Confidential

WEAPON DATA

FIRE
IMPACT
EXPLOSION

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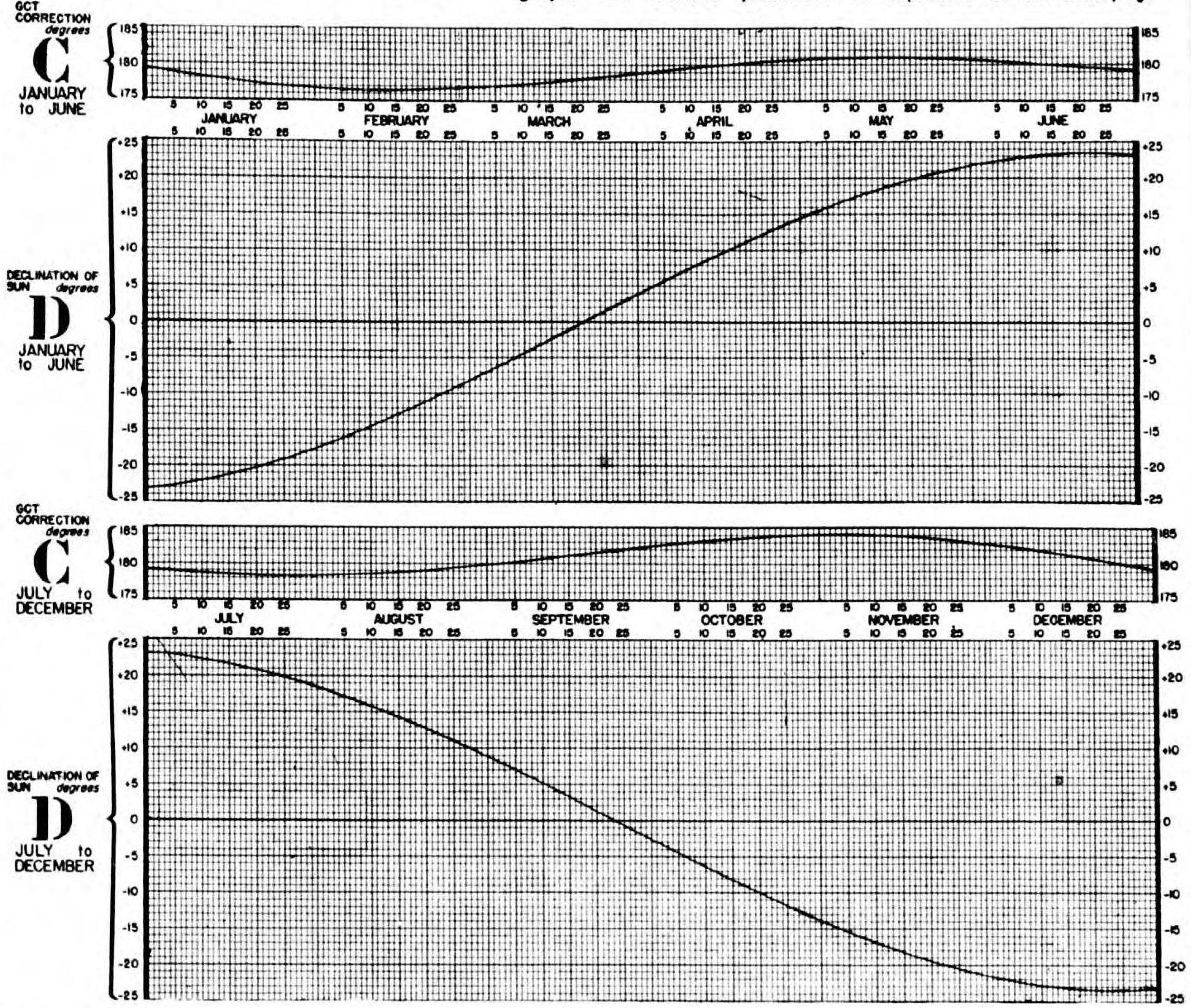
DIVISION 2, NATIONAL DEFENSE RESEARCH COMMITTEE
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

SOLAR SHADOW RATIO CHART

FOR

DETERMINING THE HEIGHT OF AN OBJECT FROM THE LENGTH OF ITS SHADOW

The following double page presents a graphical method for determining the height of an object from the length of its shadow as measured, for example, on a vertical aerial photograph. The detailed procedure is explained on the next page



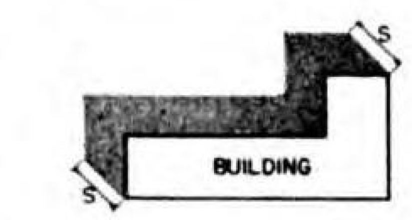
DATA

The following must be known at the time the aerial photograph was taken:

I. MONTH and DAY

II. GREENWICH CIVIL TIME (GCT)
It must be expressed *in degrees*
1 hr. = 15°

III. LATITUDE (LAT) and LONGITUDE (LONG)
Measured in degrees
North LAT is (+) South LAT is (-)
LONG East is (+) LONG West is (-)



NOTE Shadow length (S) is as measured on level ground

For vertical photographs, it is determined by measuring from some point on the object (such as a corner of the roof) to the corresponding point of the shadow on the ground, taking into account the scale of the photograph.

PROCEDURE

1. Read C on the above graph

2. Compute the Local Sun Time (T)
   T = GCT + C + LONG
   NOTE: If T turns out negative, discard the minus sign;
   If T exceeds 360°, <u>subtract</u> 360° from it;
   If T still is greater than 180° subtract it <u>from</u> 360°

3. Spot T on the bottom scale of the nomogram on the opposite page (see sketch)

4. Read D on the above graph

5. Compute LAT - D and LAT + D
   NOTE If either result turns out negative, discard the minus sign

6. Spot LAT-D and LAT+D on the nomogram on the opposite page — connect these points with a straight INDEX LINE (see sketch)

7. From the point for T, project upward to the INDEX LINE and across to the right, reading the value of H/S (see sketch)

8. **Measure shadow length (S)**

9. **Object Height (H) = (H/S) x (S)**

EXAMPLE

Given: Date = March 3
GCT = 2000 Hours = 300°
LAT = 35° N = +35°
LONG = 65° W = -65°

1. C = 177°

2. T = 300° + 177° + (-65°) = 412°
   412° - 360° = 52°

3. See sketch of nomogram

4. D = -7°

5. LAT - D = 35° - (-7°) = 42°
   LAT + D = 35° + (-7°) = 28°

6. See sketch

7. H/S = 0.48

8. Shadow on photo measures 9mm.
   Scale of photo: 1mm = 6.2 ft.
   ∴ S = 9 x 6.2 = 56 ft.

9. Object Height (H) = 0.48 x 56 ft.
   = 27 ft.

SKETCH OF NOMOGRAM

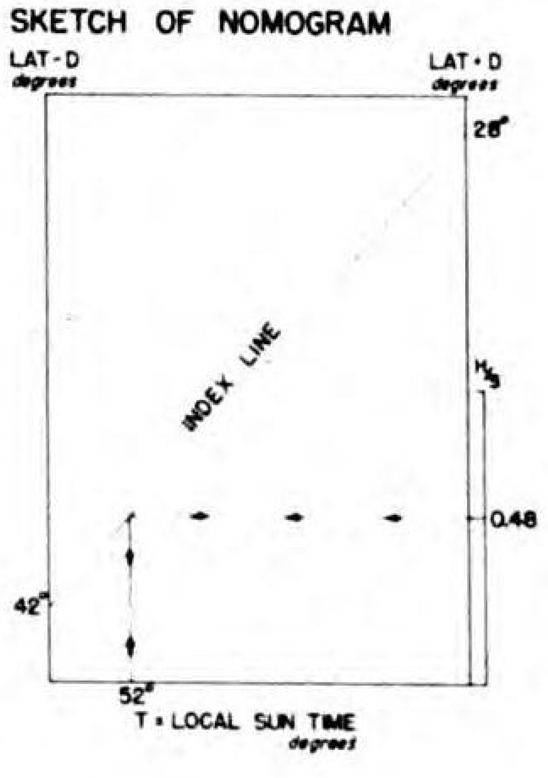


Table of Contents

Final Edition

* revised data sheets replacing former equivalent sheets

Foreword

This volume represents the final edition of a loose-leaf notebook containing sheets designed to give, in compact and accessible form, quantitative information needed in the defense and attack of various targets where airborne or ground weapons are used. The weapons considered include high explosive bombs, incendiary bombs, inert and high explosive projectiles, rockets and demolition charges. The primary concern is with the effect of the weapon on the target; auxiliary information on the physical characteristics of the weapons and their delivery to the target is included.

The first publication of the notebook contained fifteen data sheets and six incident summaries. Fifty copies were distributed on July 1, 1943. Additional loose-leaf sheets have been prepared and old sheets revised as necessary; the book now contains eighty-one data sheets and seventeen incident summaries. The distribution list has grown rapidly. More than 350 copies of the original desk-size edition have been distributed and nearly 600 copies of a pocket-size edition, first published in February 1945, have been issued. In addition to this direct distribution the Eighth Air Force reproduced 600 copies for their own use, and later USSTAF requested 1500 copies to continue this distribution. Several of the sheets have been reproduced and issued in various reports and manuals.

The final preparation of all sheets was done at Princeton University under Division 2, contract OEM-sr 260, and the analytical work on most of the material was done there. Much material prepared by other contractors of Division 2 and by other Divisions of the National Defense Research Committee, especially Section 11.3 of Division 11, has been included.

The choice of subject matter for the data sheets was greatly dependent on the work being carried out at the Princeton University Station of Division 2. Experimental work on armor perforation, air blast, earth shock and model tests of various targets has been performed at Princeton and the material used in preparation of data sheets, along with other data when available. The extensive programs of the Committee on Passive Protection Against Bombing and the Committee on Fortification Design, National Research Council, were closely related to the work of the Princeton University Station of Division 2 and the results of these tests have been used in the preparation of several data sheets. Some of the results of these investigations, such as model tests of damage to underground walls and ricochet of projectiles from concrete, have been reported only by data sheets.

The notebook includes a principal section called *Weapon Data* and an *Appendix* containing auxiliary information. The *Weapon Data* sheets deal for the most part with individual phenomena which have been studied extensively, such as penetration and perforation, and blast pressure and impulse. These sheets are based on analysis of large quantities of raw data, and where possible generalizations have been derived which allow quantitative prediction of results. Another group of *Weapon Data* sheets deals with target vulnerability and includes generalizations based on study of a number of operations reports and on analysis of the targets in terms of the fundamental phenomena observed when a weapon functions.

The *Appendix* includes sheets of an ancillary nature, Incident Summaries, and a list of the principal sources of information for the sheets. The Incident Summaries are included since they give a picture of the extent and interrelation of the several types of damage; they had the original advantage of making such information available before a large enough quantity was at hand for drawing general conclusions.

The results of bombing show wide variations among experiments conducted under supposedly identical conditions. This is particularly true in the case of structural effects where the results are strongly dependent on the details of the structure and the location of the bomb. It is thus possible that many incidents will result in much greater or much less damage than that predicted by the data sheets. Such variations are well illustrated by several of the Incident Summaries. The data sheets are based on averaging large quantities of data and attempt to give the results that would be the average of a number of incidents.

The notebook was originally issued in loose-leaf form so that available material could be distributed at once and new material added as it became available. In an expanding field there is always more to be done, and the termination of the project left undone many revisions and additions that would have been undertaken if the work had continued. In Section 1 of the book, sheets listing physical characteristics of other weapons such as rockets, armor piercing and high explosive projectiles, and hand and rifle grenades should be added, and sheets giving the striking velocities of artillery projectiles and rockets should be included. Many revisions and additions should be made in Section 2, which deals with penetration and perforation. The information given on penetration, perforation and scabbing of concrete should be revised as indicated in the list of source material in the *Appendix*; new material on perforation of armor should be incorporated in the sheets on that subject. The important problem of ricochet with all the variations made possible by different projectile designs has scarcely been touched. Sheets giving information on penetration and perforation of other materials such as stone, brickwork, and wood, and some information on underground and underwater trajectories would be useful additions to this section.

Section 3, dealing with the primary effects of explosions, deserves great enlargement. The dependence of the peak pressure of a blast wave on the bomb casing, the method of detonation and the energy loss in cratering is not fully understood; the situation regarding the positive impulse in the blast wave is somewhat better but could be improved. The effects of cone-end and other shaped charges and the effects of contact charges should receive more extensive treatment, and the sheet on perforation of concrete by cone-end charges needs revision. More experimental work is needed to provide data for further sheets on the effects of underground explosions, the effect of changing the depth of the explosive being one of the more important unknown quantities. More sheets are needed on the effects of underwater explosions.

In the original plan of the notebook, Section 4 was to contain information of a fundamental nature on the effects of incendiaries, and Section 5 was to contain information on fragmentation. Some information on the effects of incendiaries on industrial buildings and a small amount of data on the Mean Area of Effectiveness of fragmentation bombs acting on discrete targets is given in Section 6, but these two important subjects have not been studied for inclusion in the notebook. Any continuation of the work should certainly include detailed studies of fire effects and fragmentation.

Section 6, dealing with target vulnerabilities, includes sheets of two types: one group of sheets contains information on the effects of explosive weapons on components of structures; another group includes studies of the effects of weapons on targets treated as a whole. It was at first thought that the vulnerability of a target could be understood by making a detailed study of the effects of weapons on the several components and then synthesizing this information into a quantitative measure of the vulnerability of the target as a whole. The complexity of many targets and the interrelations of the various types of damage have forced the conclusion that a study of the vulnerability of the target as a single entity is the better approach.

Studies of more target types should be included in Section 6. The choice of targets treated was in most cases dictated by the availability of information and by specific requests from the Services. Additional targets for investigation will be suggested by examination of references 143-152 in the list of source material in the *Appendix*.

Several of the revisions suggested here are discussed in more detail in the list of sources of information in the *Appendix*. Many of the data needed for revisions of present sheets or addition of new sheets have been published recently, but time has not allowed the revisions or preparation of new sheets.

Many of the sheets are based on material generously made available through cooperation of the various Service branches and other research organizations. Especial thanks are due to the Research and Experiments Department of the Ministry of Home Security, Great Britain, who have sent us a complete file of their reports on weapon effectiveness and many of their work sheets and Data Compilations; the Ordnance Department, United States Army, who have been generous in giving us their reports and advice in consultations; the Office of the Chief of Engineers, United States Army, who have made data originating in their test programs available to us; the Bureau of Ordnance and the Bomb Disposal School, United States Navy, who have been of invaluable assistance; the Technical Division of the Chemical Warfare Service and the Army Air Forces Board, who have been of great help, especially in providing material concerning incendiaries. Some of the material provided by these and other organizations has been used directly in preparation of the data sheets; in other instances we have received raw data drom these sources and have made our own analysis and interpretation. We assume full responsibility for all such interpretation that appears in this book.

Other collections of data covering the same general ground have been published since the initiation of this project. Several of these are listed as "General References" in the *Appendix*. In many cases the information is necessarily taken from the sources used in preparation of this volume and data sheet material from this book is frequently quoted or reproduced in other publications. Such duplication and repetition should not be construed as lending authority to the information.

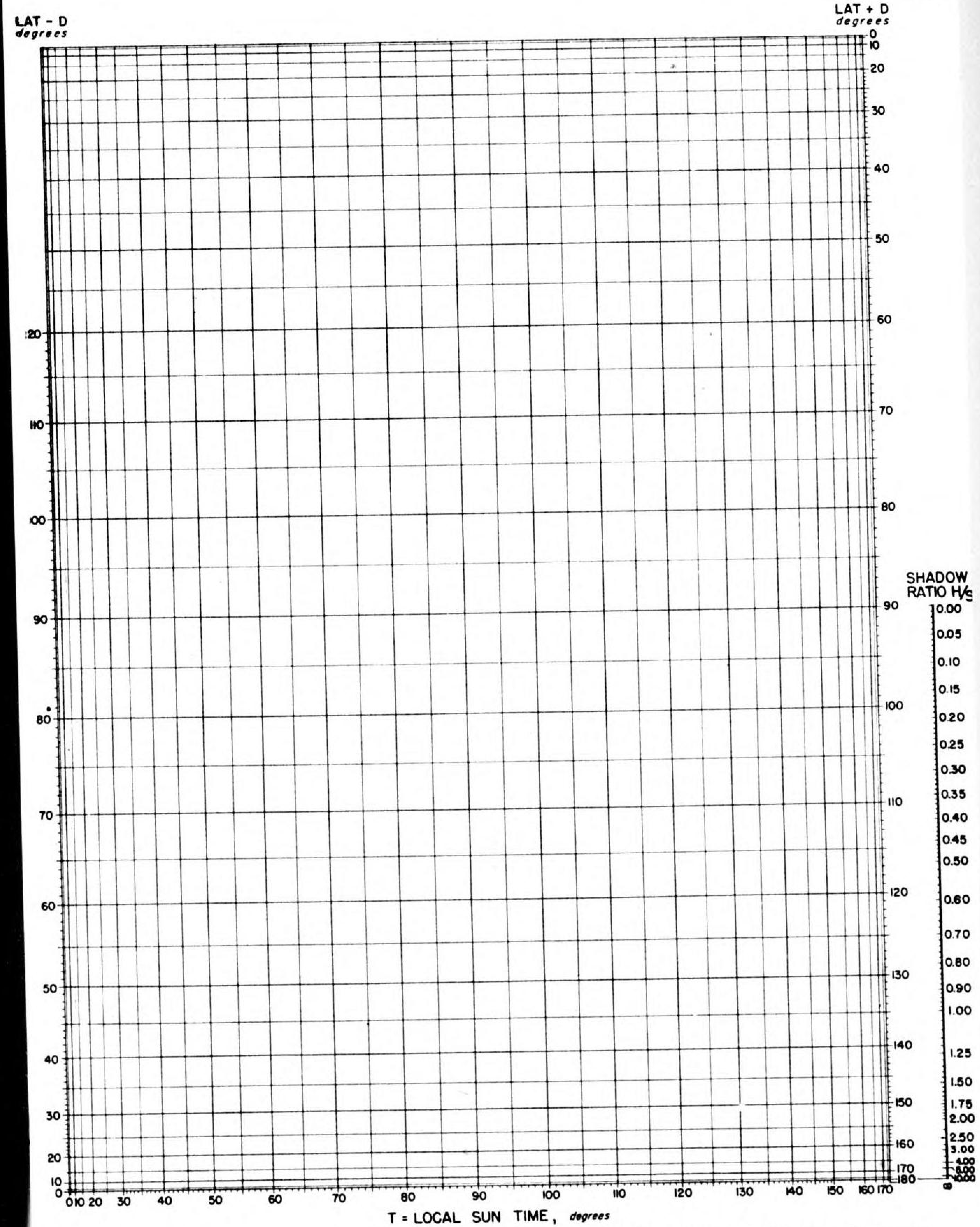
The individuals who have been most closely connected with guiding the conception and development of this notebook are Messrs. Walker Bleakney, J. E. Burchard, I. M. Freeman, N. M. Newmark, F. G. Roth, R. J. Slutz, J. G. Stipe, Jr., A. H. Taub, and E. B. Wilson, Jr., - all of Division 2 - and Mr. R. H. Ewell of Division 11.

