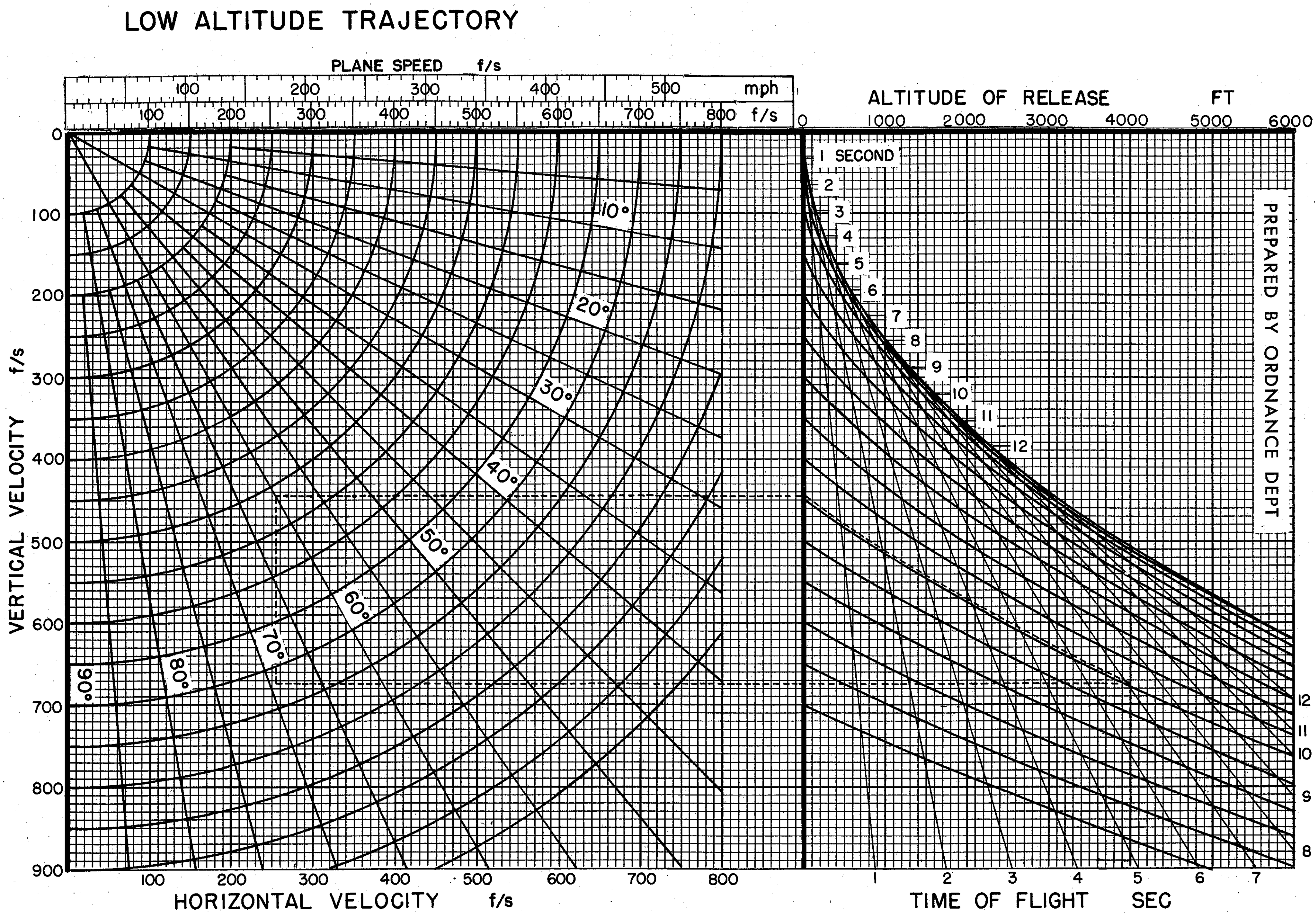

LOW ALTITUDE TRAJECTORY
PLANE SPEED f/s
100 200 300 400 500 mph
100 200 300 400 500 600 700 800 f/s
ALTITUDE OF RELEASE FT
0 1000 2000 3000 4000 5000 6000
VERTICAL VELOCITY f/s
0 100 200 300 400 500 600 700 800 900
HORIZONTAL VELOCITY f/s
100 200 300 400 500 600 700 800
10° 20° 30° 40° 50° 60° 70° 80° 90°
1 SECOND
2 3 4 5 6 7 8 9 10 11 12
12 11 10 9 8
1 2 3 4 5 6 7
TIME OF FLIGHT SEC
PREPARED BY ORDNANCE DEPT

FIGURE 20

Volume III Part 8

SHELL FRAGMENT DAMAGE

(THIS PART SUPERSEDES VOLUME II PART 3, PAGES 126 TO 139. PAGES 140 TO 173 ARE NOT SUPERSEDED.)

1. TABLES OF FRAGMENT DAMAGE.

These tables give the number B of effective hits per square foot of target area at a given distance r feet from the burst. The numbers B are averages for different directions from the burst. They are properly applied only to a considerable number of bursts with random orientation of the projectile axis relative to the target.

2. DAMAGE PATTERNS.

As distinguished from damage tables, the damage patterns represent typical individual cases and vary with the remaining velocity of the shell or rocket, the angle of fall, and the height of burst. Both damage tables and damage patterns presuppose a graze or air burst with no shielding of target. The user of the data given here must make due allowance for target shielding and the penetration of the shell or rocket into the ground before burst. The amount of this penetration will depend upon the remaining velocity, the angle of fall of the shell or rocket, the nature of the soil, and the shell or rocket and the fuze. In the fragment damage patterns, shadings of different types indicate regions of decreasing density of hits. The regions distinguished are those where there is at least one hit per 1, 4, 10, or 25 square feet of area. These units of area are understood as normal to the fragment trajectories. *Unshaded regions entering near the burst do not indicate that there are no effective hits in these regions, but merely that the density of effective hits is less than that belonging to the nearest shaded area.*

The white centers of the fragment patterns are used to indicate the origin of the polar system above which the missile bursts. In general, these areas suffer the highest type of fragment damage as well as blast damage.

This part of Volume III contains damage patterns only for the 4.5 inch HE Rocket Shell, T22. The damage patterns for various other shell are contained in Volume II Part 3, pages 140 to 173.

3. TYPES OF DAMAGE.

The types of damage considered are casualties, and normal perforations of mild steel of $\frac{1}{8}$ inch, $\frac{1}{4}$ inch, and $\frac{1}{2}$ inch thickness. A casualty is supposed caused by a hit with at least 58 foot-pounds of energy. It is incapacitation and not necessarily death. Damage occasioned by perforation of $\frac{1}{8}$ inch mild steel is considered effective against airplanes on the ground. In anti-aircraft fire against modern bombers, the most effective damage varies from that with $\frac{1}{8}$ inch perforation to $\frac{3}{8}$ inch perforation of mild steel. Damage in which there are perforations of $\frac{1}{4}$ inch or $\frac{1}{2}$ inch mild steel is effective against trucks, light armored vehicles, railway rolling stock, and targets of similar resistant nature.

[1]Including the 4.5 inch HE Rocket Shell, T22.

4. SAFETY LIMITS.

The fragment damage tables are useful in determining the distance from a burst at which a soldier stands a given chance of being wounded by a fragment. Suppose, for example, that a soldier is required to take a 1–1,000 chance of being wounded by a fragment from the 105mm HE Shell, M1. Suppose that the soldier is in open terrain in such a position that 2.5 square feet of his body are exposed to fragments coming directly from the shell. Accordingly, the number of casualty producing fragments per square foot to which the soldier is exposed is $1/1{,}000 \times 1/2.5 = 0.0004$ and by Table 48 this fragment density occurs at 300 feet from the shell. Thus on the *average* the soldier should not be much nearer than 300 feet from the shell.

If account is to be taken of the most dangerous directions from the shell, the average densities B of effective fragments as given in the tables should be multiplied by a factor of about six and then used as in the above example. In the case of a man in an airplane wearing standard flyer's body armor, a fragment capable of piercing the plane fuselage, the body armor, and then wounding a man, would be capable of perforating approximately $\frac{1}{8}$ inch mild steel. Safety limits relative to hits of this type may be found by using the tables for perforations of $\frac{1}{8}$ inch mild steel in the manner indicated in the above example.