Princeton, New Jersey

October 1945

copy no: 1083

SHADOW RATIO NOMOGRAM



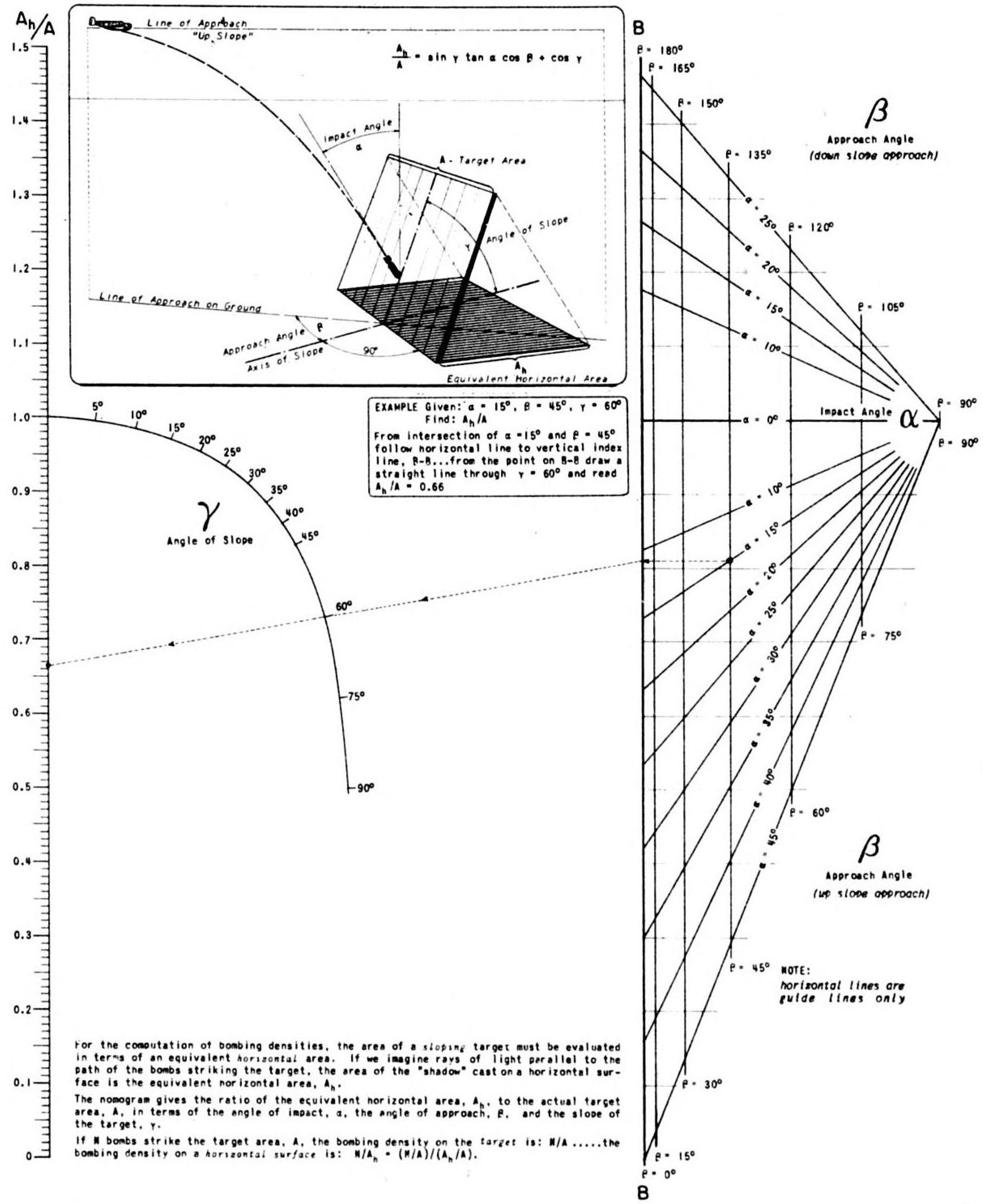
NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2: PRINCETON UNIVERSITY STATION

DATE: JULY, 1944

WEAPON DATA

EQUIVALENT HORIZONTAL AREA FOR A SLOPING TARGET

0 M 2 EQUIVALENT HORIZONTAL AREA



EXAMPLE Given: $\alpha = 15°$, $\beta = 45°$, $\gamma = 60°$
Find: A_h/A

From intersection of $\alpha = 15°$ and $\beta = 45°$ follow horizontal line to vertical index line, B-B...from the point on B-B draw a straight line through $\gamma = 60°$ and read $A_h/A = 0.66$

For the computation of bombing densities, the area of a *sloping* target must be evaluated in terms of an equivalent *horizontal* area. If we imagine rays of light parallel to the path of the bombs striking the target, the area of the "shadow" cast on a horizontal surface is the equivalent horizontal area, A_h.

The nomogram gives the ratio of the equivalent horizontal area, A_h, to the actual target area, A, in terms of the angle of impact, α, the angle of approach, β, and the slope of the target, γ.

If N bombs strike the target area, A, the bombing density on the *target* is: N/A .....the bombing density on a *horizontal surface* is: $N/A_h = (N/A)/(A_h/A)$.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

EWT 3 (PMR 73)
April 1945

WEAPON DATA

EXPLOSIVE FILLINGS FOR WEAPONS: PROPERTIES AND USES

1A1 EXPLOSIVE FILLINGS

DESIGNATION and COMPOSITION	USUAL LOADING DENSITY, d specific weight	VELOCITY OF DETONATION, m/sec, at density given	HEAT OF EXPLOSION[4] cal/gm	RELATIVE POWER (TNT = 100) EQUAL VOLUME BASIS: AIR BLAST Peak Press.	AIR BLAST Impulse	EARTH SHOCK Peak Press.	EARTH SHOCK Impulse	EARTH SHOCK Crater Diam.	UNDERWATER Peak Press.	UNDERWATER Impulse	FRAGMENTATION Initial Frag. Velocity	SENSITIVITY[5]	STABILITY[6]	PHYSICAL FORM LOADED	USES	REMARKS
TNT Trinitrotoluene (triton, trotyl, etc.)	1.57-9 cast; 1.55-61 pressed	6800 cast	1080	100	100	100	100	100	100	100	100	9	Very stable 7^B	Med. & large weapons are cast; small shell & demo chgs pressed	Standard main filling in almost every type of ordnance. Also used for blasting and demolition.	Other explosives now coming into use for bombs and shells.
AMATOL Ammonium nitrate and TNT from 40/60 to 80/20	1.55 50/50; 1.46 80/20	6300 50/50	970	93	88	108	110	102	104	106	107	9	Very stable, but very hygroscopic & hence corrosive to metal parts.	Up to 50/50 cast; 80/20 extruded.	Bursting charge for bombs and shells. Originally a TNT substitute, now in very limited use.	Produces less smoke than TNT. Only 50/50 mixture now loaded in USA.
TETRYL (CE) Trinitrophenylmethylnitramine (tetralite, pyronite)	1.55 pressed	7300 pressed	1130		105 about				100	110		5	Stable, except above melting point (130°C). 7^A, 7^B	Pressed into pellets.	Standard booster explosive for HE shells. Base for service tetryl caps for detonation of TNT	Too sensitive for main charge in all but 20 mm shells. Irritating to skin
TETRYTOL Tetryl and TNT from 50/50 to 80/20	1.60 50/50; 1.51 80/20	7200 (1.60)	1020 about		105 about							7	Moderately stable. Some exudation above 65° C. 7^A, 7^B	Cast	Almost exclusively used as a demolition explosive. Demo. block mixture is usually 75/25.	
EXPLOSIVE D Ammonium picrate (Dunnite)	1.48	6500	800								95	10	Very stable; somewhat hygroscopic. Slight danger of forming sensitive metal salts.	Pressed in increments	Main charge for AP bombs & shells and all explosive Navy projectiles over 3 inches.	Preferred to TNT or Amatol for AP weapons because less sensitive to shock.
PICRATOL 52% Ammonium picrate, 48% TNT	1.62													Cast	Filling for SAP bombs.	
COMPOSITION A 91% RDX[1], 9% wax or plasticizing oil.	1.62 about	8100	1210								116	9	Very stable, but wax exudes above 80° C. 7^B	Pressed	Now being loaded into AA shells. Also suitable for small caliber AP shell.	Wax desensitizes and permits pressing into cases
COMPOSITION B Cyclotol, RDX-Composition B B1: 59% RDX[1], 40% TNT, 1% wax B2: 60% RDX, 40% TNT.	1.60	7500	1200	110	110	112	106	109	110	108	117	7	Very stable. 7^B	Cast	More powerful replacement for TNT in large GP and Frag. bombs. High shaped-charge efficiency.	Admixture of TNT reduces RDX sensitivity, permits casting. Wax reduces sensitivity somewhat
COMPOSITION C-3 77% RDX[1], 4% TNT, 5% MNT[2], 10% DNT[3], 3% Tetryl, 1% Nitrocellulose.	1.58	7800			116 about							9	Moderately stable, tends to harden in storage. Special packaging needed to prevent exudation even at 55° C.	Plastic	Almost exclusively used as a demolition explosive.	Original Comp. C modified to provide a good explosive for molded & shaped charges.
TORPEX 2 42% RDX[1], 40% TNT, 18% Aluminum with 1% wax added (see remarks)	1.71	7200	1820	122	125				116	127	116	6	Very stable. 7^B, 8	Cast	Mainly in underwater ordnance; mines, torpedo warheads, depth bombs.	Original mixture, TPX-1, was 45% RDX, 37% TNT, 18% Al + 1% wax. Torpex-3 is TPX-2 with ½% $CaCl_2$, to reduce gas formation.
HBX 40% RDX, 38% TNT, 17% Al, 5% wax (see remarks)	1.65	7100		116	120	149	165	123	113	125		8	Stable. Very stable if nitrocellulose is replaced by more stable emulsifier. Wax exudes above 65° C. 7^B	Cast	Intended as replacement for Torpex in depth bombs.	Wax desensitizer is 84% high melting wax, 14% nitrocellulose, 2% lecithin. HBX I is HBX plus ½% $CaCl_2$
TRITONAL U.W.E. (80% TNT, 20% Al)	1.70	6600	1800	113	118	133	150	126	105	118	102	8	Very stable. 7^B, 8	Cast	Approved replacement for TNT in all American GP bombs.	
MINOL 2 40% TNT, 40% Ammonium nitrate, 20% Aluminum.	1.64	5900	1660	113	118	144	153	122	108	126	112	6	Moderately stable. Very hygroscopic. 8	Cast	British bombs, mines, warheads, etc.	Minol 3 has composition of 40% TNT, 32% Ammonium nitrate, 28% Aluminum.
PETN Pentaerythritol tetranitrate. (Penthrite, tetranitropentaerythritol, etc.)	1.60 about	7900	1390									3	Moderately stable, Except above melting point (140°C) 7^A, 7^B	Pressed	As base charge in detonators, in Primacord & as an ingredient of Pentolite.	one of most powerful high explosives. If used alone, mixed with oil to desensitize & permit pressing.
PENTOLITE PETN and TNT from 30/70 to 75/25	1.65 about	7500	1130		110				110	125 about	110	5	Moderately stable. 7^A, 7^B	Cast	Used chiefly in shaped-charge weapons.	Pentolite D-1 is Pentolite desensitized by paraffin; used in British mines.

Some figures are given on the relative performance of the various explosives, but the individual Weapon Data Sheet dealing with each effect should be consulted for details.

NOTES

1 RDX - Cyclonite, cyclomethylene trinitramine
2 MNT - Mononitrotoluol.
3 DNT - Dinitrotoluol.
4 Defined as heat evolved in the process: Solid explosive at room temperature and atmospheric pressure ⟶ products at room temperature and atmospheric pressure but with the composition which is in equilibrium at the temperature and pressure of the detonation.
5 A scale running from 1 to 10 has been established to cover the entire range of sensitivity of military explosives. Class 1 includes the most sensitive initiating explosives, such as mercury fulminate, while Class 10 includes the most insensitive of presently used explosives, such as ammonium picrate.
6 Only explosives of adequate stability are listed. Those classed as *moderately stable* will survive all but drastic and prolonged tropical storage; those classed *stable* and *very stable* will survive even this, but see notes 7 and 8.
7 A: Adversely affected by traces of *acid*. B: Adversely affected by traces of *base*.
8 Aluminized explosives, in presence of traces of moisture or of acids, generate gas (with Torpex, HBX and TNT/Al - some hydrogen). This does not cause excessive deterioration of the explosive, but causes mechanical difficulties and is, in some cases, a fire hazard.

CONVERSION FACTORS: To convert *m/sec* to *ft/sec*, multiply by 3.28.
cal/gm to *ft-lb/lb*, multiply by 1400.
specific weight to *lb/in*³, multiply by 0.0362
Temperature, from degrees *Centigrade* to degrees *Fahrenheit*; multiply by 1.8 and add 32.

SOURCES: *Explosives Research Memo No. 10*, Navy Bureau of Ordnance, March 1945.
Introduction to Explosives, OSRD 5401, August 1945.
Data from the Explosives Research Laboratory, Division 8, NDRC.
Report on HBX and Tritonal, OSRD 5406, July 1945.

WEAPON DATA

1 A3a*
AMERICAN HIGH EXPLOSIVE BOMBS

PHYSICAL CHARACTERISTICS OF AMERICAN BOMBS

DESIGNATION	TOTAL WEIGHT W, lb	TYPE OF CHARGE	WEIGHT OF CHARGE, lb: w	WEIGHT OF CHARGE, lb: $w^{1/3}$	CHARGE WEIGHT RATIO w/W, %	MAX. BODY DIA. in	LENGTH OF BOMB, in: WITHOUT TAIL	LENGTH OF BOMB, in: OVER ALL	WALL THICK-NESS in	REMARKS
GENERAL PURPOSE BOMBS										
*100-lb GP, Mk1 & Mods	116	TNT	65	4.0	56	7.9		48.8		Bomb has teardrop shape
Mk4 Mod 1	120	TNT	55	3.8	46	8.0	28.0	36.2	0.18	Single piece steel forging, cylindrical with ogival nose.
Mk4 Mod 4	105	TNT	55	3.8	52					
*500-lb GP, Mk12 Mod 2	504	TNT	256	6.4	51	14.0	42.6	59.5	0.36	Sling welded to bomb for suspension in torpedo racks
1000-lb GP, Mk13 Mod 2	1005	TNT	511	8.0	51	17.7	53.0	72.6	0.45	
100-lb GP, AN-M30;A1	110 115 121	Amatol TNT Tritonal	54 57 63	3.8 3.9 4.0	49 50 52	8.2	29.0	36.0	0.16	A1 models may have anti-withdrawal fuze. These bombs may have parachute attachment M6 to prevent rapid descent and ricochet of bombs in low-level bombing
250-lb GP, AN-M57;A1	256 260 273	Amatol TNT Tritonal	124 129 142	5.0 5.1 5.2	48 50 52	10.9	36.0	45.4	0.27	
500-lb GP, AN-M43 AN-M64;A1	510 525 535 544	Amatol TNT Comp. B Tritonal	262 267 274 293	6.4 6.4 6.5 6.6	51 51 51 54	14.2	45.0	56.8	0.3	500-lb AN-M43 and AN-M64;A1 may have parachute attachment M7 to prevent rapid descent and ricochet of bombs in lowlevel bombing. A1 models may use anti-withdrawal fuze; base plates and adapter boosters cannot be removed. AN-M64, 65, 66 & A1 models have tail fuze pockets taking hydrostatic fuze AN-M230 (11.5-lbs heavier than AN-M100 series fuzes). AN-M66A2 has slightly heavier nose section.
1000-lb GP, AN-M44 AN-M65;A1	964 990 1040 1044	Amatol TNT Comp. B Tritonal	530 558 595 612	8.1 8.2 8.4 8.5	55 56 57 59	18.8	53.1	67.1	0.5	
2000-lb GP, AN-M34 AN-M66;A1 AN-M66 A2	2050 2105 2140 2212	Amatol TNT Comp. B Tritonal	1063 1117 1142 1220	10.2 10.4 10.5 10.7	52 53 53 55	23.3	70.0	90.4	0.5	
4000-lb GP, T8	4084 4229	TNT Tritonal	1857 2002	12.3 12.6	45 47	28.0	86.5	118.9	0.88	
12000-lb GP, T10	11750	Tritonal	5100	17.2	43	38	124	252	1.25	Inertia tail fuzes. For performance see Data Sheet 7A1. Respectively same as British "Tallboy-M" and "Grand Slam", but British models filled Torpex D-1
22000-lb GP, T14	22115	Tritonal	9440	21.3	43	46	150	305	1.75	
LIGHT CASE BOMBS										
4000-lb LC, AN-M56;A1	4232 4205 4531	Amatol TNT Tritonal	3238 3362 3690	14.8 15:0 15.5	77 80 81	34.0	94.9	117.3	0.37	A1 models have hoisting at center of gravity as well as provision for suspension in British planes.
SEMI ARMOR-PIERCING BOMBS										
500-lb SAP, AN-M58	472	TNT	160	5.4	34	11.8	46.8	57.8	0.75	A2 mods may use anti-withdrawal fuzes.
AN-M58A1, A2	494	TNT	162	5.5	33					
1000-lb SAP, AN-M59;A1	995	TNT	320	6.8	32	15.1	57.3	69.3	1.0	A1 mod may use anti-withdrawal fuzes.
2000-lb SAP, M103	2040	Picratol	556	8.2	27	18.7	67.7	88.5		Solid nose construction
ARMOR-PIERCING BOMBS										
1000-lb AP, AN-Mk33	1025	Explosive D	140	5.2	14	12.0	58.0	73.0		
1600-lb AP, AN-Mk1	1590	Explosive D	215	6.0	14	14.0	59.5	83.5	1.3	Recent bombs have grooves on body to position suspension band
ANTI-AIRCRAFT BOMBS										
5-lb AA, Mk34	5.5	TNT	1.9	1.2	35	3.0	12.0	15.0	0.05	Cluster of 20 bombs in Mk3 or Mk3 Mod 1 container