GROUND BURSTS

5. THE CHOICE OF SHELL.

Ground bursts are recommended in all cases where the targets are relatively unshielded. This will include most cases of materiel targets, and of personnel other than those in foxholes or prone on rough terrain. In the case of materiel targets, the artilleryman should first decide upon the type of perforation necessary to effectively damage his target. Given the type of perforation and the range; the shell, propelling charge and elevation must be chosen. One of the factors bearing on this choice will be a knowledge of the minimum number of shell per unit area required to do the predetermined fragment damage. This can be obtained from Figures 25 to 49.

Example. Suppose an area target given at 10,000 yards range using the 155mm Howitzer M1 and that effective damage of the target requires fragments which will perforate $\frac{1}{4}$ inch mild steel. Figure 43 shows that the minimum number of shell for this range is required if Charge 5 and high angle fire are used.

6. THE REQUIRED SHELL DENSITY.

Let a target area be given in terms of square units of area 100 feet x 100 feet (i.e. multiples of the 100 feet x 100 feet area). Let it be required to wound 50 percent of the enemy personnel (4.5 square feet of area) on the given area or to damage 50 percent of materiel target elements (2 square feet of area) vulnerable to fragments of a given perforative type. The number D of shells of a given type required per unit of area (100 feet x 100 feet) is given by Figures 25 to 49 against range and charge.

To obtain the desired fragment effect, it is necessary to distribute shell over an area somewhat larger than the given target area. The *fringe of additional area* around the given target area has a width W indicated on each graph. This enlarged area should receive D shell per unit of area. Unless the edge of the target area is very well defined and of marked importance it will usually be more profitable to confine the D shell per unit area to the given target area A rather than use the enlarged area. In such cases points within A at a distance at least W from the edge of A will receive the desired fragment effect. The calculations are based on a random distribution of shell over the enlarged area with an expected shell density D. The manner of achieving this shell distribution will depend on the burst dispersion and type of fire.

In the case of enemy *materiel*, each target is supposed divided into a number of *elements* each 2 square feet in area and vulnerable to a hit of a given perforative type, i.e., 1/8 inch, 1/4 inch, or 1/2 inch perforations of mild steel. The figures give the number D of shell per unit area required to effectively damage 50 percent of these target elements. For example, an enemy vehicle may present eight of these target elements vulnerable to hits capable of perforating 1/8 inch mild steel. If the shell density is taken from Figures 25 to 49 for 1/8 inch perforations, four of these eight target elements may be expected to be effectively damaged. As in the case of casualties, the distribution of shell with the density D must be made over an area somewhat larger than the given target area. The width W of this additional fringe of area is indicated on the figure.

If the percent of target elements which it is desired to effectively damage is not 50 percent, it is sufficient to multiply the shell density given in the figures by a factor F given in Table 70 to obtain the correct shell density D.

Shielding. The shell densities D are calculated for flat unshielded terrain and, in the case of personnel, for men who are standing. For prone men or for terrain which is rolling or shielded, the shell densities should be multiplied by appropriate factors. Estimates for some of the more important cases are given following Table 70.

Blast. Blast is effective against personnel in the open for relatively small distances, in every case for distances considerably less than those at which a casualty is certain to be caused by fragments.

Example. Let the target area be 500 feet x 1,000 feet and at 5,000 yards and suppose it is desired to wound 60 percent of the enemy personnel on the area using the 105mm HE Shell, M1 and Charge 4, high angle fire. Suppose that the terrain is flat and unshielded.

Solution. The width W of the additional fringe of area is 58 feet according to Figure 38. The enlarged target dimensions are 616 feet x 1,116 feet. Thus the enlarged area contains 69 units of area. For each of these units, 0.58 shell are required in accordance with Figure 38. When the percent of wounded is to be 60 instead of 50, a multiplicative factor of 1.32 is called for as given in Table 70. Thus the number of shell which should be distributed over the enlarged area is 69 x 0.58 x 1.32 = 53.

AIR BURSTS

7. TYPES OF SHIELDING.

Air bursts are recommended against men in foxholes or open trenches and against personnel shielded by rough terrain. The type of shielding labelled "10° foxholes" is believed to be that most commonly encountered and will correspond to the shielding afforded men in foxholes when the men are somewhat below the level of the ground, or to the shielding afforded prone term by rough terrain. The term "10° foxhole" arose from its definition as a foxhole in which an occupant will on the average be unharmed by fragments with an angle of fall less than 10 degrees. (See sketch on page 67.)

Hastily dug in positions on level ground will correspond to "0° foxholes," as will trenches in which the heads of men are even with the ground. Men in "30° foxholes" are relatively safe from attack by high explosive shell, even by air burst fire. In general, Figures 50 to 56 are drawn for "10° foxholes." In the case of "0° and 30° foxholes," figures are given for the 105mm Howitzer only, and will serve as a guide for other guns and shell.

8. THE CHOICE OF SHELL.

Given the range, Figures 50 to 56 will show which weapon and which charge will obtain a 50% casualty effect with the minimum number of bursts per unit area. With the range, gun, shell and propelling charge determined, the artilleryman can use the firing tables to obtain the probable error in the height of burst. This will be needed in Rule A which follows.

Height of burst. For the shells considered, the optimum height of burst against shielded personnel is for the most part between 25 and 50 feet. This optimum is for a controlled height of burst without dispersion in height. In actual practice the height of burst of a shell in time fire suffers considerable dispersion and the best *mean* height of burst is generally higher than the best controlled height. The following practical rule assures fragment damage near the optimum against enemy personnel in medium foxholes.

RULE A

ADJUST THE MEAN HEIGHT H OF BURST TO A VALUE WHICH IS TWICE THE PROBABLE ERROR IN THE HEIGHT OF BURST AS LISTED IN THE FIRING TABLES, RESTRICTING H, HOWEVER, TO VALUES BETWEEN 30 FEET AND 120 FEET.

9. THE REQUIRED SHELL DENSITY.

As in the case of ground bursts, the target area is given in terms of units of area (100 feet x 100 feet). Once the range, weapon and charge have been chosen, Figures 50 to 56 give the number D of air bursts per unit of area required to cause 50% casualties with the type of shielding indicated on the figure. It is assumed that the mean height of burst has been adjusted in accordance with Rule A.

As in the case of ground bursts, it is necessary to distribute D bursts per unit area not only over the given target area but also over a somewhat larger area. To this end Rule B may be used.

RULE B

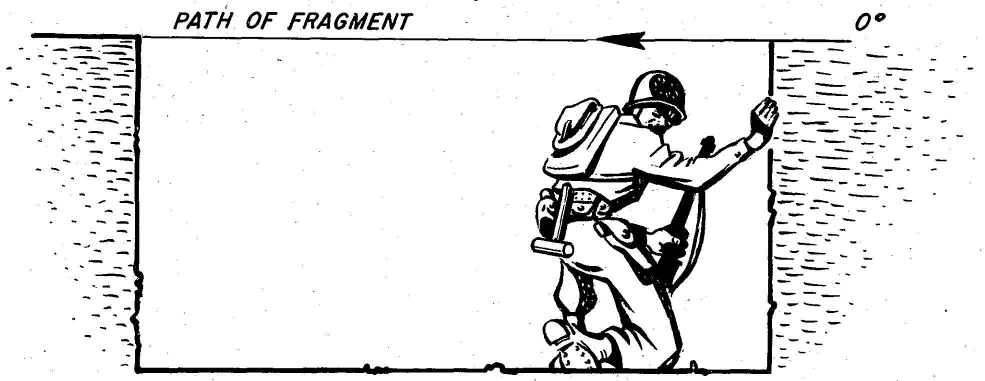
THE WIDTH W (FEET) OF THE ADDITIONAL FRINGE OF AREA IS VERY APPROXIMATELY EQUAL[2] TO THE MEAN HEIGHT H OF BURST, AS PRESCRIBED BY RULE A, PLUS 10 FEET.

If the percent casualties desired is p and not 50 percent it is sufficient as in the case of ground bursts to multiply the shell density D given by the graphs by the factor F written below p in Table 70.

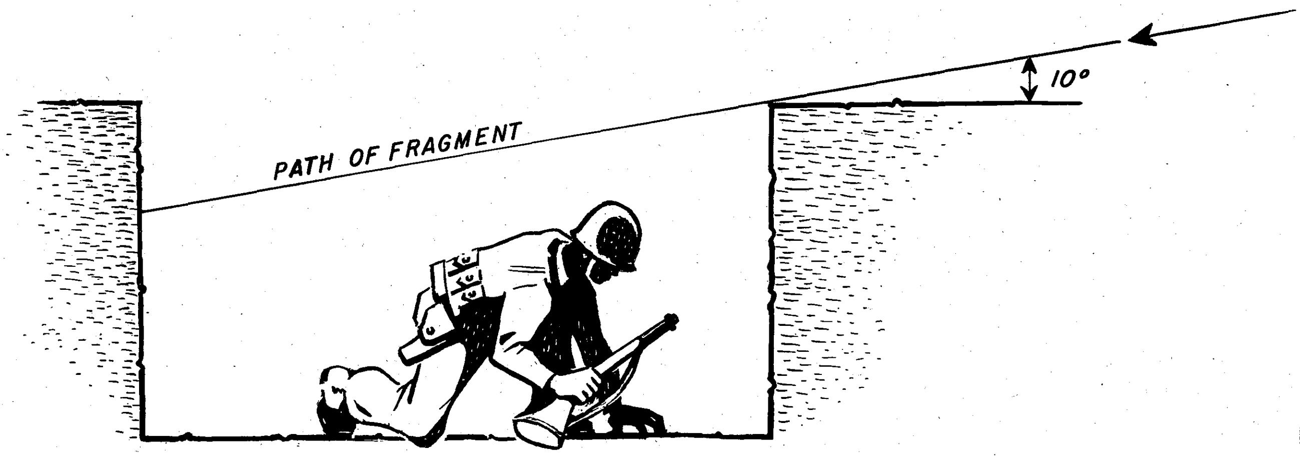
Example. Given an area target 100 feet x 500 feet, consisting of men in "10° foxholes," let it be required to wound 20 percent of the enemy personnel in the area using the 105mm Howitzer, M2A1 and Shell H.E., M1. Suppose the range is 5,000 yards.

Solution. For a range of 5,000 yards and for Charge 7, the firing table gives a probable error in the height of burst of 1 mil or 15 feet. Following Rule A, adjust the mean height H of burst to a value which is twice the probable error in the height of burst as listed in the firing tables, restricting H, however, to values between 30 feet and 120 feet. This gives H = 30 feet. According to Rule B, the width of additional fringe required is 30 + 10 = 40 feet so that the total area to be covered is 180 feet x 580 feet or 11 units (100 feet x 100 feet). Figure 54 shows that 7.5 shells are required per unit area so that 7.5 x 11 = 82.5 shells must be distributed over the enlarged area to obtain 50 percent casualties. To obtain 20 percent casualties, it appears from Table 70 that 82.5 x 0.322 = 27 shells should be distributed.

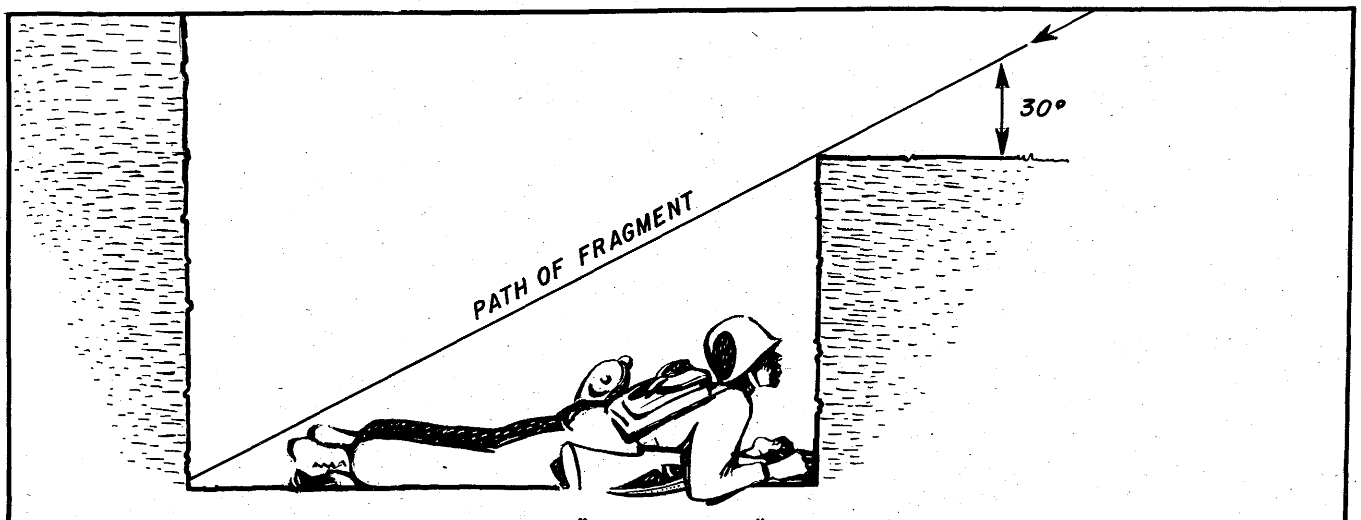
[2]Except in the case of the 155mm Howitzer in which case take W=2H.



"0° FOXHOLE"



"10° FOXHOLE"



"30° FOXHOLE"

HAND GRENADE, Mk. II

TNT Loading

INITIAL FRAGMENT VELOCITY 2,900 F/S

TABLE 34
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
10	312	0.217	0.011	2,330
20	254	0.0505	0.015	1,990
30	188	0.0166	0.022	1,640
40	147	0.0073	0.028	1,460
50	111	0.0035	0.035	1,310
60	86	0.0019	0.041	1,210
70	64	0.0010	0.048	1,120
80	47	0.0006	0.055	1,040
100	30	0.0002	0.067	943
120	19	0.0001	0.079	870
140	13	0.0001	0.089	817

TABLE 35
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
10	86	0.0686	0.041	2,550
20	43	0.0086	0.057	2,270
30	22	0.0020	0.075	2,080
40	11	0.0005	0.095	1,920
50	7	0.0002	0.120	1,810
60	4	0.0001	0.147	1,710
70	3	0.0001	0.176	1,610

20 mm HE SHELL, T16

INITIAL FRAGMENT VELOCITY 2,160 F/S

TABLE 36

CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
10	38	0.0304	0.018	1,820
20	27	0.0054	0.025	1,540
30	18	0.0016	0.033	1,340
40	12	0.0006	0.040	1,220
50	7	0.0002	0.050	1,090
60	6	0.0001	0.056	1,030
70	5	0.0001	0.062	980
80	5	0.0001	0.068	935

20 mm HEI SHELL, M97 (T23)

INITIAL FRAGMENT VELOCITY 1,960 F/S

TABLE 37

CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
10	30	0.0239	0.024	1,570
20	21	0.0042	0.033	1,340
30	15	0.0013	0.042	1,190
40	11	0.0005	0.050	1,090
50	10	0.0003	0.057	1,020
60	9	0.0002	0.063	972
70	8	0.0001	0.069	929
80	7	0.0001	0.075	891

75 mm HE SHELL, M48

INITIAL FRAGMENT VELOCITY 3,120 F/S

TABLE 38
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,070	0.213	0.014	2,060
30	920	0.0809	0.018	1,820
40	750	0.0375	0.024	1,570
60	640	0.0141	0.037	1,270
80	510	0.0064	0.051	1,080
100	450	0.0036	0.063	972
150	370	0.0013	0.090	813
200	320	0.0006	0.116	716
300	250	0.0002	0.173	587
400	200	0.0001	0.244	494

TABLE 39
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	534	0.106	0.049	2,390
30	442	0.0391	0.065	2,180
40	386	0.0192	0.082	2,010
60	300	0.0066	0.127	1,790
80	242	0.0030	0.185	1,580
100	197	0.0016	0.253	1,430
130	132	0.0006	0.375	1,270
160	86	0.0003	0.508	1,160
190	57	0.0001	0.655	1,080
225	39	0.0001	0.820	1,020

3 in. HE SHELL, M42A1

INITIAL FRAGMENT VELOCITY 2,260 F/S

TABLE 40
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	547	0.109	0.026	1,510
30	498	0.0440	0.033	1,340
40	465	0.0231	0.040	1,220
60	409	0.0090	0.055	1,040
80	370	0.0046	0.067	943
100	331	0.0026	0.080	862
150	282	0.0010	0.108	742
200	244	0.0005	0.137	660
300	191	0.0002	0.197	549
400	149	0.0001	0.275	466

TABLE 41
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	284	0.0565	0.106	1,860
30	242	0.0214	0.139	1,740
40	205	0.0102	0.177	1,600
60	151	0.0033	0.270	1,400
80	113	0.0014	0.375	1,270
100	90	0.0007	0.480	1,180
130	64	0.0003	0.648	1,080
160	43	0.0001	0.825	1,020
190	28	0.0001	1.01	963