* Obsolescent

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

continued, over

*Revised:
August 1945

1A3a

PHYSICAL CHARACTERISTICS OF AMERICAN BOMBS
continued

DESIGNATION	TOTAL WEIGHT W, *lb*	TYPE OF CHARGE	WEIGHT OF CHARGE, *lb*: w	WEIGHT OF CHARGE, *lb*: $w^{1/3}$	CHARGE WEIGHT RATIO w/W %	MAX. BODY DIA. *in*	LENGTH OF BOMB, *in*: WITHOUT TAIL	LENGTH OF BOMB, *in*: OVERALL	WALL THICK-NESS, *in*	REMARKS
FRAGMENTATION BOMBS										
4-lb F, M83 (Butterfly)	3.2	TNT	0.47	0.77	15	3.0	3.0		0.25	Adaptation of German SD-2; dropped in clusters
23-lb F, AN-M40;A1 M72;A1	20**	TNT	2.7	1.4	14	3.6	11.3	26.7	0.56	Bombs dropped in clusters. M72 is modified version of AN-M40 adapted for vertical suspension. A1 mods facilitate clustering with fuzed bombs
20-lb F, AN-M41;A1	20	TNT	2.7	1.4	14	3.6	11.3	19.5	0.56	Designed also for vertical suspension, may be dropped in cluster of 6 bombs. A1 mods facilitate clustering with fuzed bombs
90-lb F, M82	90	Comp. B	11	2.2	12	6.0	19.8	28.0	0.94	Suspended by single lug or in cluster of 6 bombs
120-lb F, M86 (Para)	90**	Comp. B	11	2.2	12	6.0	19.8	55.3	0.94	May be suspended singly or in a two-bomb cluster in a 500-lb bomb station
220-lb F, M88 260-lb F, AN-M81	216 260	Comp. B Comp. B	47 34	3.6 3.2	22 13	8.0 8.0	32.8 32.8	43.7 43.6	1.00 1.25	Horizontal suspension helical steel spring wound around steel tubing

FRAGMENTATION CLUSTERS

DESIGNATION	CLUSTER FUZING	TOTAL WEIGHT *pounds*	MAX. BODY DIAMETER *inches*	OVERALL LENGTH *pounds*	REMARKS
100-lb M1 or AN-M1A1 6-20 lb F, AN-M41		125	8.8	46.6	Fuzes shipped installed. Use cluster adapter AN-M1A2
100-lb AN-M1A2 6-20 lb F, AN-M41A1		125	8.8	46.6	Fuzes shipped in sealed cans; installed in the field. Use cluster adapter AN-M1A3
100-lb S1ZBL 6-20 lb F, AN-M41		125	8.8	46.6	[illegible] designation. Use cluster adapter AN-M1A2.
100-lb AN-M4 3-23 lb F, AN-M40		87.2	11	31.0	Use cluster adapter AN-M3. Fuzes shipped installed
100-lb AN-M4A1, A2 3-23 lb F, AN-M40;A1		87.2	11	31.0	Fuzes shipped in sealed cans; installed in field. Use cluster adapter AN-M3, A1.
100-lb M28, M28A1, A2 24 - 4-lb F, M83	M111A2 M146 M155	155	8.0	47.3	Should be released from altitude of 3000-5000 feet with fuze set to function 5(M28) & 8(M29) sec. after release, to form a pattern of approx. 200x300 feet. Use M15,A1,A2 adapters for M28,A1, A2; use M16,A1, A2 for M29, A1.
500-lb M29, M29A1 90-4 lb F, M83		415	14	59.6	
500-lb M26, M26A1, A2 20-20 lb F, AN-M41;A1	M111A2 M146 M155 T77	415	15	53.5	Use cluster adapter M13,A1,A2; can have quick or delayed opening
500-lb M27 6-90 lb F, M82	M111A2 M146 M155	590	15	59.0	Use cluster adapter M14. Has inst. and 5-92 second delay

*Obsolescent **Weight without parachute

NOTES:

Bomb weight given includes weight of standard Army - Navy fuzes, AN-M103 (nose) and AN-M100 (tail); due to slight variations in case thickness and density of filling, weights are accurate to ±5%.

The designation **Amatol**, above, implies a filling of 50% Amm. Nitr. & 50% TNT; **TNT** represents 100% TNT; **Tritonal** signifies 80% TNT and 20% Aluminum. Tritonal has been approved as the main charge in GP and LC bombs which are to be used where those loaded TNT were formerly considered suitable. The charge weights of tritonal - filled bombs listed above were calculated using a density of 1.70 for tritonal as compared with 1.55 for TNT.

Abbreviations:

BOMB TYPE, U. S.	BRITISH DESIGNATION	APPROXIMATE CHARGE-WEIGHT RATIO
General Purpose, GP	MC	50%
Light Case, LC	HC	80%
Semi-Armor-Piercing, SAP	GP	30%
Armor Piercing, AP	AP	15%
Fragmentation, F		
Anti-Aircraft, AA		

For Bomb-Fuze combinations, see Weapon Data Sheet 1 A3.

SOURCE: Information supplied by the United States Navy Bomb Disposal School.

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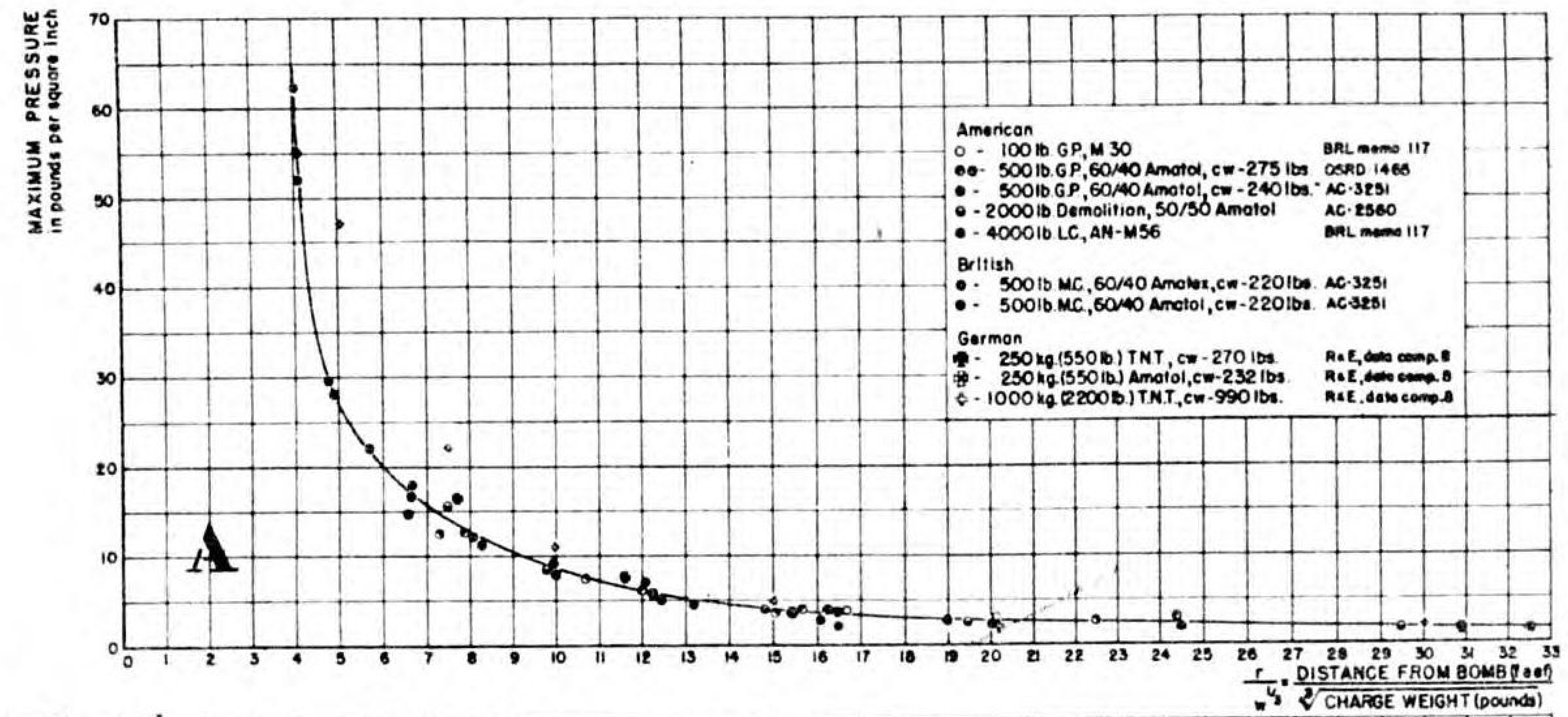
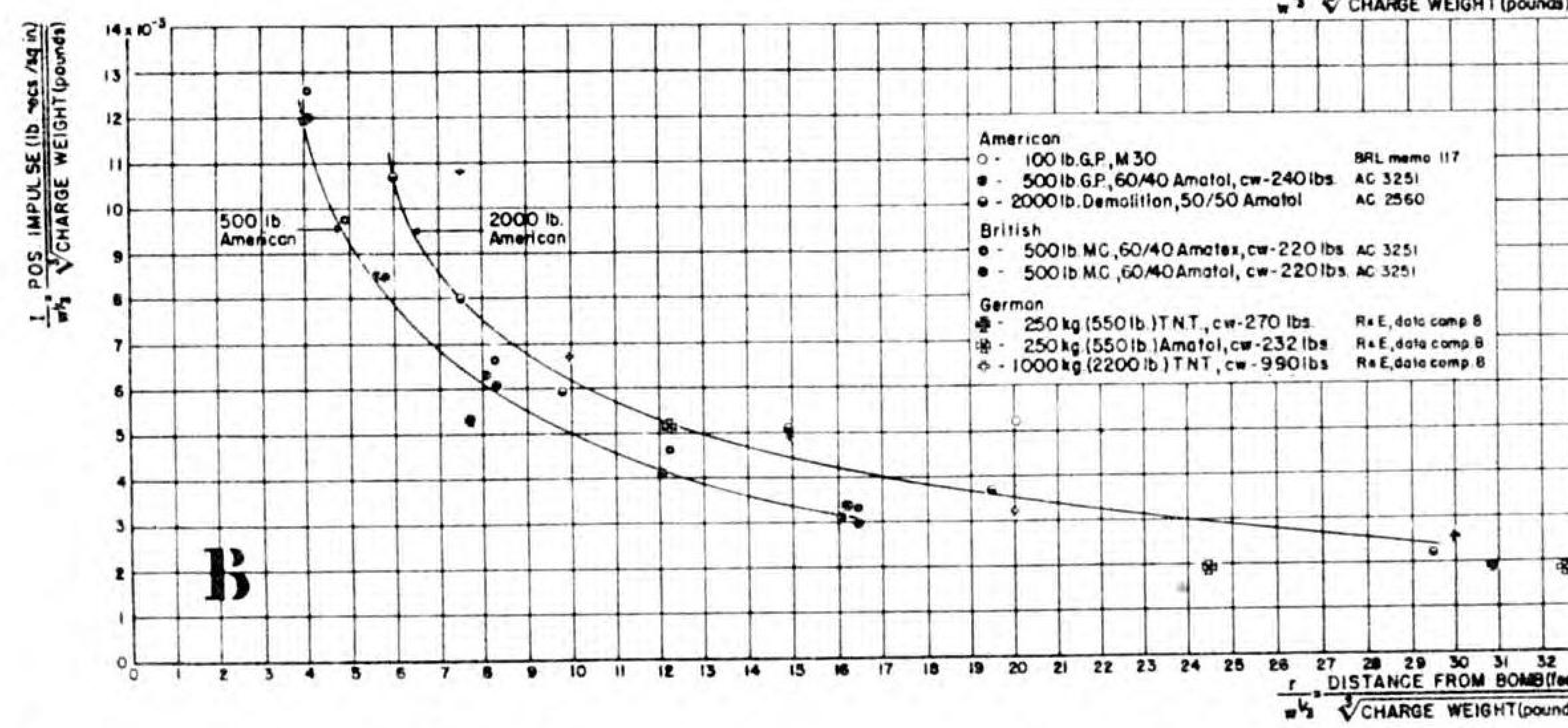
WEAPON DATA

1A2
COMPARISON

COMPARISON OF AMERICAN, BRITISH AND GERMAN BOMBS





MAXIMUM PRESSURE

A

Within 10-20% the peak pressures from American, British and German bombs are given by the same function of $r/w^{1/3}$. This indicates that within the accuracy of the curve the same model law applies to the three types of bombs. The 1000 kg. German bomb, whose filling is not precisely known but is presumed to be T.N.T., seems to be an exception in that the pressures corresponding to small values of $r/w^{1/3}$ lie above the curve.

POS IMPULSE

B

From the model law one would expect that $I/w^{1/3}$ is a function of $r/w^{1/3}$. The figure indicates that $I/w^{1/3}$ for American, British and German bombs lie between those of the 500-lb. American G.P. bomb and the 2000-lb. American G.P. bomb. The difference between these curves is of the order of 20 percent. Since impulse is extremely difficult to measure accurately, it may be concluded that within the accuracy of measurement the positive impulses delivered by American, British and German bombs are equal. The detonation of the 2000-lb. American G.P. bomb was initiated with booster pads whereas that of the 500-lb. American G.P. bomb was not. This may be the reason for the difference between the two curves. The technique involved in measuring the positive impulse of the 100-lb. American G.P. bomb was different from that used on the other bombs and the fact that the point corresponding to this bomb lies above the curve is probably due to this cause.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

WEAPON DATA

1 A 3
page one
U.S. BOMBS & FUZES

UNITED STATES BOMBS AND FUZES

ABBREVIATIONS:

Inst	- instantaneous	primer-det	- primer-detonator
mech	- mechanical	adap. bstr	- adapter booster
mod(s)	- modification(s)	aux. bstr	- auxiliary booster
v. rev	- vane revolutions	CV	- aircraft carrier
air tr	- air travel	arm.	- arming
pyro	- pyrotechnic	imp.	- impact
		A/C	- aircraft

* time is given in *seconds* unless noted otherwise, ie: *feet of water, hours* or *minutes*.

** if air burst setting *fails* to function, these fuzes will function instantaneously upon impact, providing fuze is armed.

NOTE: The nominal functioning time and the *actual range* of functioning time of some of the important fuze settings, determined from static firing test data, are given below:

NOMINAL FUNCTIONING TIME, *seconds*	ACTUAL RANGE OF FUNCTIONING TIME, *seconds*		
Inst. (av. 0.001)	0.000	to	0.003
Non-delay (av. 0.003)	0.0025	to	0.006
0.01	0.008	to	0.013
0.025	0.018	to	0.032
0.1	0.100	to	0.150
0.24	-		-

A: BOMB-FUZE COMBINATIONS *for High Explosive Bombs*

ARMY "M" and ARMY-NAVY "AN-M" BOMBS

BOMB	NOSE FUZE		TAIL FUZE	
model number	model number	functioning time, *seconds**	model number	functioning time, *seconds**
FRAGMENTATION BOMBS - F				
4-lb, F M83 "Butterfly"	-		M129 T48 E1 (M130) T49 (M131)	impact or air burst** 10; 20; 30; minutes anti-disturb.
20-lb, F AN-M41 A1	M110 AN-M110 A1	inst.	-	-
23-lb, F AN-M40 A1 M72 A1	AN-M104 AN-M120,A1	inst.	-	-
90-lb, F M82	AN-M103,A1 M163 M135	inst., (0.1) 5-92 air burst**	- -	- -
220-lb, F M88 260-lb, F AN-M81	M135 A1 M136 M136 A1 M139,A1;M164 M140,A1;M165	10-92 air burst** 5-30.6 air burst** 10-30.6 air burst** inst.; (0.01) inst.; (0.025)	AN-M100 A1 AN-M100 A2 M160	non-delay; (0.01; 0.025; 0.1; 0.24)
120-lb, F M86	AN-M104 AN-M120,A1	inst. inst.	-	-
FRAGMENTATION CLUSTERS - FC				
100-lb, FC M28	M111	15-93 air burst**	-	-
500-lb, FC M29	M111 A1 M111 A2	5-92 air burst**		
500-lb, FC M26	M146 - 5.92 air burst** used in M28 & M29 only.			
500-lb, FC M27	M155 - 5.92 air burst** used in M26 & M27 only.			
GENERAL PURPOSE BOMBS - GP				
100-lb, GP AN-M30,A1 250-lb, GP AN-M57,A1 500-lb, GP AN-M43 AN-M64,A1 1000-lb, GP AN-M44 AN-M65,A1 2000-lb, GP AN-M66,A1	AN-M103,A1 M163 M135 M135 A1 M136 M136 A1 M139,A1;M164 M140,A1;M165 M149 AN-Mk219 Mk232-1 *(special)* Mk239-0 Mk243-0	inst.; 0.1 5-92 air burst** 10-92 air burst** 5-30.6 air burst** 10-30.6 air burst** inst.; 0.01 inst; 0.025 Blast Pressure...see fuse table inst inst or elec. impulse 0.01 0.025	AN-M100,A1,A2 & M160 series M112 series M112A1 series M115 series M123,A1 series M132 series AN-Mk230 (AN-M64,65,66 & A1 series) Mk231-0 (AN-M64,A1) Mk237-0 (AN-M64,A1) Mk238-0 (AN-M65,A1; AN-M66,A1) Mk240 (AN-M65,A1; AN-M66,A1)	non-delay; 0.01; 0.025; 0.1; 0.24 4-5; 8-11 4-5; 8-11; 8-15 4-5; 8-11; 8-15 1-144 hrs 10 minutes 25-125 *ft of water* 25 *ft of water* 2; 10; 30 hrs 2; 10; 30 hrs 25 *ft of water*
100-lb, GP 250-lb, GP 500-lb, GP	Anti-ricochet Bombs		M151	8-15
LIGHT CASE BOMBS - LC				
4000-lb, LC AN-M56	AN-M103,A1 M135 M135 A1 M136 M136 A1 M139,A1 M140,A1 M149 AN-Mk219	inst. only 5-92 air b'st** 10-92 air b'st** 5-30.6 air b'st** 10-30.6 air b'st inst. only inst. only Blast Pressure inst.	AN-M102 A1 AN-M102 A2 M162	non-delay (to avoid break-up of bomb case)

SOURCE:
Publications of the U.S.Navy and U.S.Army Bomb Disposal Schools and the Ballistic Research Laboratory, U.S.A., Aberdeen Proving Ground, Md.

ARMY "M" and ARMY-NAVY "AN-M" BOMBS *(continued)*

BOMB	NOSE FUZE		TAIL FUZE	
model number	model number	functioning time, *seconds**	model number	functioning time, *seconds**
SEMI-ARMOR-PIERCING BOMBS - SAP				
500-lb, SAP AN-M58 AN-M58 A1 AN-M58 A2	AN-M103,A1 M163 (M135) (M135 A1) (M136) (M136 A1) M139,A1 M164	(inst); 0.1 (5-92 air b'st**) (10-92 air b'st**) (5-30.6 air b'st**) (10-30.6 air b'st** (inst); 0.01	AN-M101 A1,A2 M161 M113 M113 A1 M116 M124,A1 M133	non-delay; 0.01; 0.025; 0.1; 0.24 4-5; 8-11 4-5; 8-11; 8-15 4-5; 8-11; 8-15 1-144 hrs 10 minutes
1000-lb, SAP AN-M59 AN-M59 A1 2000-lb, SAP M103 (no nose fuzes)	M140,A1 M165 (M149) AN-Mk219 (Mk232-1 *special*) Mk239-0 Mk243-0	(inst); 0.025 (Blast Pressure) (Inst.) (inst or elec. impulse) 0.01 0.025	AN-M102 A1,A2 M162 M114 M114 A1 M117 M125,A1 M134	non-delay 0.01; 0.025; 0.1; 0.24 4-5; 8-11 4-5; 8-11; 8-15 4-5; 8-11; 8-15 1-144 hrs 10 minutes

NAVY "Mk" and ARMY-NAVY "AN-Mk" BOMBS

BOMB	NOSE FUZE		TAIL FUZE	
GENERAL PURPOSE BOMBS - GP				
100-lb, GP Mk 4 & mods (obsolescent)	AN-Mk219 Mk233 *(special)*	inst elec. impulse	-	-
500-lb, GP Mk12 & mods (obsolescent) 1000-lb, GP Mk13 & mods (obsolescent)	AN-Mk219 Mk221 Mk232-1 *(special)* Mk239-0 Mk243 AN-M103,A1 M163 M135 M135 A1 M136 M136 A1 AN-M139,A1 M164 AN-M140,A1 M165 M149	inst 0.01 inst or elec. impulse 0.01 0.025 inst; 0.1 5-92 air b'st** 10-92 air b'st** 5-30.6 air b'st** 10-30.6 air b'st** inst; 0.01 inst; 0.025 Blast Pressure	Mk223 Mk229 AN-M102 A1,A2 M162 M114 M114 A1 M117	0.01 25-125 *ft of water* non-delay; 0.01; 0.025; 0.1; 0.24 4-5; 8-11 4-5; 8-11; 8-15 4-5; 8-11; 8-15
ARMOR-PIERCING BOMBS - AP				
1000-lb, AP AN-Mk33 1600-lb, AP AN-Mk1		-	AN-Mk228 AN-M102 A1,A2 M162	0.08 non-delay, 0.01; 0.025; 0.1; 0.24
DEPTH BOMBS - DB				
325-lb, DB AN-Mk17 AN-Mk41 AN-Mk44 AN-Mk47 (obsolescent)	AN-Mk219 Mk232-1 *(special)* AN-M103,A1 M139,A1 AN-M140,A1 M149 M163 M164	inst inst or elec. impulse inst; (0.1) inst; (0.01) inst; (0.025) Blast Pressure inst; (0.1) inst; (0.01)	AN-Mk224 AN-Mk234 (Athwartship fuzes)	25-125 *ft of water*
325-lb, DB Mk53 350-lb, DB Mk54			AN-Mk230 Mk231-0	25-125 *ft of water* 25 *ft of water*
650-lb, DB Mk37 Mk38* 700-lb, DB Mk49 (obsolescent)			AN-Mk224 AN-Mk234 (Mk38,49 only) (Athwartship) Mk229 AN-Mk230	25-125 *ft of water*
ANTI-AIRCRAFT BOMBS - AA				
5-lb, AA Mk34	Mk227	inst	-	-

NOTE:
Parentheses ( ) enclosing functioning time or fuze number indicate that use is possible but unlikely or not recommended.

B: FUZE CHARACTERISTICS *(for High Explosive Bomb Fuzes)*

ARMY "M" and ARMY-NAVY "AN-M" FUZES

MODEL NUMBER	TYPE	NOMINAL FUNCTIONING TIME, *seconds*	ARMING TIME OR DISTANCE, *ft*	MIN. ALT. TO ARM AT 200 mph, *ft*	BOMBS USED IN:	COMPANION FUZE	ADDITIONAL COMPONENT PARTS	REMARKS
AN-M100 A1	Tail: mech. impact.	non-delay 0.01 0.025 0.1 0.24	720 v.rev		100 GP, AN-M30, A1; 250 GP; 220 F; 260 F	AN-M103 Mk 243	M14 primer-det M102 adap bstr with Navy GP's	non-delay only for 260 F, 4000 LC......for GP's and SAP's delays are governed by tactical use.......the AN-M100 A1 series can be prearmed 350 v.rev; this series is obsolescent
AN-M100 A2			150-170 v.rev 445-485 air tr	40-50				
AN-M101 A1			720 v.rev		500 GP, AN-M43(64A1); 500 SAP			
AN-M101 A2			150-170 v.rev 555 air tr	60-70				
AN-M102 A1			720 v.rev		1000 GP; 500 GP, Mk12; 2000 GP; 1000 SAP; 4000 LC			
AN-M102 A2			150-170 v.rev 465-665 air tr	85				
AN-M103	Nose: mech. impact	Inst. 0.1	inst: 330 v.rev 760-1600 air tr	inst: 450	All depth bombs, GP's (except 100 GP, Mk4) and 90F (except M103) 220 F, 260 F...may be used in SAP's for frag effects; results are inconsistent...... 4000 LC	AN-M100 A1, A2 series	none	usable for dive bombing, not recommended for mast-head attack..AN-M103: not crash-proof, unsafe for CV use..AN-M103 A1: is crash-proof, safe for CV use...modified arming vanes required for use with flat nose bomb
AN-M103 A1			0.1: 220 v.rev 510-1080 air tr	0.1: 210				
AN-M104	Nose: mech. impact	Inst.	2.5 seconds pyrotechnic	80	23 F, AN-M40; M72 120 F, M86	none	none	sensitive mushroom striker head....being replaced by AN-M120, A1 ..unsafe for CV use
M110	Nose: mech. impact	Inst.	570 v.rev		20 F, AN-M41	none	none	unsafe for CV use...alternate for AN-M103 using M117 adapter booster
AN-M110 A1			260 v.rev	60				
M111	Nose: mech. time aerial burst	15-93 imp. inst	570 v.rev	450	500 F Clusters: M26 (20 - 20 F's) M27 (6 - 90 F's) M29 (90 - 4 F's) 100 F Cluster: M28 (24 - 4 F's)	none	none	mt detonator safe...obsolescent; being replaced by T55 E2 (M146) & T71 (M155)
M111 A1		5-92 imp. inst	570 v.rev	450				
M111 A2		5-92 imp. inst	260 v.rev	195				
M112	Tail: mech. impact pyro. delay	4-5 8-11	15-20 v.rev 100 air tr		100 GP, AN-M30, A1; 250 GP	none	M16 primer-det	these fuses (M112-M114, & mods) are supersensitive min. altitude bombing fuses and will function at impact angle of 3°..unsafe for CV use...M102 adapter booster used with Navy GP's
M112 A1		4-5 8-11 8-15					M16; M16 A1 primer-det	
M113		4-5 8-11			500 GP; 500 SAP		M16 primer-det	
M113 A1		4-5 8-11 8-15					M16; M16 A1 primer-det	
M114		4-5 8-11			1000 GP; 1000 SAP; 2000 GP; 500 GP, Mk12 1000 GP, Mk 13 & mods using M102 adapter bstr & spacer ring		M16 primer-det	
M114 A1		4-5 8-11 8-15					M16; M16 A1 primer-det	
M115	Tail: mech. impact pyro. delay	4-5 8-11 8-15	150-170 v.rev 485 air tr	40-50	100 GP; 250 GP	none	M16; M16 A1 primer-det M102 adap. bstr. with Navy GP's..	minimum altitude bombing fuses.....safe for CV use
M116			150-170 v.rev 555 air tr	60-70	500 GP; 500 SAP			
M117			150-170 v.rev 665 air tr	85	1000 GP; 2000 GP; 1000 SAP; 500 GP, Mk 12; 1000GP, Mk13			
AN-M120	Nose: mech. impact	Inst.	2.5 sec (±0.25) mech. delay		23 F, AN-M40 A1, M72 A1; 120 F, M86 using M117 adapter booster	none		unsafe for CV use.....not available in Navy clusters ..for lower level attack, the AN-M120 A1 is preferred
AN-M120 A1			1.9 sec (±0.15) mech. delay					
M123	Tail: chem. time anti-removal (A1 series: direct drive; earlier mods: gear reduct.)	1, 2, 6, 12, 24, 36, 72, 144 hours	75.6-190 v.rev 370 air tr	180	100GP, AN-M30, A1; 250 GP 220 F; 260 F (A1 mods preferred)	anti-disturbance nose fuse is being developed	M19 primer-det	chemicals in glass ampoule considered armed if dropped. ..sensitive to temperature changes..not to be used in temp. over 120°F...delays vary with concentration of alcohol-acetone solution & thickness of celluloid disc .equipped with ball-locking anti-removal device...cannot be prearmed
M123 A1			4-6 v.rev				M19 A2 primer-det	
M124			75.6-190 v.rev 370 air tr	215	500 GP; 500 SAP (A1 & A2 mods preferred)		M19 primer-det	
M124 A1			4-6 v.rev				M19 A2 primer-det	
M125			75.6-190 v.rev 370 air tr	310	1000 GP; 1000 SAP; 2000 GP (A1 and A2 mods preferred)		M19 primer-det	
M125 A1			4-6 v.rev				M19 A2 primer-det	
M129	ground or air burst	Impact or air burst	2.5 seconds		4 F, M83 "Butterfly"	none	none	impact has slight inherent delay....fuse is shipped installed in bomb

B: FUZE CHARACTERISTICS *(continued)*

ARMY "M" and ARMY-NAVY "AN-M" FUZES *(continued)*

MODEL NUMBER	TYPE	NOMINAL FUNCTIONING TIME, *seconds*	ARMING TIME OR DISTANCE, *ft*	MIN. ALT. TO ARM AT 200 mph *ft*	BOMBS USED IN:	COMPANION FUZE	ADDITIONAL COMPONENT PARTS	REMARKS
T48 E1 (M130)	mech. time	10,20,30 minutes	3½ rotations of arming spindle		4 F, M83 "Butterfly"	none	none	setting pre-set at factory ..fuse is shipped installed in bomb
T49 (M131)	anti-disturbance	-	about 5 secs. after impact		4 F, M83 "Butterfly"	none	none	supersensitive; vibrations from nearby A/C propeller sufficient to fire fuse... fuse is shipped installed in bomb
M132	Tail: chem. time anti-removal	10 minute nominal delay.... range of 6-80 min. delay due to temp. variation	63-84 v. rev 300 air tr		100 GP, AN-M30, A1; 250GP	none	M19 primer-det	similar to M123 series, but safer in that solvent is in copper bellows instead of glass ampoule..delays vary with change of temperature but always sufficient to allow forward planes of large formations to drop bombs from low altitude without endangering rear planes....has ball-locking anti-removal device
M133			63-84 v. rev 370 air tr		500 GP, AN-M64, A1: 500 SAP		M19 primer-det	
M134			63-84 v. rev 300-450 air tr		1000 GP, AN-M65, A1; 1000 SAP; 2000 GP			
M135	Nose: mech. time air burst	5-92 or imp. inst.	approximately 260 v. rev 750 air tr		All GP's (except 100 GP Mk4) 4000LC, may be used in 90 F, 220 F and 260 F (and SAP's)	normally none, unless AN-M100 A2 series is used as an insurance fuse	none	setting can be adjusted to 0.1 second.......will fire accurately to ± one sec... detonator safe; not suitable for naval use....min. setting of 10 sec. recommended
M135 A1		10-92 or imp. inst.						
M136	Nose: mech. time air burst	5-30.6 or imp. inst.	approximately 260 v. rev 750 air tr		All GP's (except 100 GP Mk4) 4000LC; may be used in 90 F, 220 F, and 260 F (and SAP's)	normally none, unless AN-M100 A2 series is used as an insurance fuse	none	improved clockwork, more accurate than M135, A1.... setting can be adjusted to 0.2 second.......will fire accurately ± 0.3 sec...... detonator safe; not suitable for naval use....min. setting of 10 sec recommended
M136 A1		10-30.6 or imp. inst.						
M139 AN-M139 A1	Nose: mech. impact	Inst. 0.01	inst: 330 v. rev 765-1600 air tr	inst: 450;	All depth bombs, GP's (except 100 GP, Mk4) & 90 F, 220 F, 260 F.. may be used in SAP's ...4000 LC	AN-M100 A2 series	M14 primer-det	companion fuses to AN-M100 A2 series with shorter delays than AN-M103, A1 ..... M139 A1 and M140 A1 are crash-proof
M140 AN-M140 A1		Inst. 0.025	0.01 & 0.025: 220 v. rev	0.01 & 0.025: 210				
M146	Nose: clockwork air burst	5-92 imp. inst	approximately 260 v. rev		100 F Cluster: M28 (24 - 4 F's) 500 F Cluster: M29 (90 - 4 F's)	none	none	detonator safe
M148	Nose: mech. impact	Inst: 0.1	same as AN-M103	same as AN-M103	Japanese Navy bombs	none	modified booster cup	modified AN-M103
M149	Nose: blast pressure or mech. impact	see remarks	12 - 13 v. rev		All GP's (except 100 GP, Mk4), 4000 LC (and SAP's)	none	none	first bomb of stick detonates on impact; remainder by blast pressure of preceding bomb - about 25 ft apart for 500 GP dropped in train of 0.05 sec. intervals, air speed 200 mph, altitude 10,000 feet ..... detonator safe
M151	Tail: mech. impact pyro. delay	.8 - 15	approximately 12 v. rev		100, 250 GP (anti-ricochet) using M7 parachute and M202 fuse adapter; 500 GP (anti-ricochet) using M6 parachute & M200 fuse adapter	none	M16 A1 primer-det	similar to M112 A1 series with transverse arming stem and anemometer vane
M155	Nose: mech. time air burst	5 - 92 imp. inst	6-9 v. rev		500 F Clusters: M26 (20 - 20 F's) M27 (6 - 90 F'S)	none	none	supercedes M111 A2 with omission of gear reduction system resulting in quicker arming
M160	Tail: mech. impact	non-delay 0.01 0.025 0.1 0.24	720 v. rev 1780-1950 air tr	650	100 GP, AN-M30, A1; 250 GP; 220 F; 260 F	M163	M14 primer-det M102 adap. bstr with Navy GP's	similar to AN-M100 series except for slower arming designed to prevent premature explosions of bombs within range of releasing aircraft (especially B29)...non-delay only for the 220 F, 260 F and 4000 LC
M161			720 v. rev 1910-2230 air tr	805	500 GP, AN-M43 (64 A1) 500 SAP			
M162			720 v. rev 1710-2680 air tr	1130	1000 GP, AN-M44 (65 A1) 2000 GP; 1000 SAP; 4000 LC			
M163	Nose: mech. impact	Inst. 0.1	inst: 1710-3625 air tr	1775	All depth bombs, GP's (except 100 GP, Mk4) & 90 F; 220 F; 260 F and SAP's	M160 series	none	similar to AN-M103, M139, A1, M140, A1 respectively, except for slower arming designed to prevent premature explosions of bombs within range of releasing aircraft (especially B29s)
M164		Inst. 0.01	0.01 & 0.025: 1140-2420 air tr	915				
M165		Inst. 0.025						