81 mm HE SHELL, M43A1

INITIAL FRAGMENT VELOCITY 3,930 F/S

TABLE 42
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	818	0.163	0.009	2,570
30	695	0.0615	0.014	2,060
50	645	0.0321	0.017	1,870
60	541	0.0120	0.027	1,480
80	459	0.0057	0.038	1,250
100	384	0.0031	0.051	1,080
150	267	0.0009	0.077	880
200	169	0.0003	0.104	758
300	76	0.0001	0.159	611

TABLE 43
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	541	0.108	0.027	2,970
30	473	0.0418	0.036	2,670
40	407	0.0202	0.047	2,430
60	282	0.0062	0.073	2,090
80	164	0.0020	0.105	1,870
100	88	0.0007	0.146	1,720
120	58	0.0003	0.197	1,530
140	40	0.0002	0.258	1,420
180	23	0.0001	0.399	1,240

81 mm HE SHELL, M56

INITIAL FRAGMENT VELOCITY 6,180 F/S

TABLE 44
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	2,580	0.513	0.004	3,860
30	2,060	0.182	0.006	3,150
40	1,680	0.0836	0.008	2,720
60	906	0.0200	0.014	2,060
80	614	0.0076	0.021	1,680
100	412	0.0033	0.029	1,430
150	170	0.0006	0.056	1,030
200	112	0.0002	0.080	862
300	63	0.0001	0.128	682

TABLE 45
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,040	0.208	0.012	4,060
30	762	0.0674	0.017	3,580
40	583	0.0290	0.022	3,200
60	314	0.0069	0.035	2,700
80	193	0.0024	0.051	2,360
100	130	0.0010	0.071	2,110
120	76	0.0004	0.097	1,900
140	63	0.0003	0.128	1,780
170	40	0.0001	0.188	1,560

90 mm HE SHELL, M71

INITIAL FRAGMENT VELOCITY 2,900 F/S

TABLE 46
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	668	0.133	0.015	1,990
30	594	0.0525	0.022	1,640
40	547	0.0272	0.028	1,460
60	474	0.0105	0.041	1,210
80	427	0.0053	0.055	1,040
100	398	0.0032	0.067	943
150	347	0.0012	0.094	796
200	319	0.0006	0.120	705
300	264	0.0002	0.180	575
500	208	0.0001	0.340	418

TABLE 47
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	424	0.0844	0.057	2,270
30	380	0.0336	0.075	2,080
40	345	0.0172	0.095	1,920
60	288	0.0064	0.147	1,710
80	243	0.0030	0.210	1,500
100	222	0.0018	0.287	1,370
120	203	0.0011	0.377	1,260
150	163	0.0006	0.519	1,150
200	113	0.0002	0.772	1,040
275	59	0.0001	1.16	935

105 mm HE SHELL, M1

INITIAL FRAGMENT VELOCITY 3,500 F/S

TABLE 48
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,160	0.231	0.010	2,440
30	1,115	0.0986	0.014	2,060
40	1,072	0.0533	0.019	1,770
60	996	0.0220	0.030	1,410
80	932	0.0116	0.043	1,180
100	875	0.0070	0.055	1,040
150	745	0.0026	0.083	846
200	642	0.0013	0.109	738
300	513	0.0004	0.166	598
400	433	0.0002	0.232	507
500	358	0.0001	0.312	438

TABLE 49
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	975	0.194	0.035	2,700
30	923	0.0816	0.047	2,430
40	853	0.0424	0.061	2,220
60	700	0.0155	0.095	1,920
80	570	0.0071	0.137	1,750
100	470	0.0037	0.192	1,550
120	403	0.0022	0.255	1,420
140	341	0.0014	0.326	1,320
170	262	0.0007	0.448	1,200
200	210	0.0004	0.580	1,120
300	88	0.0001	1.05	955

105 mm HE SHELL, M38A1

INITIAL FRAGMENT VELOCITY 3,320 F/S

TABLE 50
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,120	0.222	0.012	2,230
30	1,090	0.0967	0.017	1,870
40	917	0.0456	0.023	1,620
60	807	0.0178	0.034	1,320
80	735	0.0091	0.047	1,130
100	680	0.0054	0.060	1,000
150	592	0.0021	0.088	822
200	529	0.0011	0.112	729
300	431	0.0004	0.170	592
400	360	0.0002	0.237	501
600	256	0.0001	0.412	380

TABLE 51
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	751	0.149	0.043	2,510
30	707	0.0625	0.053	2,330
40	652	0.0324	0.069	2,130
60	538	0.0119	0.107	1,860
80	448	0.0056	0.159	1,670
100	372	0.0030	0.222	1,480
120	326	0.0018	0.290	1,360
140	282	0.0011	0.367	1,280
170	223	0.0006	0.495	1,170
200	175	0.0003	0.632	1,090
300	85	0.0001	1.13	940

4.5 in. HE SHELL, M65

INITIAL FRAGMENT VELOCITY 2,810 F/S

TABLE 52

CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,310	0.261	0.017	1,870
30	1,220	0.108	0.023	1,620
40	1,180	0.0588	0.028	1,460
60	1,080	0.0240	0.043	1,180
80	1,030	0.0128	0.057	1,020
100	966	0.0077	0.069	928
150	879	0.0031	0.095	792
200	802	0.0016	0.122	698
300	661	0.0006	0.183	570
500	482	0.0002	0.342	417
700	371	0.0001	0.550	329

TABLE 53

PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	993	0.198	0.061	2,220
30	940	0.0831	0.079	2,040
40	864	0.0430	0.100	1,890
60	735	0.0162	0.153	1,690
80	606	0.0075	0.222	1,480
100	515	0.0041	0.303	1,340
120	443	0.0024	0.400	1,240
140	399	0.0016	0.493	1,170
170	337	0.0009	0.642	1,090
200	282	0.0006	0.802	1,020
300	155	0.0001	1.36	896

120 mm HE SHELL, M73

INITIAL FRAGMENT VELOCITY 2,410 F/S

TABLE 54
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	484	0.0963	0.022	1,640
30	467	0.0413	0.028	1,460
40	458	0.0228	0.036	1,280
60	435	0.0096	0.051	1,080
80	413	0.0051	0.065	958
100	398	0.0032	0.077	880
150	367	0.0013	0.103	760
200	333	0.0007	0.133	669
300	290	0.0003	0.199	547
400	263	0.0001	0.275	465
500	239	0.0001	0.366	403

TABLE 55
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	376	0.0748	0.089	1,960
30	350	0.0309	0.117	1,820
40	319	0.0159	0.149	1,710
60	278	0.0061	0.230	1,470
80	246	0.0031	0.333	1,310
100	228	0.0018	0.427	1,220
120	212	0.0012	0.531	1,150
140	198	0.0008	0.640	1,090
170	178	0.0005	0.809	1,020
200	160	0.0003	0.987	968
300	118	0.0001	1.58	859

155 mm HE SHELL, M107

INITIAL FRAGMENT VELOCITY 3,500 F/S

TABLE 56
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,460	0.291	0.010	2,440
30	1,400	0.124	0.014	2,060
40	1,360	0.0676	0.019	1,770
60	1,280	0.0283	0.030	1,410
80	1,190	0.0148	0.043	1,180
100	1,130	0.0090	0.055	1,040
150	990	0.0034	0.083	846
200	900	0.0018	0.109	738
300	767	0.0007	0.161	598
400	669	0.0003	0.233	505
600	540	0.0001	0.402	383

TABLE 57
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,240	0.247	0.035	2,700
30	1,170	0.104	0.047	2,430
40	1,100	0.0547	0.061	2,220
60	945	0.0209	0.095	1,920
80	820	0.0102	0.137	1,750
100	717	0.0057	0.192	1,550
120	648	0.0036	0.255	1,420
140	592	0.0024	0.326	1,320
170	513	0.0014	0.448	1,200
200	440	0.0009	0.580	1,120
300	265	0.0002	1.05	955
400	111	0.0001	1.61	856

8 in. HE SHELL, M103

INITIAL FRAGMENT VELOCITY 2,500 F/S

TABLE 58
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,860	0.370	0.020	1,730
30	1,770	0.156	0.027	1,480
50	1,680	0.0533	0.040	1,220
70	1,560	0.0253	0.055	1,040
100	1,470	0.0117	0.074	897
150	1,360	0.0048	0.101	768
200	1,260	0.0025	0.130	676
300	1,080	0.0010	0.195	553
500	865	0.0003	0.359	407
800	647	0.0001	0.715	289

TABLE 59
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	1,440	0.286	0.082	2,010
30	1,330	0.118	0.107	1,860
40	1,250	0.0622	0.136	1,750
60	1,060	0.0233	0.207	1,510
80	922	0.0115	0.293	1,360
100	835	0.0066	0.390	1,250
150	670	0.0024	0.655	1,080
200	567	0.0011	0.934	983
300	418	0.0004	1.52	867
500	257	0.0001	2.98	733

TABLE 60
PERFORATION OF 1/4 IN. MILD STEEL

r	N	B	m	v
20	762	0.152	0.485	2,230
30	711	0.0629	0.566	2,110
40	670	0.0333	0.655	2,020
60	590	0.0130	0.855	1,850
80	514	0.0064	1.10	1,710
100	447	0.0036	1.37	1,600
150	323	0.0011	2.16	1,390
200	252	0.0005	3.15	1,240
275	179	0.0002	4.70	1,110
400	106	0.0001	7.45	983

TABLE 61
PERFORATION OF 1/2 IN. MILD STEEL

r	N	B	m	v
20	245	0.0487	3.27	2,360
30	232	0.0205	3.55	2,290
40	225	0.0112	3.86	2,230
60	188	0.0042	4.53	2,110
80	156	0.0019	5.23	2,010
100	133	0.0011	5.97	1,930
120	119	0.0007	6.81	1,850
140	100	0.0004	7.72	1,780
170	80	0.0002	9.20	1,680
225	40	0.0001	13.3	1,470

240 mm HE SHELL, M114

INITIAL FRAGMENT VELOCITY 3,300 F/S

TABLE 62
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	4,160	0.825	0.013	2,140
30	4,080	0.360	0.017	1,870
50	3,660	0.117	0.028	1,460
70	3,310	0.0538	0.040	1,220
100	3,000	0.0239	0.060	1,000
150	2,720	0.0096	0.087	827
250	2,360	0.0030	0.140	652
400	1,990	0.0010	0.240	498
700	1,520	0.0002	0.521	338
1,000	1,050	0.0001	0.928	253

TABLE 63
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag- ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	3,250	0.647	0.042	2,530
30	3,070	0.271	0.055	2,300
50	2,720	0.0865	0.087	1,970
70	2,420	0.0393	0.132	1,770
100	2,040	0.0162	0.220	1,480
150	1,670	0.0059	0.412	1,230
200	1,360	0.0027	0.639	1,090
275	1,010	0.0011	0.980	970
400	638	0.0003	1.70	841
600	379	0.0001	3.05	729

TABLE 64
PERFORATION OF 1/4 IN. MILD STEEL

r	N	B	m	v
20	2,000	0.399	0.235	2,880
30	1,910	0.169	0.276	2,720
40	1,820	0.0903	0.325	2,560
60	1,640	0.0362	0.436	2,310
80	1,460	0.0182	0.560	2,120
100	1,280	0.0102	0.700	1,970
150	885	0.0031	1.17	1,680
200	622	0.0012	1.75	1,480
300	362	0.0003	3.28	1,230
500	177	0.0001	7.05	997

TABLE 65
PERFORATION OF 1/2 IN. MILD STEEL

r	N	B	m	v
20	700	0.139	1.54	3,070
30	638	0.0564	1.70	2,980
40	597	0.0297	1.85	2,880
60	498	0.0110	2.23	2,700
80	432	0.0054	2.60	2,550
100	383	0.0030	3.01	2,420
150	333	0.0012	4.22	2,160
200	251	0.0005	5.60	1,970
250	165	0.0002	7.27	1,810
300	82	0.0001	9.15	1,680

4.5 in. HE ROCKET SHELL, T22

TNT Loading

NOSE SECTION

INITIAL FRAGMENT VELOCITY 3,500 F/S

TABLE 66
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	377	0.228	0.010	2,440
30	316	0.0850	0.014	2,060
40	264	0.0400	0.019	1,770
60	199	0.0134	0.030	1,410
80	152	0.0057	0.043	1,180
100	125	0.0030	0.055	1,040
150	102	0.0011	0.083	846
200	93	0.0006	0.109	738
300	76	0.0002	0.166	598
400	59	0.0001	0.232	507

TABLE 67
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective frag-ments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	179	0.108	0.035	2,700
30	143	0.0384	0.047	2,430
40	112	0.0170	0.061	2,220
60	99	0.0066	0.095	1,920
80	84	0.0032	0.137	1,750
100	68	0.0016	0.192	1,550
120	52	0.0009	0.255	1,420
150	36	0.0004	0.365	1,280
200	23	0.0001	0.580	1,120
225	18	0.0001	0.700	1,060

Remaining velocity of rocket = 500 f/s

The nose section limits are 0° and 70° from the nose.

4.5 in. HE ROCKET SHELL, T22

TNT Loading

SIDEWALL SECTION

INITIAL FRAGMENT VELOCITY 4,000 F/S

TABLE 68
CASUALTIES

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	868	0.410	0.009	2,570
30	695	0.146	0.014	2,060
40	601	0.0710	0.018	1,820
60	456	0.0240	0.028	1,460
80	353	0.0104	0.040	1,220
100	289	0.0054	0.052	1,070
150	231	0.0019	0.078	873
200	207	0.0010	0.104	758
300	168	0.0004	0.160	610
400	130	0.0002	0.223	517

TABLE 69
PERFORATION OF 1/8 IN. MILD STEEL

Distance from burst (ft)	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight (oz)	Velocity (f/s)
r	N	B	m	v
20	481	0.227	0.026	3,020
30	390	0.0819	0.035	2,700
40	321	0.0379	0.045	2,470
60	236	0.0124	0.071	2,110
80	207	0.0061	0.104	1,870
100	180	0.0034	0.144	1,720
120	148	0.0020	0.195	1,540
150	102	0.0008	0.290	1,360
200	61	0.0003	0.474	1,190
250	41	0.0001	0.680	1,070

Remaining velocity of rocket = 500 f/s

The sidewall section limits are 70° and 120° from the nose.

4.5-IN. HE ROCKET SHELL, T22

CASUALTIES

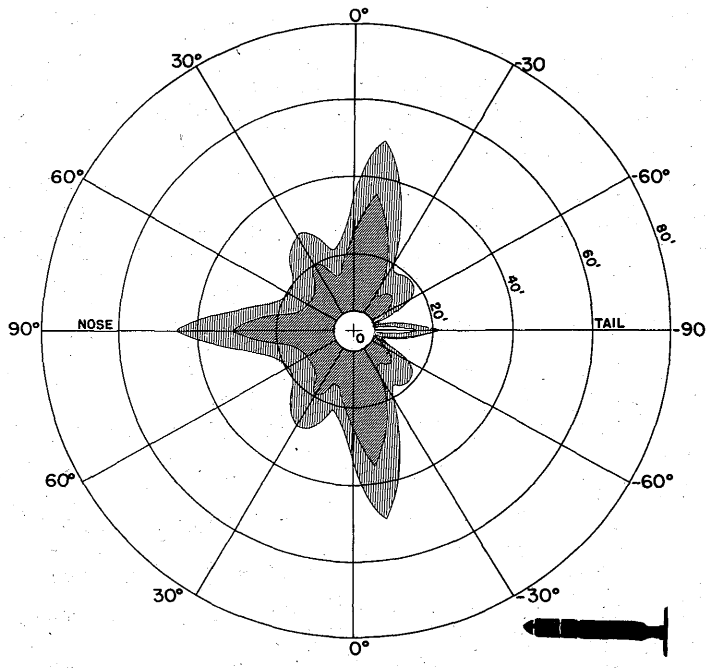


FIGURE 21

PERFORATIONS OF 1/8-IN. MILD STEEL

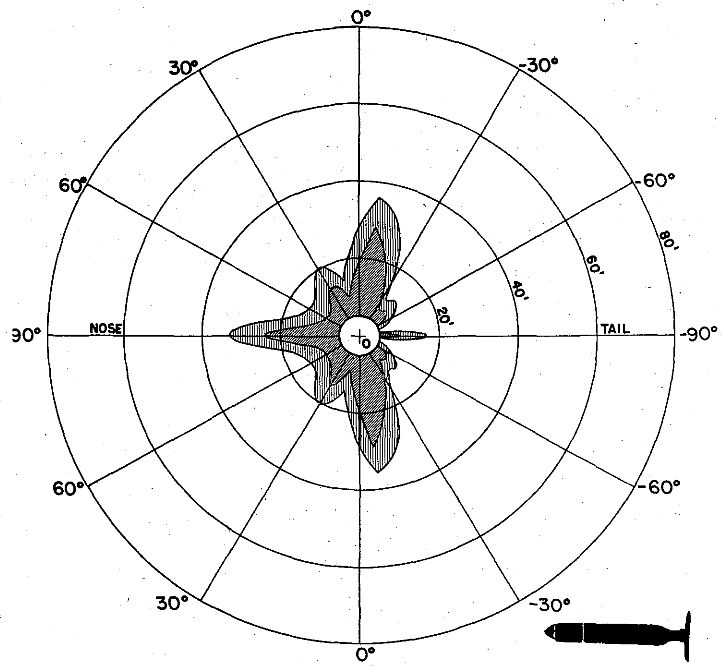
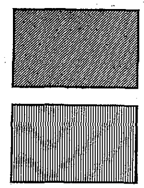


FIGURE 22

Ground Burst
Rocket Horizontal at Rest



At least 1 hit per 4 sq. ft.