1A3 B: FUZE CHARACTERISTICS *(continued)*

NAVY "Mk" and ARMY-NAVY "AN-Mk" FUZES

MODEL NUMBER	TYPE	NOMINAL FUNCTIONING TIME, *seconds*	ARMING TIME OR DISTANCE, *ft*	MIN. ALT. TO ARM AT 200 mph, *ft*	BOMBS USED IN:	COMPANION FUZE	ADDITIONAL COMPONENT PARTS	REMARKS
AN-Mk219 & mods	**Nose:** mech. impact rotor arm.	Inst.	170 v.rev 1100 air tr; 2000-2500 air tr. for flatnose depth bombs		All GP's and DB's and SAP's	GP's & SAP's: Mk223 (Navy GP's) AN-M100 A2 and M160 series DB's: AN-Mk224 Mk229 AN-Mk230 AN-Mk234	adap. ring & Mk1, aux. bstr with all DB's and 500 GP, Mk12; 1000 GP Mk 13 & mods ..adap. ring & Mk4 bstr pellet with all "M" and "AN-M" GP's	will function on impact with water or denser medium providing it has been dropped from sufficient altitude to arm..crash-proof...36" and 42" extension rods available with this fuse
Mk221	**Nose:** mech. impact rotor arm.	0.01	165 v.rev 850-1100 air tr		500 GP, Mk 12 1000 GP, Mk 13	Mk223	none	obsolescent will fit nose of all DB's, but delay may rupture case....400 ft/sec striking velocity is needed to activate fuse on water impact
Mk223 & mods	**Tail:** mech. impact rotor arm.	0.01	approximately 150 v.rev 850-1100 air tr		500 GP, Mk12 & mods 1000 GP, Mk 13	AN-Mk219 Mk221 and... see remarks	none	obsolescent..other companion fuzes: AN-M103, A1; M135, A1; M136, A1; AN-M139 A1; AN-M140A1; M149; Mk239; Mk243
AN-Mk224 & mods	**Athwartship** hydrostatic	25,50,75, 100,125 ft of water	completely armed at 12 to 25 ft depth	-	All DB's except Mk53 and Mk54	AN-Mk219; AN-M103; Mk221 and Mk229 in 650 & 700 DB's	spacer ring required with 650 & 700 DB's	obsolescent
Mk227 mod 0	**Nose:** mech. impact, centrifugal force arm.	Inst.	at sea level: 1500 air tr 20,000' alt: 3000 air tr		5 AA bomb, Mk34	none	none	fuse designed for air to air bombing, but proved unsuccessful.....limited use against parked aircraft
AN-Mk228 & mods	**Tail:** mech. impact rotor arm.	0.08	140-160 v.rev 1100 air tr	200	1000 AP; 1600 AP; (500 GP, Mk12 mod 2 1000 GP, Mk13 mod 2)	none	none	
Mk229 & mods	**Tail:** hydrostatic mech. arming	25,50,75, 100,125 ft of water	110 v.rev 500 air tr	60	650 & 700 DB's; 500 GP, Mk12; 1000 GP, Mk13	AN-Mk219 AN-M103 Mk243	none	mod 3 preferred in operational missions for its additional safety features
AN-Mk230 & mods	**Tail:** hydrostatic mech. arming	25,50,75, 100,125 ft of water	110 v.rev 300-400 air tr	60	325 DB, Mk53; 350 DB, Mk54; 500, 1000, 2000 GP's AN-M64, 65, 66, & mods by removing adapter from M115 adapter booster; 650 & 700 DB's by removing Mk1 bstr pellet and inserting 2 Mk2 booster pellets	AN-Mk219 AN-M103 Mk243	-	mod 1, 3 obsolescent...mod4 is preferred for its crash-proof features......mod5, identical to mod4, is converted from Mk229
Mk231 mod 0	**Tail:** hydrostatic	25 ft of water	40-45 v.rev	60	325 DB, Mk53; 350 DB, Mk54; 500 GP, AN-M64, A1 / 1000 GP, AN-M65, A1 2000 GP, AN-M66, A1		none	under development......no availability date set.... crash-proof and detonator safe
Mk240	*Identical to Mk231 but has longer arming stem*							
Mk232 & mods	**Nose:** impact or elec. firing	Inst. or electric impulse	9 v.rev		GP's, (SAP's) and DB's except 100 GP, Mk4	usually none	none	special purpose fuze... will not function on impact with water at striking velocity less than 700 ft/sec
Mk233 mod 0	**Nose:** elec. firing	electrical impulse			100 GP, Mk4			special purpose fuse....... limited availability
AN-Mk234 & mods	**Athwartship** hydrostatic	25,50,75 100,125 ft of water	partially armed when dropped... completely armed at 12 to 25 ft depth		all DB's except Mk53 and Mk54	AN-M103 AN-Mk219 Mk221 Mk229	spacer ring required with 650 & 700 DB's	differs from AN-Mk224 in that it has external setting device..not air arming type; not recommended for use....cannot be installed when trunnion band is used
Mk237 mod 0 / Mk238 mod 0	**Tail:** long delay	2,10,30 hrs at 60°F	approximately 150 v.rev plus impact		500 GP, AN-M64, A1 / 1000 GP, AN-M65, A1 2000 GP, AN-M66, A1	none	none	detonator & jettison safe ...anti-removal device... fuse may function without delay on multiple impact.. minimum safe altitude same as for instantaneous fuses
Mk239 mod 0	**Nose:** mech. impact rotor arm.	0.01	1100 air tr		All GP's (except 100 GP, Mk 4) & SAP's	Mk223 for Army bombs use Army fuzes		modified Mk221....requires 400 ft/sec striking velocity to function on impact with water
Mk243 mod 0	**Nose:** mech. impact	0.025	130 v.rev 500 air tr		All GP's (except 100 GP, Mk4) and SAP's	AN-M100 series AN-Mk230 Mk229	M14 primer-det	designed specifically for use against submarines and ships.....will function on impact with ¼" plate, but not with water from altitude of 15,000 ft or at impact angle of less than 45°

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WEAPON DATA: INCENDIARIES

1 A3b AMERICAN INCENDIARY BOMBS

PHYSICAL CHARACTERISTICS OF AMERICAN INCENDIARY BOMBS

DESIGNATION nominal weight model no.	ACTUAL WEIGHT pounds	DIMENSIONS DIAM inches	 LENGTH inches	INCENDIARY CHARGE	OTHER CHARGES	TOTAL HEAT LIBERATED BTU	FUSING type & number	STRIKING VELOCITY from 20,000 ft. feet/sec	CLUSTER SIZES AND TYPES
100-lb. AN-M47A2 AN-M47A3	72+ 73+	8.12 8.12	48.9 51.9	40 lb. Gasoline Gel	M12 Burster Black Powder 7.8 oz. Mg. Powder 7.4 oz. M13-M9, Burster-Igniter W.P.-21 oz., TNT-2.4 oz. Tetryl-0.07 oz.	669,000 (includes heat of White Phos)	Nose Impact M-126A1 or M-108	740	Not clustered but sometimes loaded by multiple suspension on 100-lb. and 500-lb stations
4-lb AN-M50A2	3.6	1.69	21.3	1.1 lb Mag alloy 0.6 lb Therm-64C	First Fire* 0.71 oz.	13,100	Tail Inertia	420	500-lb size, Aimable 100-lb size, } Quick- 500-lb size, } Opening
4-lb AN-M50XA3 (anti-personnel explosive nose)	3.7	1.69	21.3	1.05 lb Mag. alloy 0.6 lb Therm-64C	First Fire* 0.71 oz. Tetryl (type A) 1.4 oz Tetryl (type B) 1.6 oz	12,300	Tail Inertia	425	Clustered with AN-M50A2
2-lb AN-M52A1**	1.7	1.69	14.2	0.95 lb Mag. alloy 0.5 lb Therm-64C	First Fire* 0.7 oz.	11,200	Tail Inertia	340	500-lb size, Aimable 100-lb size, } Quick- 500-lb size, } Opening
4-lb AN-M54	3.7	1.69	21.3	1.6 lb Thermate	First Fire* 0.7 oz.	2,600	Tail Inertia	420	100-lb size, } Quick- 500-lb size, } Opening
6-lb AN-M69++	6.2	2.87	19.5	2.6 lb Gasoline Gel	Black Powder 0.27 oz Mag. Powder 0.23 oz	44,000	Nose Inertia; M1	230	500-lb size, Aimable 100-lb size, } Quick- 500-lb size, } Opening
6-lb M69X (anti-personnel explosive nose)	7.0	2.87	19.5	2.2 lb Gasoline Gel	Black Powder 0.27 oz Mag. Powder 0.23 oz Tetryl 4.6 oz	37,000	Nose Inertia; M1	245	Clustered with AN-M69
10-lb M74	8.4	2.87	19.5	2.8 lb PT-1 mixture	White Phos. 6.0 oz Mag. Powder 0.11 oz Black Powder 0.07 oz	38,000 (includes heat of white Phos)	Nose Inertia; M142	420	500-lb size, Aimable 100-lb size, } Quick- 500-lb size, } Opening
500-lb AN-M76	475	14.18	59.2	175 lb PT-1 mixture	Tetryl 1.2 lbs. White Phos. 9.0 lb	2,210,000 (includes heat of white Phos)	Nose Impact AN-M103 Tail Inertia AN-M101A2	965	Not clustered

AN-M69 and M74 are tail ejection type bombs - explosive charge throws incendiary material out of the tail. Other gasoline gel filled bombs are burster types which disperse the incendiary material in chucks in all directions.

From time of impact until explosion of head, AN-M50XA3 Type A burns 2-4 min; Type B burns 30-70 sec.

★ First Fire is the agent for initiating combustion of main filling.

★★ Several redesigns of this bomb are now under consideration for standardization.

+ Weight given is for this bomb with M13-M9 burster-igniter and M126A1 fuse. The M12 burster weighs 3 pounds less than the M13-M9 burster-igniter; the M108 fuse, 0.5 pounds less than M126A1 fuse.

++ New type AN-M69 in production has gross weight of 6.4 lb. and contains 2.2 lb. of gasoline gel, 6.0 oz. of white phosphorous and liberates 41,000 BTU.

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WEAPON DATA: INCENDIARIES

1 A3c AMERICAN INCENDIARY CLUSTERS

PHYSICAL CHARACTERISTICS OF AMERICAN INCENDIARY BOMB CLUSTERS

BOMB TYPE model no. nominal wt.	CLUSTER DESIGNATION nominal size, lb model number	 type	ACTUAL WEIGHT* pounds	NUMBER OF BOMBS**	TOTAL HEAT PER CLUSTER BTU	DISPERSION PATTERN▲ RACE-TRACK▲▲	 Sq. ft/bomb (90% of bombs)	FUSING position and model	BOMBING TABLE BT:
AN-M50 (4 lb)	500-lb, AN-M17A1 100-lb, AN-M6 500-lb, AN-M7	Aimable } Quick- } opening	465 135 525	110 34 128	1,420,000 440,000 1,660,000	420 x 630 700 x 2450 700 x 2450	2,300 53,000 14,000	Nose: M145● Q.O: no fuse Q.O: no fuse	500-J-2 4-5-1 4-8-1
AN-M52 (2 lb)	100-lb, AN-M10 500-lb, AN-M11	} Quick- } opening	105 425	51 192	570,000 2,150,000	1100 x 3300 1100 x 3300	75,000 20,000	C.0: no fuse C.0: no fuse	2-A-1 2-A-1
AN-M69 (6 lb)	500-lb, M18(E6R2) 500-lb, E46 100-lb, AN-M12 500-lb, AN-M13	Aimable Aimable } Quick- } opening	350 425 105 425	38 38 14 60	1,670,000 1,670,000 620,000 2,640,000	340 x 510 240 x 360 400 x 1000 400 x 1000	4,300 2,200 29,000 6,800	Nose: M145● Tail: 2-M152● Q.O: no fuse Q.O: no fuse	500-K-2 500-Q-1 6-A-2 6-A-2
M74 (10 lb)	500-lb, E48 100-lb, E64 500-lb, E57	Aimable } Quick- } opening	525 140 550	38 14 60	1,440,000 530,000 2,280,000	640 x 960	15,400	Tail: 2-M152●	

NOTES

★ Weights may vary as much as 5% from average values given.

★★ All incendiary clusters are supposed to contain 20% of corresponding X-bomb (anti-personnel type), but the percentage may vary with supply and operational requirements.

▲ Patterns given include 90% of the bombs and are for quick-opening clusters dropped from 10,000 feet and for aimable clusters dropped from 20,000 feet and opened at 5,000 feet. Data on quick-opening clusters are less reliable than those on aimable clusters.

▲▲ A *race-track* figure (rectangle with semi-circular ends) was selected as the most suitable figure for representing the patterns of aimable and quick-opening clusters (better than *ellipse, rectangle, circle* or *square*). The area of a race-track is given by $xy - 0.215x^2$, where x = the smaller dimension. In determining dimensions of 90% pattern, axial ratios used were restricted to 1.5, 2.0, 2.5, 3.0, 3.5, 4.0.

● M145 (T55E1), M138 (T39E1), and M127 (T39) are alternate fuses for these clusters; M145 preferred.

● M152 (T53E1), M153 (T73) and M145 (with reversed vanes) are alternate fuses for these clusters; M152 preferred.

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WEAPON DATA

PHYSICAL CHARACTERISTICS OF AMERICAN DEPTH BOMBS, AIRCRAFT MINES AND TORPEDOES

1A3d AMERICAN BOMBS MINES AND TORPEDOES

DESIGNATION nominal weight	model	TOTAL WEIGHT W lbs	TYPE OF CHARGE	WEIGHT of CHARGE pounds w	WEIGHT of CHARGE pounds $w^{1/3}$	CHARGE WEIGHT RATIO w/W, %	DIMENSIONS LENGTH OVERALL inches	DIMENSIONS LENGTH of BODY inches	DIAM inches	WALL THICK-NESS inches	FUSING NOSE	FUSING ATHWART SHIP	FUSING TAIL
A DEPTH BOMBS													
325-lb 350-lb	AN-Mk17-2 AN-Mk44	323 355	TNT TPX	242 268	6.23 6.45	75 76	52.5	31.1	15.0	0.06	(AN-Mk219 (AN-Mk221	AN-Mk234 AN-Mk224	- -
325-lb 350-lb	AN-Mk41 AN-Mk47	325 351	TNT TPX	222 248	6.06 6.28	68 71	49.9	27.8	15.0	0.06	(AN-M103 (AN-Mk219 (AN-Mk221	AN-Mk224 AN-Mk234	- - -
325-lb 350-lb	Mk53-1 Mk54-1 *	320 339	TNT TPX	225 252	6.08 6.32	70 74	54.6	30.1	13.5	0.06	(AN-M103 (AN-Mk219	- -	(AN-Mk230
650-lb 700-lb	Mk37 ** Mk38-1 Mk49-1	635 634 669	TNT TNT HBX	464 425 472	7.74 7.52 7.79	73 67 71	58.5	36.4	17.7	0.12	(AN-Mk219 (AN-M103	AN-Mk224 ● AN-Mk234 ●	Mk229 ×)AN-Mk230
			●										
B AIRCRAFT MINES													
1000-lb,Mk13-0,4,5		1025	TNT	621	8.53	-	68.8	-	19.9	0.12	m0,4: Mag.Induc.Type m5: Acoustic Type		
1000-lb,Mk26-1		1000 1060	TNT TPX	465 525	7.75 8.07	-	68.5	-	18.6	0.12	Magnetic Induction Type		
1000-lb,Mk36		1020 1085	TNT TPX	570 635	8.29 8.59	-	70.6	-	18.6	0.12	Magnetic Induction Type		
1600-lb Mk12-1		1595 1725	TNT TPX	1095 1225	10.3 10.7	- -	134	-	20.8	0.25	Magnetic Needle Type		
4		1565 1690	TNT TPX	1065 1190	10.2 10.6	-	134	-	20.8	0.25	Magnetic Needle Type		
1800-lb,Mk10-6,8,9		1850	TNT	420	7.49	-	121.5	-	20.8	0.25	Magnetic Needle Type		
2000-lb,Mk25		1863 2017	TNT TPX	1120 1274	10.38 10.84	-	86.5	-	22.5	0.15	Magnetic Induction Type		
C AIRCRAFT TORPEDOES													
Mk 13-2A, 3, 5 Mk 13-6, 7, 9		2140 o 2228 o	TNT TPX	600 600	8.43 8.43	-	161.0	-	22.4	0.12	Contact: Mk4-6 Mk8-6		

NOTES:

* This Depth Bomb is currently being filled with HBX instead of Torpex (TPX).
** Because the tail assembly was too weak, the Mk37 was revised producing the Mk38.
● In this group, these fuses are used in the 650-lb Mk37 D.B. only; the Mk38 and Mk49 do not use an athwart-ship or side fuse.
× The Mk229 fuse is used only in the Mk37 D.B.; the newer depth bombs, Mk38 and Mk49, use the AN-Mk230.
o The total weight may vary as much as ± 20 pounds from the weight given.

General Purpose bombs (GP 500-lb AN-M64, 1000-lb AN-M65, 2000-lb AN-M66) fitted with the AN-Mk230 hydro-static tail fuse are also used as depth bombs.

Since Aircraft Mines are usually dropped by parachute, the over all length dimension is given including the parachute pack; without it this dimension is approximately 4 inches less.

SOURCE: Publications of the Bureau of Ordnance and the Bomb Disposal School, U.S.Navy.

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WEAPON DATA

PHYSICAL CHARACTERISTICS OF BRITISH BOMBS

1A4a PHYSICAL CHARACTERISTICS

A HIGH EXPLOSIVE BOMBS

DESIGNATION name, type and model	TOTAL WEIGHT- pounds	TYPE of CHARGE	WEIGHT of CHARGE pounds	CHARGE-WEIGHT RATIO percent	MAX. BODY DIAMETER inches	LENGTH without TAIL inches	OVERALL LENGTH inches	BODY WALL THICKNESS inches
20-lb. F., Mk III	20	TNT	3	15	3.9	11.9	21.8	0.35
40-lb. G.P., Mk III	38.5	Amatol 60/40	6.5	17	5.0	15.9	27.3	0.47
250-lb. G.P., Mk IV	230	Amatol 60/40	67	29	10.3	25.6	55.7	0.52
500-lb. G.P., Mk IV	470	Amatol 60/40	143	30	13.0	36.5	70.3	0.72
500-lb. G.P., Mk IV	467	Amatol 60/40	143	31	13.0	36.5	57.3	0.72
1000-lb. G.P., Mk II	1072	Amatol 60/40	357	33	16.2	52.5	72.5	0.77
1900-lb. G.P., Mk II	1785	Amatol 60/40	470	26	18.5	65.5	101.0	1.15
4000-lb. G.P., Mk I & II	3587	Amatol 60/40	1072	30	24.5	81.0	106.0	1.35
250-lb. S.A.P., Mk V	245	TNT	42	17	9.2	31.5	42.2	0.91 — 0.99
500-lb. S.A.P., Mk V	490	TNT	89	18	11.5	41.8	62.0	1.22—1.32
500-lb. S.A.P., Mk V	483	TNT	89	19	11.5	41.8	52.0	1.22—1.32
2000-lb. A.P., Mk III	1934	Shellite	.166	9	13.5	80.0	113.0	
100-lb. A.S., Mk IV	98	TNT	44	45	8.0	25.0	42.0	0.11
250-lb. A.S., Mk IV	243	TNT	134	55	11.3	36.0	58.0	0.14
500-lb. A.S., Mk IV	490	TNT	282	58	14.3	50.0	73.5	0.18
500-lb. M.C., Mk I & II	447	Amatol 60/40	224	50	12.9	42.0	70.6	0.3
500-lb. M.C., Mk I & II	439	Amatol 60/40	224	51	12.9	42.0	57.8	0.3
500-lb. M.C., Mk III	510	Amatol 60/40	210	41	12.9	42.0	70.6	0.42
500-lb. M.C., Mk III	502	Amatol 60/40	210	42	12.9	42.0	57.8	0.42
500-lb. M.C., Mk IV	440	Amatol 60/40	174	40	12.9	36.5	70.3	0.42
500-lb. M.C., Mk IV	437	Amatol 60/40	174	40	12.9	36.5	57.3	0.42
500-lb. M.C., Mk V	510	Amatol 60/40	210	41	12.9	42.0	70.6	0.42
1000-lb. M.C., Mk I	1021	Amatol 60/40	475	47	17.5	52.5	72.5	0.42
4000-lb. M.C., Mk I		Amatol 50/50 Amatol 60/40 Amatol 60/40-fine grained Amatex 9 RDX/TNT		55	30.0	74.5	109.5	0.75
2000-lb. H.C., Mk I	1842	Amatol 60/40	1340	73	18.5	99.5	162.0	0.19
2000-lb. H.C., Mk II & III	1723	Amatol 60/40	1230	71	18.5	89.0	131.0	0.19
4000-lb. H.C., Mk III & IV	3944	Amatol 60/40	2960	75	30.0	82.0	110.0	0.31
8000-lb. H.C., Mk I & II	7860	Amatol 60/40	5361	68	38.0	nose 47.2 rear 47.8	133.0	0.50
12000-lb. H.C.	11800	Amatex 9	7800	66	38.0		180.0	

ABBREVIATIONS

		AMERICAN EQUIVALENTS	GERMAN EQUIVALENTS
M.C.	MEDIUM CHARGE, charge-weight ratio about 50%	GP	S.C.
H.C.	HEAVY CHARGE, charge-weight ratio about 70-75%	L.C.	
G.P.	GENERAL PURPOSE, charge-weight ratio about 30%	S.A.P.	S.D.
A.P.	ARMOR PIERCING, charge-weight ratio about 5-8%	A.P.	
S.A.P.	SEMI-ARMOR PIERCING, chg-wt ratio about 18%		P.C.
A.S.	ANTI-SUBMARINE		
F.	FRAGMENTATION, anti-personnel		

NOTE: COMPILED FROM DATA SUPPLIED BY THE BRITISH MINISTRY OF SUPPLY

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WEAPON DATA

PHYSICAL CHARACTERISTICS OF GERMAN BOMBS AND MINES

1A5a PHYSICAL CHARACTERISTICS

A HIGH EXPLOSIVE BOMBS

TYPE	TOTAL WEIGHT- pounds	TYPE of CHARGE	WEIGHT of CHARGE pounds	CHARGE-WEIGHT RATIO percent	MAX. BODY DIAMETER inches	LENGTH without TAIL inches	BODY WALL THICKNESS inches	NOSE CORRECTION inches
2 kg. S.D.2 Anti-personnel "Butterfly"	4.4	TNT-cast	7.5 oz	11	3.0	3.1	3/8	*(See Data Sheet 1 B1 for definition of nose correction)*
12-kg. S.C. 10 Anti-personnel	26	TNT	2.0	7.7	3.25	15	0.5	
30-35-kg. S. Be50 Anti-personnel	66-77	TNT	15		7.0	27	1.75	
10-kg. B.D.C.								
50-kg. S.C.	113	TNT or Amatol	53.7	48	8.0	28-31	3/16	3.83
50-kg. S.D.	113	TNT	36.1	32	8.0	23.5	3/8	3.83
70-kg. S.C.	154	TNT	46.2	30	8.0	28-31	0.39	
100-kg. S.C.	220		110	50	10	33	5/32	
250-kg. S.C.	519	TNT or Amatol	286	55	14.5	46.5 or 47.0	9/32 or 5/16	6.80
250-kg. S.D.	528	TNT	174	33	14.5	36.0	7/8	6.80
500-kg. S.C.	1120	TNT or Amatol	484	43	18, 18.5 or 19	60, 52 or 54.5 resp.	9/32 or 5/16	9.39
500-kg. S.D.	1087 1100	TNT/wax TNT-cast	165 165	15 15	15.6 15.0	54.0 32.5	0.9 1.6	8.35 8.35
500-kg. S.D.	1190	TNT	420	35	17.5	54	1.19	
500-kg. P.C. Rocket Bomb	1100	TNT-cast	220	20	15.6	42.7-54.0		
1000-kg. S.C. "Hermann"	2200 2400	TNT-cast & granulated	1190	54 50	26.2	75.0	3/8	12.57
1000-kg. S.C.	2070 ?					65 ?		
1000-kg. S.D. "Esau"	2240	TNT/wax	319	14	19.8	57.8	1.38	
1000-kg. P.C. Rocket Bomb	2200	TNT-cast	308	14	19.8	58.0		11.72
1000-kg. R.S.-P.C.	2200		121	5.5	15.5	47.0		
1200-kg. S.C.	2640		1590	60	26.2	74.0		
1400-kg. S.D. "Fritz"	3010	TNT/wax	660	22	22.0	75.0	1.5	
1400-kg. P.C.	3080		660	21	21.9	76.5		12.06
1700-kg. S.C.D.	3760	TNT-cast	1630	43	25.5	92.0	15/16	11.73
1730-kg. S.C. "Moorhead"	3810		1600	42	25.5	91.5	1.0	
1800-kg. S.C. "Satan"	3900	TNT or Amatol	2100	54	25.9	104	0.4	13.72
1800-kg. R.S.-P.C.	3960		374	9.4				
2500-kg. S.C. "Max"	5500	TNT		Excessive (80 ?)	30-31			

ABBREVIATIONS

S.C. (SPRENGCYLINDRISCH) THIN WALLED, GENERAL PURPOSE.... CHARGE-WEIGHT RATIO APPROXIMATELY 50%. USED PRIMARILY FOR GENERAL DEMOLITION... MAIN FILLING USUALLY TNT OR AMATOL.

S.D. (SPRENGDICKENWAND) THICK WALLED, SEMI-ARMOR-PIERCING OR ARMOR-PIERCING... CHARGE-WEIGHT RATIO APPROXIMATELY 30%.... USED PRIMARILY AGAINST SHIPS AND FORTIFICATIONS... CONTAIN TNT PELLETS COATED WITH LIGNITE WAX TO REDUCE THE SENSITIVITY OF THE EXPLOSIVE.

P.C. ARMOR-PIERCING.... CHARGE-WEIGHT RATIO APPROXIMATELY 20%.

ALL BOMBS LARGER THAN THE 50-kg. HAVE A COLUMN OF TNT PELLETS WRAPPED IN PAPER AND EXTENDING THROUGH THE CENTER OF THE BOMB TO INSURE HIGH-ORDER EXPLOSION.

COMPILED FROM DATA IN THE U.S. WAR DEPARTMENT TECHNICAL MANUAL, TM-E9-1983 AND FROM DATA SUPPLIED BY THE BRITISH MINISTRY OF HOME SECURITY

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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WEAPON DATA

PHYSICAL CHARACTERISTICS OF GERMAN BOMBS AND MINES (continued)

1A5b PHYSICAL CHARACTERISTICS

B INCENDIARY BOMBS

TYPE	TOTAL WEIGHT pounds	TYPE of CHARGE	WEIGHT of CHARGE pounds	CHARGE-WEIGHT RATIO percent	MAX. BODY DIAMETER inches	LENGTH WITHOUT TAIL inches	BODY WALL THICKNESS inches
B 1-kg. El.	2.03	Thermite	0.44		1.97	9.64	25/64
B 1-kg. El. plus explosive charge	2.03	Thermite TNT	0.44 0.016		1.97	9.64	25/64
B 1.3-kg. Steel Nose	2.78	Thermite	0.44		1.97	9.64	25/64
B 2.2-kg. El-2(IBEN) Incend. & anti-person'l	4 lb.-14 oz.	Thermite TNT (in nose)	0.56 0.37		Incend. 1.96 Nose 1.78	16.8	Incend. 25/64 Nose 1/4
50-kg. Thermite Incendiary.	75.0	Thermite TNT	— 20.0		8.0	28.0	0.15
50-kg. Phosphorus Incendiary	90.0	Benzine 86% Phosphorus 4% Rubber 10%	30.0	33	8.0	30.0	1/8
50-kg. Sb. C	110		16-17	15		28.3 - 30.3	
110-kg. (Flam) Incendiary	242	Gasoline TNT	110	45	14.5	40.0	1/16
250-kg. (Flam) Incendiary	550	Gasoline TNT			18.0	62.0	1/16
ABB 500 (152-kg.) Incendiary Container	336.0	120 1-kg. Incend. Bombs		79	18.4	25.2	0.05

C MISCELLANEOUS BOMBS AND MINES

TYPE	TOTAL WEIGHT pounds	TYPE of CHARGE	WEIGHT of CHARGE pounds	CHARGE-WEIGHT RATIO percent	MAX. BODY DIAMETER inches	LENGTH WITHOUT TAIL inches	BODY WALL THICKNESS inches
Mortar Grenade	2.2	TNT-cast	4.2oz.	12	2.0	4.2	0.16
Hand Grenade Chemical Warfare					1.5	4.1	0.026
Plane Destroying Bomb	6.6	TNT			Dimensions in inches - 7.5 x 6.5 x 2.8		
Ring Charges (2 sizes)	A - 2.64 B - 7.04	TNT - compressed			inside 4.0 inside 6.8		
Shrapnel	9.0	Tolite (TNT)	1.0	11	3.9	height 5.7	0.08
Tellermine	19	Tolite (TNT)	11	56	12.8	height 4.0	1/16
Bell Demolition Charges (2 sizes)	A - 27.5 B - 110.0	TNT TNT					
500-kg. D Parachute-mine	1100		675	58	26.0		
1000-kg. C Parachute-mine	2200		1536	70	26.0		
1000-kg. G Bomb-mine	2200		1615	73	25.5	78.0	

ABBREVIATIONS

Sb. - THERMITE INCENDIARY CONTAINING AN EXPLOSIVE CHARGE.

El. - THERMITE INCENDIARY WITH ELECTRON METAL CASE (?)

COMPILED FROM DATA IN THE U.S. WAR DEPARTMENT TECHNICAL MANUAL, TM-E9-1983, AND FROM DATA SUPPLIED BY THE BRITISH MINISTRY OF HOME SECURITY

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Confidential

August 1943

WEAPON DATA

PHYSICAL CHARACTERISTICS OF JAPANESE HIGH EXPLOSIVE AND INCENDIARY BOMBS

A. HIGH EXPLOSIVE AND FRAGMENTATION BOMBS

DESIGNATION	FUZE SETTING	TOTAL WEIGHT W *pounds*	MAX. BODY DIAM. *inches*	LENGTH WITHOUT TAIL *inches*	WALL THICK-NESS *inches*	TYPE OF CHARGE	WEIGHT OF CHARGE w, *lb.*	CHARGE WEIGHT RATIO w/W, %	REMARKS
1/3-kg AA, grounded, Army	Inst.	0.66	1.6	4.6	0.03	TNT	0.24	32	80° cone-end charge; air burst containers of 30 or 76 bombs.
Bolo Bomb, AA Army	Inst.	0.87	2.5	4.4	3/32	Cyclonite and TNT	0.53	60	Parachute attached; air-to-air bombing.
1/2-kg AA, grounded, Army	Inst.	0.90	2.1	2.7	3/64	RDX/TNT	0.44	49	
1-kg AA, Spherical Missile		2.3	5.5	5.5	0.1	Black Pwdr burster			Paper wall. 32 pellets @ 2/3 oz.
1-kg AA Navy	Inst.	2.2	1.8	8.4	0.07	TNA/HND	0.69	31	cone-end charge; air burst container of 40 bombs.
1-kg Anti-pers. Navy	Inst.	2.2	2.4	5.5	1/32	TNA/HND	1.1	50	36 in air-burst container.
10-kg Anti-pers. Type 94, Army substitute	Inst.	22	4.1	18.2	1.0	Black Pwdr	1.2	5.5	Concrete case; steel central tube.
15-kg Anti-pers. Army	Inst.	32	4.0	14.5	1/32	Picric burster			Cast steel case filled with concrete and steel pellets.
15-kg Anti-pers. Type 92 Army	Inst.	33	3.9	14.6	0.53	Picric	9.7	29	Body wall made of 26 steel rings.
30-kg Anti-pers. Type 1, Army substitute	Inst.	63	5.1	19.9	1/16	Black Pwdr burster			Cast steel case filled with concrete and steel pellets.
30-kg Anti-pers. Type 2, Army substitute	Inst.	66	5.1	20.6	1/16	Black Pwdr burster			Cast steel case filled with concrete
30-kg GP, Type 99, Army	Inst; short delay; 15-16 seconds	66	5.9	19.7	0.29	Picric	26	39	
32-kg Stream-lined, Navy	Inst.	70	7.6	19.7	1/4				Resembles British Bombs.
50-kg GP, Type 94, Army	Inst; short delay; 15-16 seconds	110	7.1	24.4	0.27	Picric or RDX/TNA	44	40	
50-kg Time Bomb, Type 1 & 94 (mod) Army	15-16 sec; 2-24 hrs.	110	7.1	23.2	9/32	Picric	44	40	Type 1 can use anti-withdrawal tail fuze.
60-kg Type 3 Navy	Inst; short delay	143	7.9	21.8	0.28	Picric	86	60	
60-kg Type 97 Navy	In Navy Gaine*	124	7.9	21.8	0.28	Hexanite and TNA	50	41	
60-kg Anti-Sub Type 99 Navy	3½, 10 sec. delays	141	9.4	21.0	0.18	TNA/HND	86	61	
63-kg Stream-lined, Navy	Inst.	139	9.0	25.5			65.8	47	Resembles British Bombs.
63-kg GP, Type 99 Navy	Inst.	139	8.9	25.5	0.25	Picric or TNA/HND	70	50	
100-kg GP, Type 3 and 94 Army	Inst; short delay; 15-16 seconds	220	9.5	31.2	0.4	Picric	99	45	
100-kg Time, Type 1 and 94 (mod) Army	15-16 sec; 2-24 hrs.	238	9.5	30.2	0.4	Picric	104	44	Type 1 can use anti-withdrawal tail fuze.
250-kg GP, Type 1, Navy	Inst; short delay; ½-125 hrs.	550	13.8	35.5	0.25	TNA/HND	330	60	
250-kg GP, Type 1, Blunt Nose * Navy	Inst; short delay	378	11.7	30.4	0.5	TNA/HND	175	33	May use electric firing mechanism for proximity bursts. Explosive-filled tail.
250-kg Anti-Ship, Type 3 Army	2 & 5 secs.	550	11.8	46.5	0.5	Picric & TNT	230	42	
250-kg Explosive-filled Tail Type 3, Navy	In Navy Gaine*	650	12.0	39.6	0.5	TNA/HND	263	40	Designed for better fragmentation of tail.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

continued, over

JAPANESE HIGH EXPLOSIVE & INCENDIARY BOMBS continued

DESIGNATION	FUZE SETTING	TOTAL WEIGHT W *pounds*	MAX. BODY DIAM. *inches*	LENGTH WITHOUT TAIL *inches*	WALL THICKNESS *inches*	TYPE OF CHARGE	WEIGHT OF CHARGE w, *lb.*	CHARGE WEIGHT RATIO w/W, %	REMARKS
250-kg GP, Type 92 Army	In Navy Gaine*	550	11.7	59.5	1/4	Picric	230	42	Length includes tail cone.
250-kg GP, Type 98 Navy	Inst; short delay; ½-125 hrs.	532	12.0	39.6	0.5	Picric or TNA/HND	210	40	
250-kg Time, Type 1 Army	2-24 hrs.	527	11.7	45.4	1/4	Picric	228	43	Anti-withdrawal device in nose
250-kg Anti-sub, Type 1 Navy	Inst; short delay; 5.5 & 10 secs.	650	14.0	35.6	0.25	TNA/HND	396	61	Mod 1 has anti-ricochet nose ring.
250-kg SAP, Type 99 Navy	In Navy Gaine*	540	11.5	39.7	0.75	TNA	133	25	
250-kg Streamline Navy	Inst; short delay	556	14.0	44.5	0.60	Picric	229	41	One-piece cast or forged steel body.
500-kg AP, Type 2 Navy	In Navy Gaine*	1100	15.5	38.5	Nose: 7½ Base: 1	TNA/HND	148	13	
500-kg GP, Type 92 Army	Inst; short delay	1100	14.5	77.0		Picric	493	46	Length includes tail cone.
500-kg Anti-Ship, Type 4 Army	2 & 5 secs.	1123	15.0	57.5	0.56	Picric & TNT	540	48	Explosive-filled tail.
500-kg SAP, Navy	In Navy Gaine*	1080	16.5	45.0	Nose: 4 Base: ½	TNA/HND	457	42	
800-kg GP. Navy	Inst; short delay	1820	17.5	62.0		TNA	770	42	One-piece forged steel body possibly carried in torpedo racks
800-kg Type 3, #80 Land Bomb Navy	Inst; short delay	1584	17.8	71.1	15/32	TNA/HND	922	58	Also delays incorporated in Navy Gaine*
800-kg GP, Type 3 Navy	Inst; short delay	1760	18.0	72.0		Picric	842	48	May use electric firing mechanism for proximity bursts
800-kg, AP, Type 99 Navy	Short delay	1642	16.1	48.3	Nose: 4 Base: 2	TNA	66	4	One-piece forged machine steel...two base fuzes