At least 1 hit per 10 sq. ft.

4.5-IN. HE ROCKET SHELL, T22

CASUALTIES

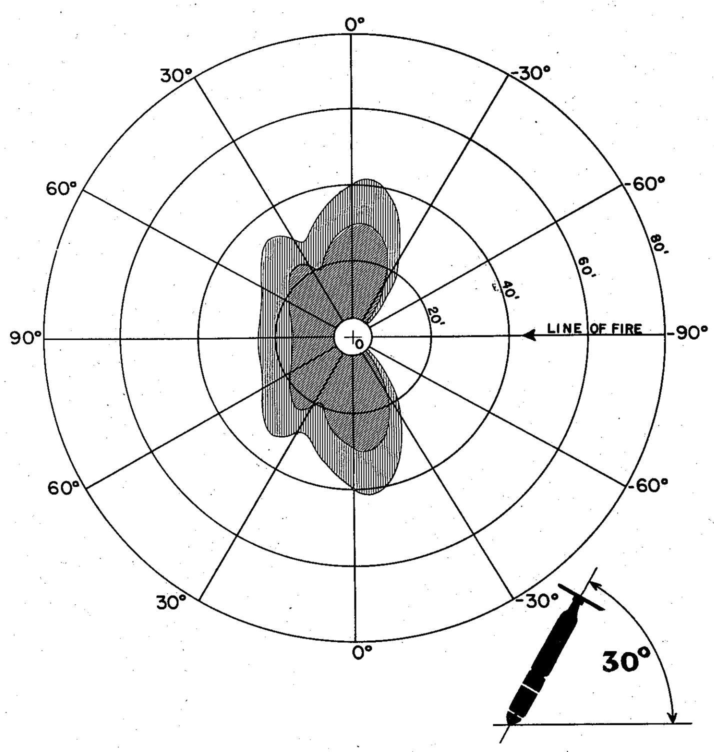


FIGURE 23

PERFORATIONS OF ⅛-IN. MILD STEEL

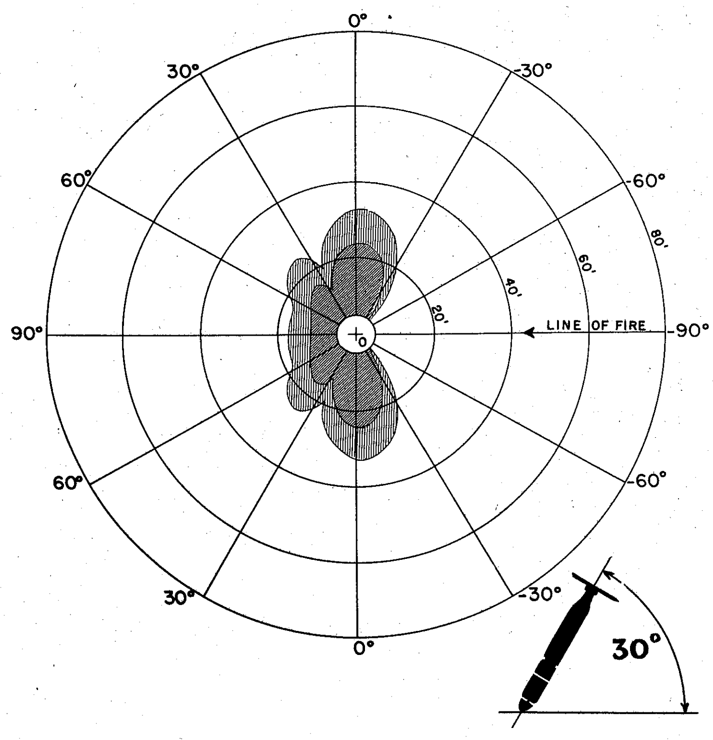
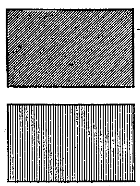


FIGURE 24

Ground Burst
Remaining Velocity 500 f/s



At least 1 hit per 4 sq. ft.

At least 1 hit per 10 sq. ft.

GROUND BURSTS

SHELL DENSITIES REQUIRED IN AREA FIRE

Figures 25 to 49 give the shell densities D per unit area (100 feet x 100 feet) required to cause damage of the type specified on the graph. To obtain p percent casualties or damage to p percent of the materiel target elements (see paragraph 6), the values of D obtained from the graphs should be multiplied by the factor F given in the following table under p.

TABLE 70

Percent p	10	20	30	40	50	60	70	80	90
The factor F	0.150	0.322	0.516	0.740	1.00	1.32	1.74	2.32	3.32

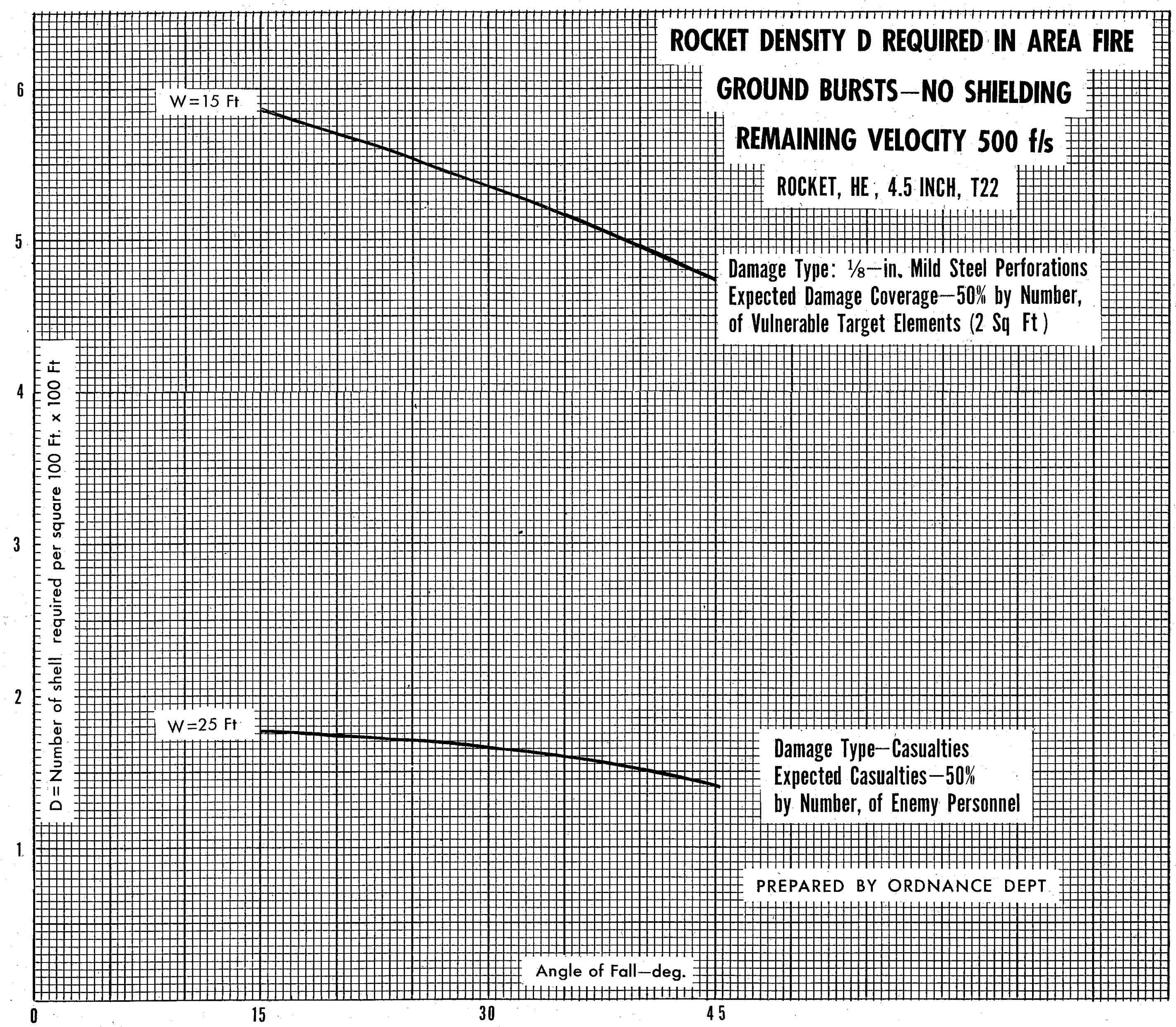
In case the target area is not flat or is shielded, or the men are not standing, the above values of D should be multiplied by an appropriate factor. Estimates of this factor are given below for a number of typical cases.