B. INCENDIARY BOMBS

1-kg Army	Inst.	2.7	2.1	8.3	3/8	Thermite-filled magnesium containers dropped in clusters.
5-kg	Inst.	11	3.7	6.7	1/8	Thermite filled
12-kg, Type 97 Army	Short delay	26	4.0	14.5	3/16	Thermite-filled magnesium firepots; black powder ignition charges.
32-kg, Shrapnel Type 99, Navy	0-20; 5-20; 0-50 sec. air burst delay	70	5.7	13.5	0.19	198 phosphorus-filled steel pellets; picric acid charge.
50-kg, Type 97 Army	Inst; short delay	110	7.5	26.4	0.2	Gas bomb used as incendiary. CS_2 solution of white phosphorus with 475 rubber bungs...picric acid charge.
50-kg, Type 100 Army	Inst; short delay	96	7.0	23.8	0.125	
60-kg, Type 3 Navy	0-20; 5-20; 0-50 sec. air burst delay	118	7.8	23.0	0.12	Three cylindrical cannisters each containing 87 white phosphorous-filled steel pellets. Explosive tube of TNA/HND
70-kg, Type 98 Short Delay, Navy	short delay	156	7.9	21.8	0.3	"Electron" firepots filled with thermite scattered by black powder charge.
70-kg, Type 98, Oil Navy	short delay	145	9.5	21.0	0.18	20-lb inflammable mixture; 75-lb thermite scattered by black powder charge.
70-kg, Type 1 Navy	In Navy Gaine*	160	9.5	21.0	0.125	Contains 182 cylindrical incendiary pellets and grey powder bursting charge.
250-kg, Type 2 Navy	0-20; 5-20; 0-50 sec. air burst delay	550	12.0	40	0.22	750 steel tubes filled with incendiary metallic rubber mixture. 33 kg. bursting charge of H.E. or black powder scatters mixture over 175 yds. radius when air burst occurs 100 ft. above ground.

*Four types of Navy Gaine are known. Type A has delays of 0.014, 0.017, 0.025 and 0.031 seconds; Type B is instantaneous; Type C is instantaneous; Type D has selective delay from a fraction of a second to 1.5 second.

Source: US Navy Bomb Disposal School and Ordnance Department, US Army.

Restricted

WEAPON DATA

PHYSICAL CHARACTERISTICS OF AMERICAN LAND MINES AND FIRING DEVICES

1 A7a
AMERICAN LAND MINES

A: LAND MINES

DESIGNATION	THICKNESS OR HEIGHT *inches*	DIAM OR WIDTH *inches*	TOTAL WEIGHT *pounds*	CASE	EXPLOSIVE TYPE	EXPLOSIVE WEIGHT *pounds*	FUZE	FORCE TO OPERATE *pounds*	FUZE FUNCTION	REMARKS
Mine, Anti-Tank, M1	4	8 diam	10.6	Steel	Cast TNT	5.5	M1	500 center 250 edge	Pressure cuts shear pin. Balls release striker	No longer in production. Booster integral with fuze. Spider 8.2 *in* diameter.
Mine, Anti-Tank, M1A1	4	8 diam	10.6	Steel	Cast TNT	5.5	M1A1	500 center 250 edge	Pressure cuts shear pin. Balls release striker	Booster separate from fuze. Spider 8.2 *in*
							M1A2	500 center 250 edge		Same as mine with fuze M1A1 except fuze M1A2 has more powerful detonator to insure high order detonation. Spider 8.2 *in* diameter.
Mine, Anti-Tank, M4	4	8 diam	10.6	Steel	Cast TNT	5.5	M4	500	"Cricket" metal diaphragm snaps striker down	2 activator wells* : side, bottom. Internal construction of fuze M4 makes mine safe to re-use. Spider 8.2 *in* diameter.
Mine, Anti-Tank, M5	5.5	10 diam	14.5	Ceramic	TNT or Tetrytol	5.6	M5 Chem.	275-425	Pressure breaks glass vial. Chem. ignites flash mixture	1 activator well* : bottom..fuze made of plastic.
Mine, Heavy Anti-Tank, M6	3.25	12.5 diam.	20	Steel	Cast TNT	12	M600 Chem.	300-400	Piston crushes glass vial. Chem. ignites flash mixture	2 activator wells*: side; bottom. Solid pressure plate
Mine, Light Anti-Tank, M7 (or Anti-Personnel-see remarks)	2.5	4.5x7	4.5	Steel	Tetrytol	3.25	M601 Chem.	300-400	Piston crushes glass vial. Chem. ignites flash mixture	1 activator well*: side. Any standard firing device may be used in activator well to convert to anti-personnel mine.
Mine, Anti-personnel, M2 (M2A1, M2A2, M2A3, M2A3B1, M2A3B2, M2A4, M2A4B2)	6.12	Body: 2.5 diam. Base: 5¼ diam. or 3x4	Shell: 2.5 Total: 5 to 6.5	Steel or Malleable iron	Flaked TNT	0.34	M2 M2A1	PULL 3-6 PRESS 20-40	Pressure or pull on trip wire releases spring driven striker	Various mods differ in manufacturing details of base. Projects 2½ *lb* shell which detonates 6-8 *ft* from mine. Lethal range 30-60 *ft*. Dangerous to 150 *ft*. Any standard firing device with igniter tube may be used as a fuze.
	6.5						M6	PULL 6-10 PRESS 10-30		
Mine, Anti-Personnel, M3	3.5	3.5x5.4	9.6	Cast Iron	Flaked TNT	0.85	M3 M3A1	PULL 3-6 PRESS 20-40	3 prongs...pressure on 1 or more prongs or pull on release pin releases spring driven striker.	Lethal range approx. 30 *ft*. 3 activator wells*: Top, side, and end.
							M7	PULL 6-10 PRESS 10-30		

*Activator wells have standard thread to fit any of the standard firing devices listed below. These may be used for anti-personnel devices or for otherwise booby trapping mines.

Note: In addition to the mines listed above, various demolition charges, the bangalore torpedo, hand grenades, etc. may be equipped with one or more of the standard firing devices listed below and used as anti-tank or anti-personnel mines.

B: FIRING DEVICES
over

Source: Publications of War Department; Ordnance Department, US Army; Office of the Chief of Engineers, US Army; Bureau of Ordnance, US Navy; and US Navy Bomb Disposal School.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Ref: PTM No. 110
July 1945

B: FIRING DEVICES

DESIGNATION	FORCE TO OPERATE, *lb*	METHOD OF FUNCTIONING	REMARKS
Firing Device, Pull Type, MI	3-6 pull	Pull on release pin releases spring driven striker	
Firing Device, Pull Friction Type, M2	3-9 pull	Pulling coated wire through friction compound ignites compound.	Made of plastic for use in non-metallic mines or booby traps.
Firing Device, Pressure Type, MIAI	20 press (see remarks)	Moving trigger pin inward allows spring driven striker pin to operate	Operates on 5 lb press with trigger spring removed. Has adjustable extension rod with 3 prongs
Firing Device, Release Type, MI	Restraining load at least 2 lb.	Removal of restraining load allows spring driven hammer to drive striker pin.	In sheet metal box, 1-7/8 x 1-7/8 x 2-3/8 *inches*
Firing Device, Pull Release Type, M3	6-10 pull or tension release	Pull or release of tension on release pin releases spring driven striker	
Firing Device, Pressure Release Type, M5	Restraining load at least 5 lbs.	Removal of restraining load allows spring driven striker to detonate cap.	In sheet metal box 1-3/4 x 15/16 x 11/16 *inches*
Firing Device, Combination, MI	3-6 pull or 20 press	Pressure on cap or pull on release pin releases spring driven striker	With igniter or blasting cap this is fuze M2 or M3 for anti-personnel mines M2 and M3
Fuze Combination, M6	6-10 pull or 10-30 press	Pressure on one or more prongs or pull on release pin releases spring driven striker	Firing devices complete with igniter. M6 has black powder igniter; M7 has blasting cap. Used as fuzes in anti-pers. mines M2, M3
Fuze Combination, M7	6-10 pull or 10-30 press	Pressure on one or more prongs or pull on release pin releases spring driven striker	
Firing Device Delay Type, MI	15-25 to crush ampule	Crushing ampule releases corrosive liquid which eats away restraining wire, releasing spring-driven striker pin.	Widely variable delays, color coded on safety tab. Delay is strongly temperature dependent.
Detonator, 15-second Delay, MI	5-20 pull	Pulling coated wire through friction compound causes flash igniting 15 sec. delay powder train.	Made of plastic. May be used under water. Complete with blasting cap as igniter.
Firing Device (Navy) Demolition, MkI mod 0	31 pull, release, or pressure	Pressure on cap or pull or release of trip line releases spring driven striker	MkI mod 0 and MkI mod I differ in mounting details. MkI mod I ratchet takeup for adjusting trip line. Can be used for pull-release or pressure, but not for both.
Firing Device (Navy) Demolition, MkI mod I	11-16 pull, release or pressure	Pressure on cap or pull or release of trip line releases spring driven striker	
Firing Device (Navy) Demolition, Mk6 mod 0 *concussion detonator*		Air or water pressure snaps diaphragm through dead center driving striker pin	For sympathetic detonation in air or water up to 12 *ft* deep. Various arming cells to give arming delays of 9-90 minutes in sea water at 60° F.

All firing devices listed here have standard threaded coupling and may be used to detonate anti-personnel mines, demolition charges, bangalore torpedoes, hand grenades, etc. which have standard threaded activator wells. Igniter tube, non-electric blasting cap, or Activator MI must be used with all firing devices uhless otherwise noted (Fuze M6, Fuze M7, Detonator MI). Primacord, properly attached, may be used to connect firing device to demolition charge.

WEAPON DATA

1 A7b
AMERICAN
DEMOLITION CHARGES

PHYSICAL CHARACTERISTICS OF AMERICAN DEMOLITION, SHAPED AND LINE CHARGES

A: DEMOLITION CHARGES

DESIGNATION	LENGTH *inches*	WIDTH *inches*	THICKNESS *inches*	TYPE	WEIGHT *pounds*	TOTAL WEIGHT *pounds*	CASE MATERIAL	REMARKS
DEMOLITION CHARGES, U.S. ARMY								
Demolition Block, Chain, M1	$11\frac{3}{4}$	9	$4\frac{1}{2}$	Tetrytol	20	22	Cloth Bag	8 blocks, strung on primacord, in bag.
Demolition Block, M2	11	2	2	Tetrytol	2.4	2.5	Paper	Issued as 8 blocks in bag with strap.
Demolition Block, M3	11	2	2	Comp C-2	$2\frac{1}{4}$	$2\frac{1}{4}$	Paper	Issued as 8 blocks in bag with strap.
Demolition Block, M4	6	1	$1\frac{1}{4}$	Comp C-2	$\frac{1}{2}$	$\frac{1}{2}$	Paper	
Block, TNT, $\frac{1}{2}$-lb.	$3\frac{11}{16}$	$1\frac{29}{32}$	$1\frac{29}{32}$	Pressed TNT	$\frac{1}{2}$	$\frac{1}{2}$	Cardboard	
Block, TNT, 1-lb	7	$1\frac{29}{32}$	$1\frac{29}{32}$	Pressed TNT	1	1	Cardboard Metal Ends	Two $\frac{1}{2}$-lb Blocks in one container.
Block, Nitrostarch, $\frac{1}{4}$-lb.	$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	Nitrostarch	$\frac{1}{4}$	$\frac{1}{4}$	Paper	Three $\frac{1}{12}$-lb Blocks wrapped together.
Block, Nitrostarch, $\frac{1}{2}$-lb.	$3\frac{1}{16}$	$1\frac{29}{32}$	$1\frac{29}{32}$	Nitrostarch	$\frac{1}{2}$	$\frac{1}{2}$	Cardboard Metal Ends	
Block, Nitrostarch, 1-lb.	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	Nitrostarch	1	1	Paper	Four $\frac{1}{4}$-lb Blocks wrapped together.
Cratering Explosive	17	$8\frac{1}{4}$-in. diam.		Ammonium Nitrate	40		Metal	
Commercial Dynamite, $\frac{1}{2}$-lb.	8	$1\frac{1}{4}$-in. diam.		Dynamite 40%, 50%, 60%	$\frac{1}{2}$	$\frac{1}{2}$	Paper	
DEMOLITION CHARGES, U.S. NAVY								
Demolition Charge, Mk2 Mod 0	14.2	9.25	9.25	TNT	$55\frac{1}{2}$		Steel	For electrical firing
Demolition Charge, Mk2 Mod 1	14.2	9.25	9.25	TNT	$55\frac{1}{2}$		Steel	For electrical or mechanical firing.
Demolition Charge, Mk2 Mod 2	14.2	9.25	9.25	TNT	$55\frac{1}{2}$		Steel	Has standard threaded activator well
Demolition Charge, Mk3	$3\frac{11}{16}$	$1\frac{29}{32}$	$1\frac{29}{32}$	Pressed TNT	$\frac{1}{2}$	$\frac{1}{2}$	Cardboard Metal Ends	Same as Army Block, TNT $\frac{1}{2}$-lb.
Demolition Charge, Mk4	$3\frac{11}{16}$	$1\frac{29}{32}$	$1\frac{29}{32}$	Cast TNT	$\frac{1}{2}$	$\frac{1}{2}$	Cardboard	Two tetryl pellet boosters.
Demolition Charge, Mk5	13	13	13	TNT	120		Fiber Board	$2\frac{1}{2}$-lb Tetryl booster Obsolescent; See Mk14
Demolition Charge, Mk9, Mod 0,1	13	13	13	Cast TNT	112	115	Steel	Fitted with standard bomb nose fuze seat for $1\frac{3}{4}$-in. fuzes.
Demolition Charge, Mk10	11	2	2	Tetrytol	$2\frac{1}{2}$	$2\frac{1}{2}$	Paper	Same as one section of Army Demolition Block, Chain M1, with detonating cord attached. Issued as 8 blocks in cloth bag with strap. Obsolete
Demolition Charge, Mk14, Mod 0	13	13	$6\frac{1}{2}$	Cast TNT	$48\frac{1}{2}$	50	Fiber-board	46-lbs Cast TNT plus $2\frac{1}{2}$-lb tetryl booster. Self-contained detonating cord.
Demolition Charge, Mk14, Mod 1	13	13	$6\frac{1}{2}$	Cast TNT	49	50	Fiber-Board	No booster. Designed for sympathetic detonation.
Demolition Charge, Mk20	12	$2\frac{1}{2}$	$1\frac{3}{4}$	Comp C-2	$2\frac{1}{2}$	$2\frac{1}{2}$	Paper	Issued as 10 blocks in haversack with strap. Two sacks issued together as Dem. Outfits, Mk127.