MEN

Factor	The Tactical Case
3	Men prone, flat terrain, no shielding.
2	Men standing, rolling terrain, no shielding.
4	Men prone, rolling terrain, country fields.

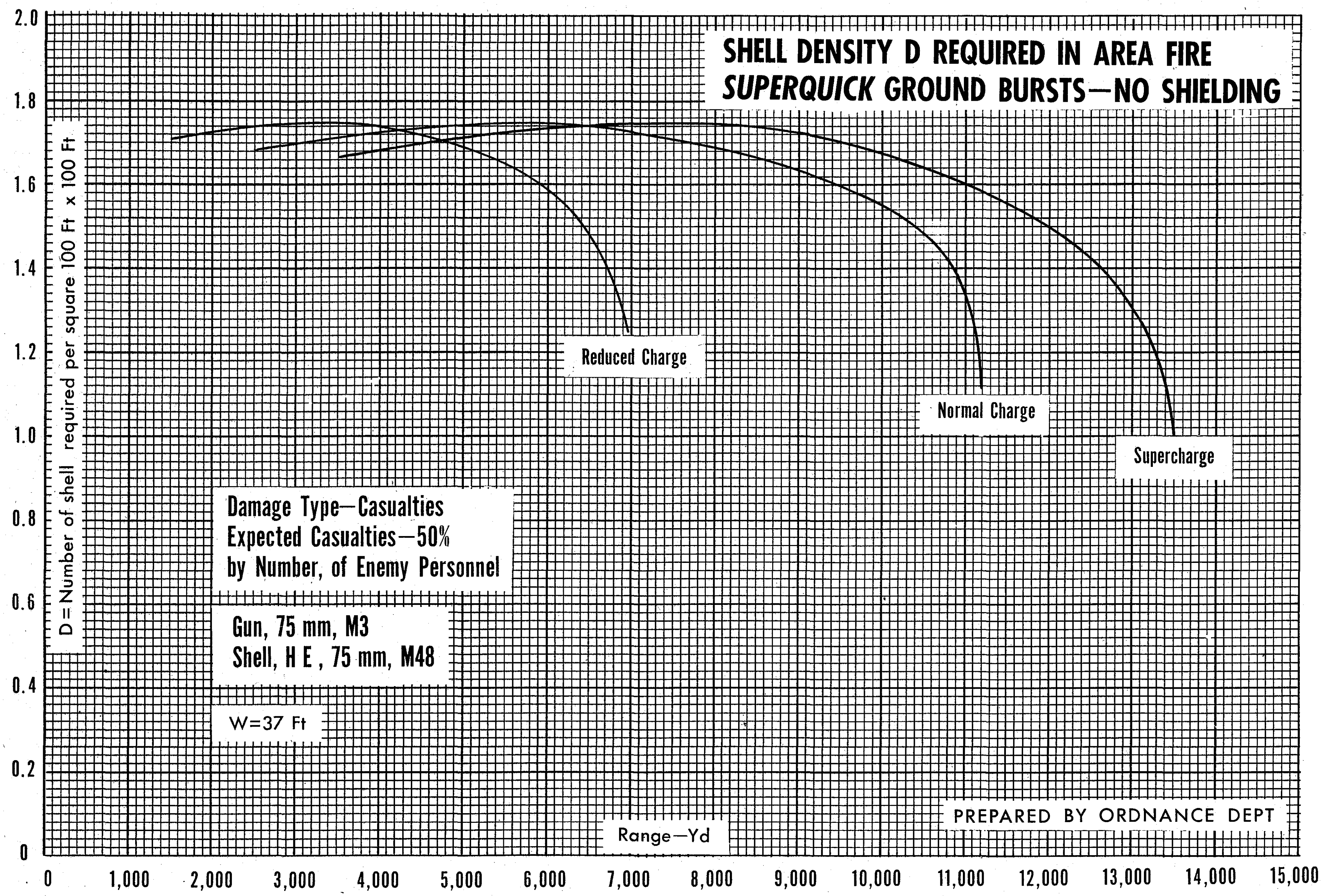
MATERIEL

Factor	The Tactical Case
2	Rolling terrain, no shielding.
3	Rolling terrain, rough country.



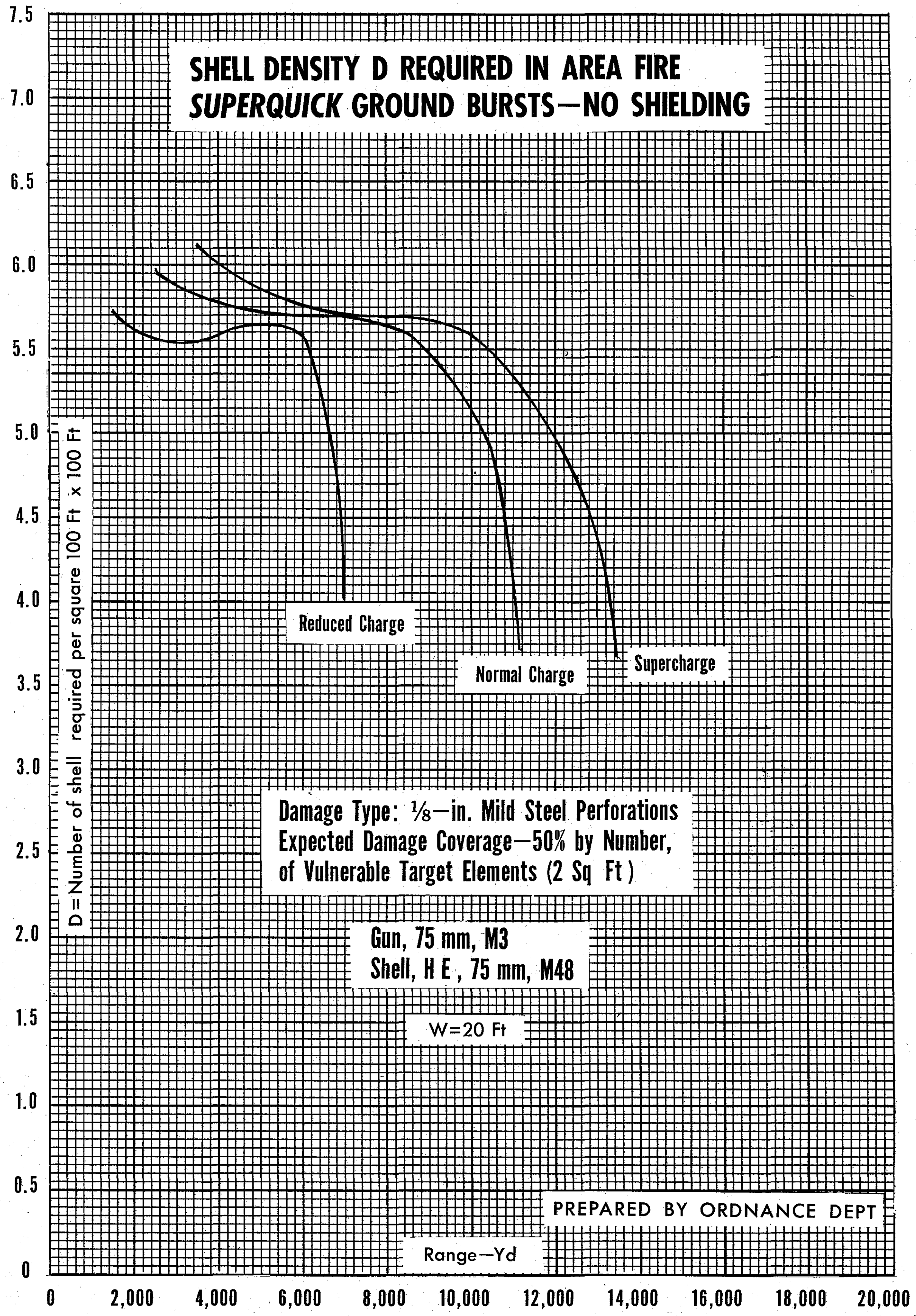
W=Width of fringe around target area requiring the burst density D.

FIGURE 25



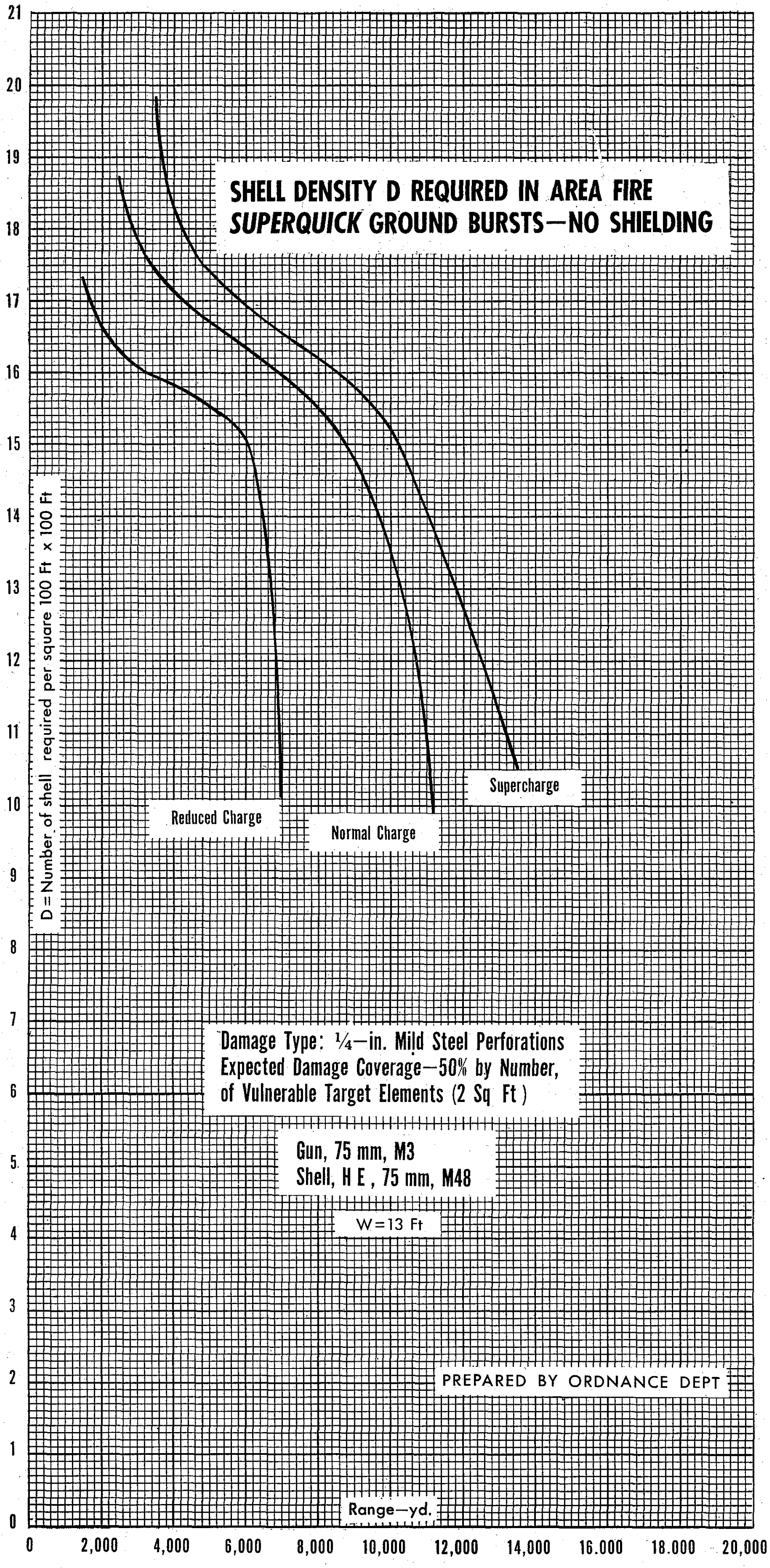
W=Width of fringe around target area requiring the burst density D.

FIGURE 26



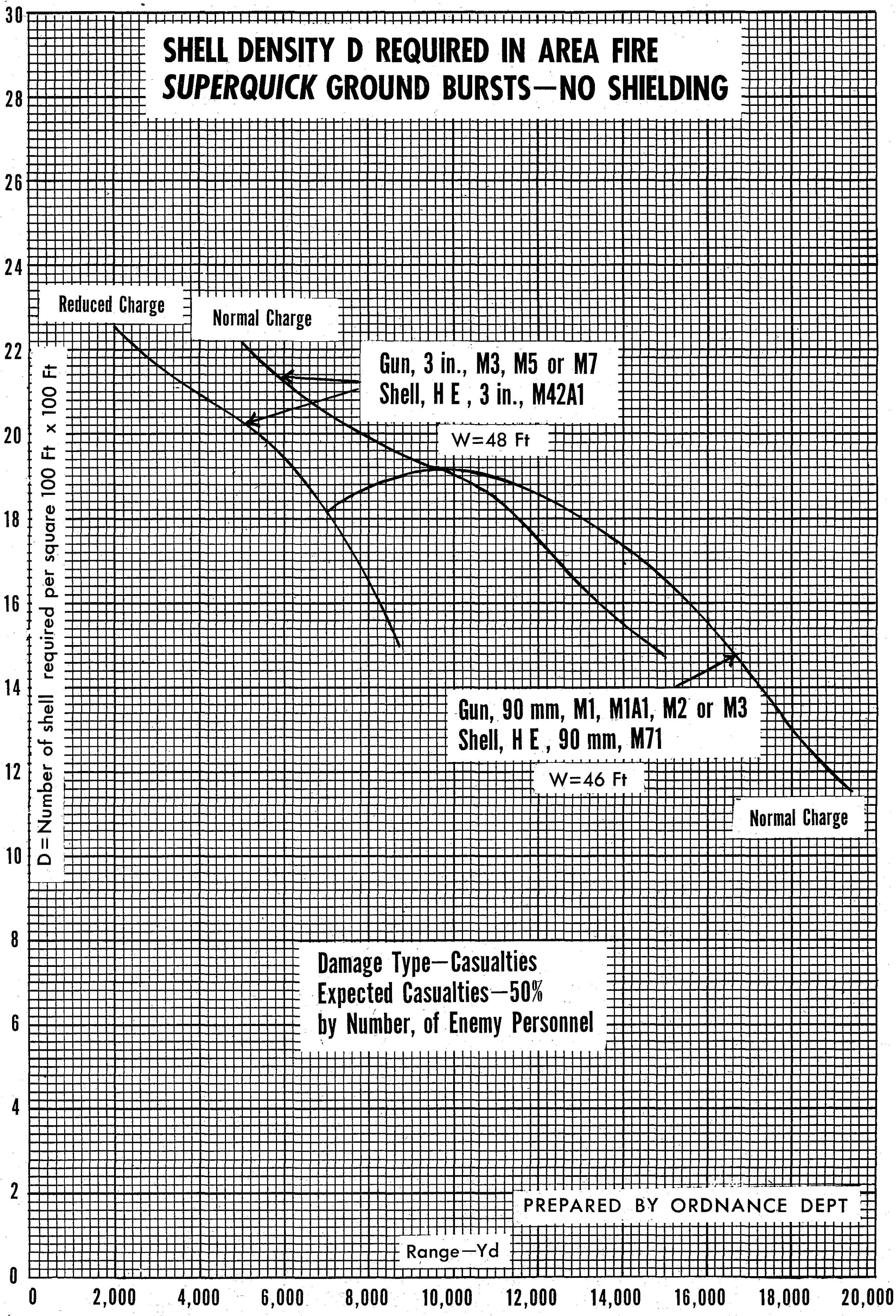
W=Width of fringe around target area requiring the burst density D.

FIGURE 27



W=Width of fringe around target area requiring the burst density D.

FIGURE 28



W=Width of fringe around target area requiring the burst density D.

FIGURE 29