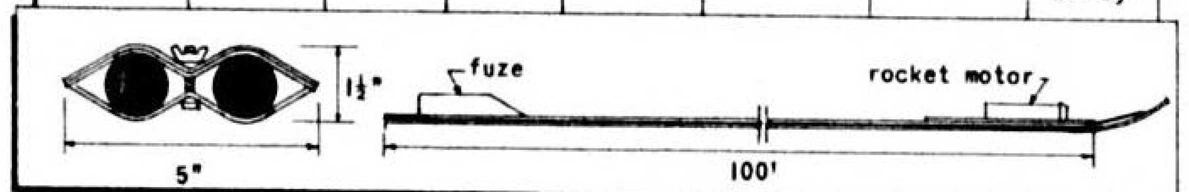
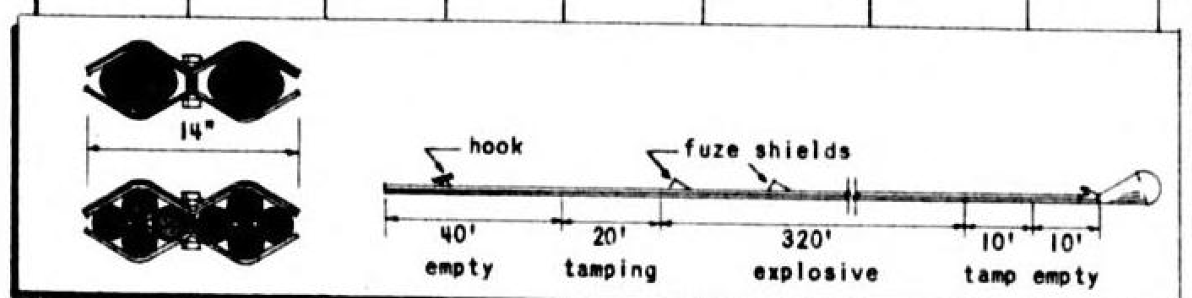
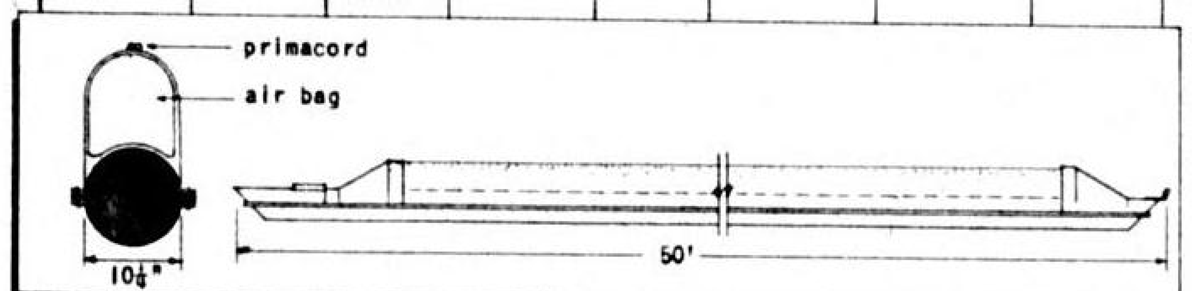
B: SHAPED CHARGES *cone-end*

DESIGNATION	OVERALL LENGTH *inches*	LENGTH OF BODY *inches*	STAND-OFF *inches*	CONE DIAM. *inches*	CONE ANGLE *degrees*	CONE THICKNESS *inches*	LINER MATERIAL	CHARGE TYPE	CHARGE WEIGHT *pounds*	TOTAL WEIGHT *pounds*	CASE MATERIAL	REMARKS
SHAPED CHARGES, U.S. ARMY *all have standard threaded activator well.*												
Charge, Shaped, 10-lb M1	13.5	8.8	4.7	6	80	0.125	Steel	TNT	9.5	13	Steel	Obsolete.
Charge, Shaped, 10-lb M2	15.8	10.2	5.6	6	60	0.39	Glass	Pentolite 50/50	10	13.5	Plastic	Standoff tube 7.5 in. diam.
Charge, Shaped, 10-lb M2A1	14.3	8.7	5.6	6	60	0.39	Glass		10	13.4	Impreg. Cloth	Same as M2 with top reduced in length.
Charge, Shaped, 15-lb, M2A3	16.4	10.9	5.4	6	60	0.39	Glass		11.5	14.7	Fiber-Bd.	
Charge, Shaped, 40-lb M3	29.5	15.4	14.1	9.5	60	0.16	Steel		29.2	43.5	Steel	Detachable legs
CAVITY CHARGE CONTAINERS, U.S. NAVY												
Cavity Charge Container, Mk1	$7\frac{1}{4}$	$4\frac{5}{32}$	3	$2\frac{1}{4}$	42	0.06	Steel	Comp C-2	2/3		Steel	Empty containers to be filled Comp C-2
Cavity Charge Container, Mk2	$9\frac{1}{4}$	$1\frac{1}{4}$	8	1	80	0.03	Steel		$\frac{3}{4}$ oz		Steel	
Cavity Charge Container, Mk3	10	4	6	3	80	0.09	Steel		$1\frac{1}{3}$		Steel	

C: LINE CHARGES, *over*

1A7b page two

C: LINE CHARGES

DESIGNATION	OVERALL LENGTH *feet*	CHARGE LENGTH *feet*	TOTAL WEIGHT *pounds*	CHARGE Type	CHARGE Weight *pounds*	LINEAR CHG.WT. *lb/ft*	EXPL. CASE MATERIAL	BODY MTRL.	REMARKS
Cable, Detonating Mine Clearing and Anti-Personnel, M1	variable			PETN Primacord		0.078			13 strands oil soaked PETN Primacord in common outer wrapper. total weight 0.11 lb/ft.
Bangalore Torpedo M1A1	5	5	14	Amatol 80/20	9	1.8	Steel		Sections of 2-1/8 inch diameter pipe, filled Amatol 80/20 with 4 inches TNT each end. Activator well at each end. Sections can be coupled for use in multiple lengths up to 200 ft. Packed in kits containing 10 torpedoes, 10 connecting sleeves, 1 nose sleeve.
Demolition Charge, Mk7 Navy	25	25		Flexed TNT	50	2	Rubber Hose		Obsolete. See Mark 8 Mod 0.
Demolition Charge, Mk8 Mod 0 Navy	25	25		Flexed TNT	50	2	Rubber Hose		Booster and Granular TNT in each end. Sections can be coupled for use in multiple lengths.
Snake, Mine Clearing & Anti-Personnel, M1	100	100	160	TNT	67	0.67	Paraffin Paper	Magnesium alloy	Propelled by rocket motor near nose. Fired by 150 foot trip cord. Explosive in paper cartridges, TNT, 8 inches long, one inch diameter
									
Snake, Demolition M2	400	320	12,500	Amatol 80/20	3200	10 (or 14.4)	Steel	Steel	Front 20 ft. and rear 60 ft. have no charge. Explosive in steel cylinders 4 ft. long, 20 pounds each. Filled Amatol 80/20 with 6 inches TNT each end. Can be filled with 4 Bangalore torpedoes each side giving a linear charge weight of 14.4 lb/ft. Bullet impact fuze.
									
Snake, Demolition M2A1 *see figure for* M2	400	320	15,000	Amatol 80/20	4480	14	Alum.	Steel	Front 20 ft. and rear 60 ft. have no charge. Explosive in Aluminum elliptical cylinders, 5ft. long, 35 pounds each, filled Amatol 80/20 with 6 inches TNT each end. Has two bullet impact fuzes.
Snake, Demolition M3 *see* M2	400	320	9,000	Amatol 80/20	4480	14	Alum.	Alum.	Same as Snake M2A1 except corrugated plates are made of aluminum.
Reddy Fox Charge Army Demolition Outfit Mk119 Navy	50	48	694 without explosive	Comp C-2 Tetrytol TNT	2115 1590 1760	44 33 37		Steel	Supplied in kits for 50-ft. lengths. Two of these may be used to make a 90-ft. length. Floated by air bags. Detonation of prima-cord along top releases airbags and allows charge to sink. Charge detonated after delay of about 5 minutes. Charge weights are given for unpacked explosives. Smaller weights result if packaged explosives are used.
									

Source: Publications of War Department; Ordnance Department, US Army; Office of the Chief of Engineers, US Army; Bureau of Ordnance, US Navy; and US Navy Bomb Disposal School.

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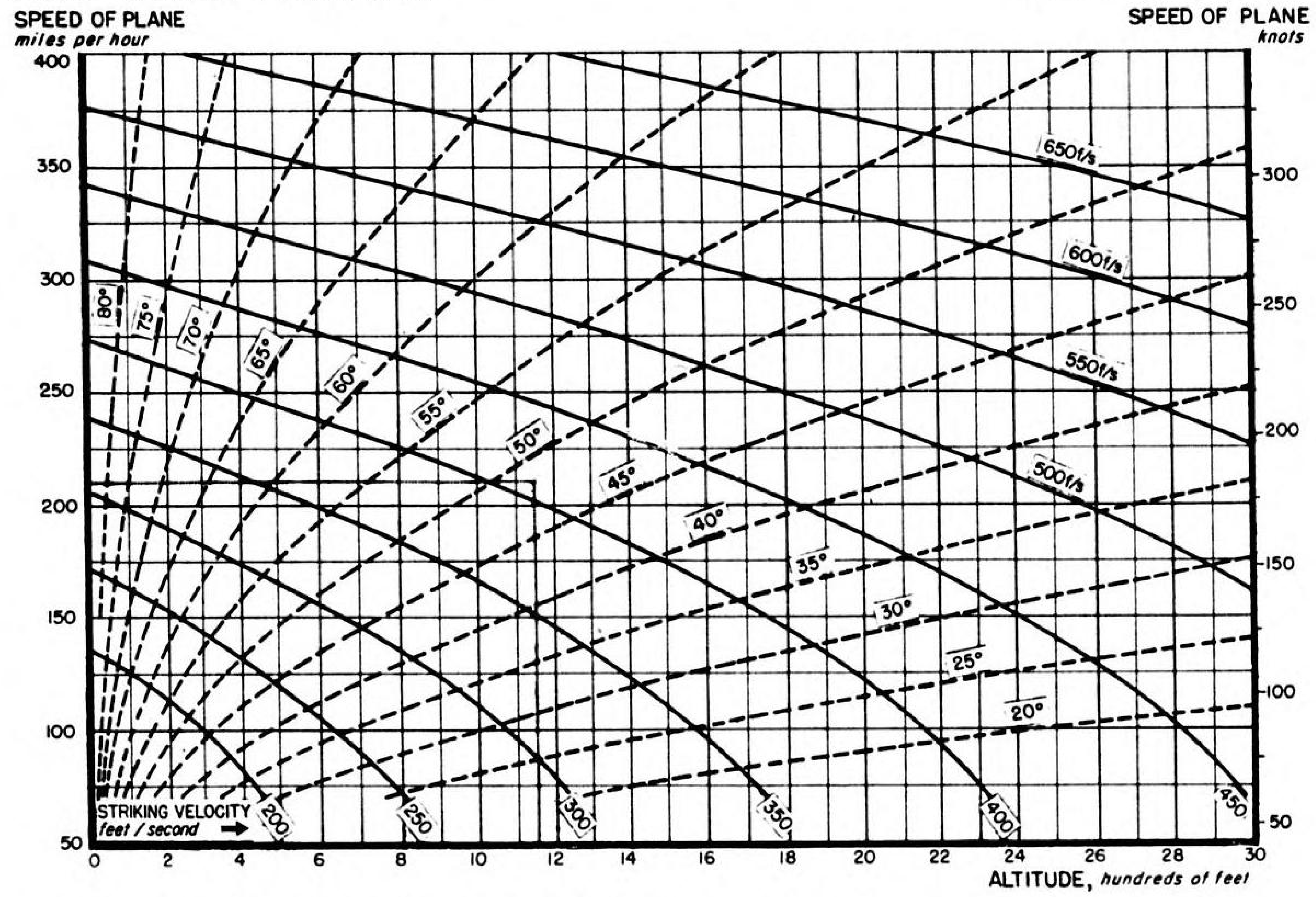
WEAPON DATA

1 B 4
FLIGHT
LOW LEVEL

LOW LEVEL BOMBING



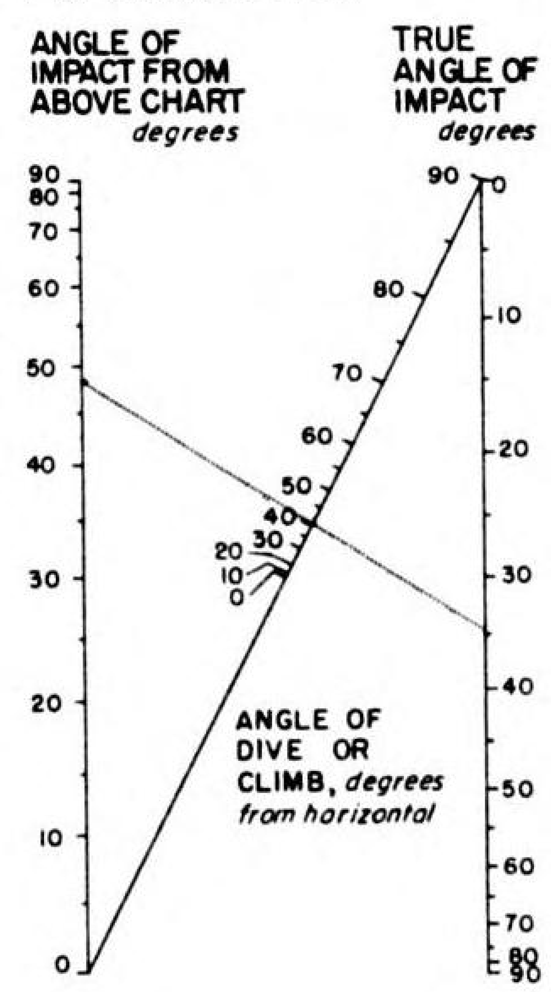
This sheet gives flight characteristics of bombs released from low altitude (up to 3,000 ft), based on the trajectory in a vacuum. True striking velocity and angle of impact will both be less than values read from chart, but at the highest plane speed and altitude on graph, the error in striking speed is 18% for the 100 lb G.P. bomb and 7% for the 1000 and 2000 G.P. Errors in impact angle are 3° or less. For data on level-flight bombing from altitudes above 2000 ft it is advisable to use sheets following, which give actual flight characteristics for individual bombs.

HORIZONTAL FLIGHT: Locate a point on the graph by projecting upward from the given altitude and across from the given plane speed. Using this juncture, interpolate between the solid-line curves to obtain striking velocity and between the broken-line curves to read angle of impact (measured from the vertical).

DIVE OR CLIMB: Magnitude of striking velocity is determined same as for horizontal flight. Impact angle is found by reading an angle from the chart as for horizontal flight and correcting it by means of the angle of dive or climb, using the nomogram.

Examples: Dotted lines on graph show that a bomb dropped from a plane flying at a speed of 210 mi/hr at an altitude of 1150 ft in either horizontal or inclined flight will strike the ground at a speed of 410 ft/sec. If this plane is flying level, the impact angle (measured from vertical) will be about 48°; if at an angle of 40° the impact angle (see dotted line on nomogram) will be about 35°.

ANGLE CORRECTION FOR INCLINED FLIGHT



FORMULAS: BOMB TRAJECTORY IN VACUUM IS BASED ON FOLLOWING RELATIONS.

$V_s = 1.467\sqrt{V_o^2 + 29.9h}$ $\qquad X = 1.467\, V_o\, t \cos\alpha$

$\sin\Theta_o = \dfrac{V_o}{\sqrt{V_o^2 + 29.9h}}$ $\qquad \sin\Theta_\alpha = \sin\Theta_o \cos\alpha = \dfrac{V_o \cos\alpha}{\sqrt{V_o^2 + 29.9h}}$

$t = 0.0456\left[\sqrt{V_o^2 \sin^2\alpha + 29.9h} \pm V_o \sin\alpha\right]$ (use + sign for climb, -sign for dive)

where:

- V_o = airplane speed, mi./hr.
- h = altitude of bomb release, ft.
- V_s = striking speed, ft./sec.
- t = time of flight, sec.
- Θ_o = impact angle for level flight, degrees from vertical
- Θ_α = impact angle for inclined flight, degrees from vertical
- α = angle of dive or climb, degrees from horizontal
- X = horizontal range of bomb trajectory, feet

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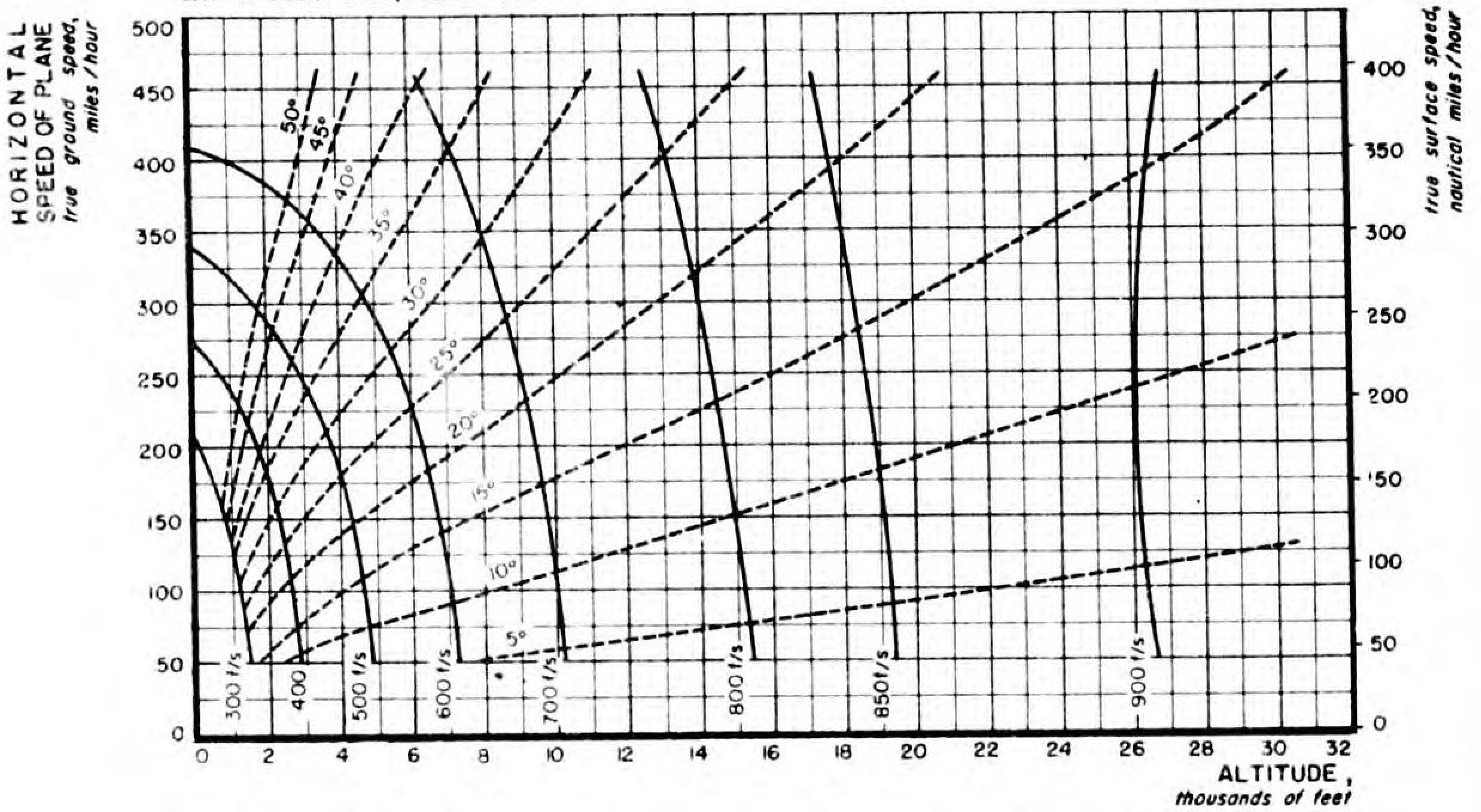
WEAPON DATA

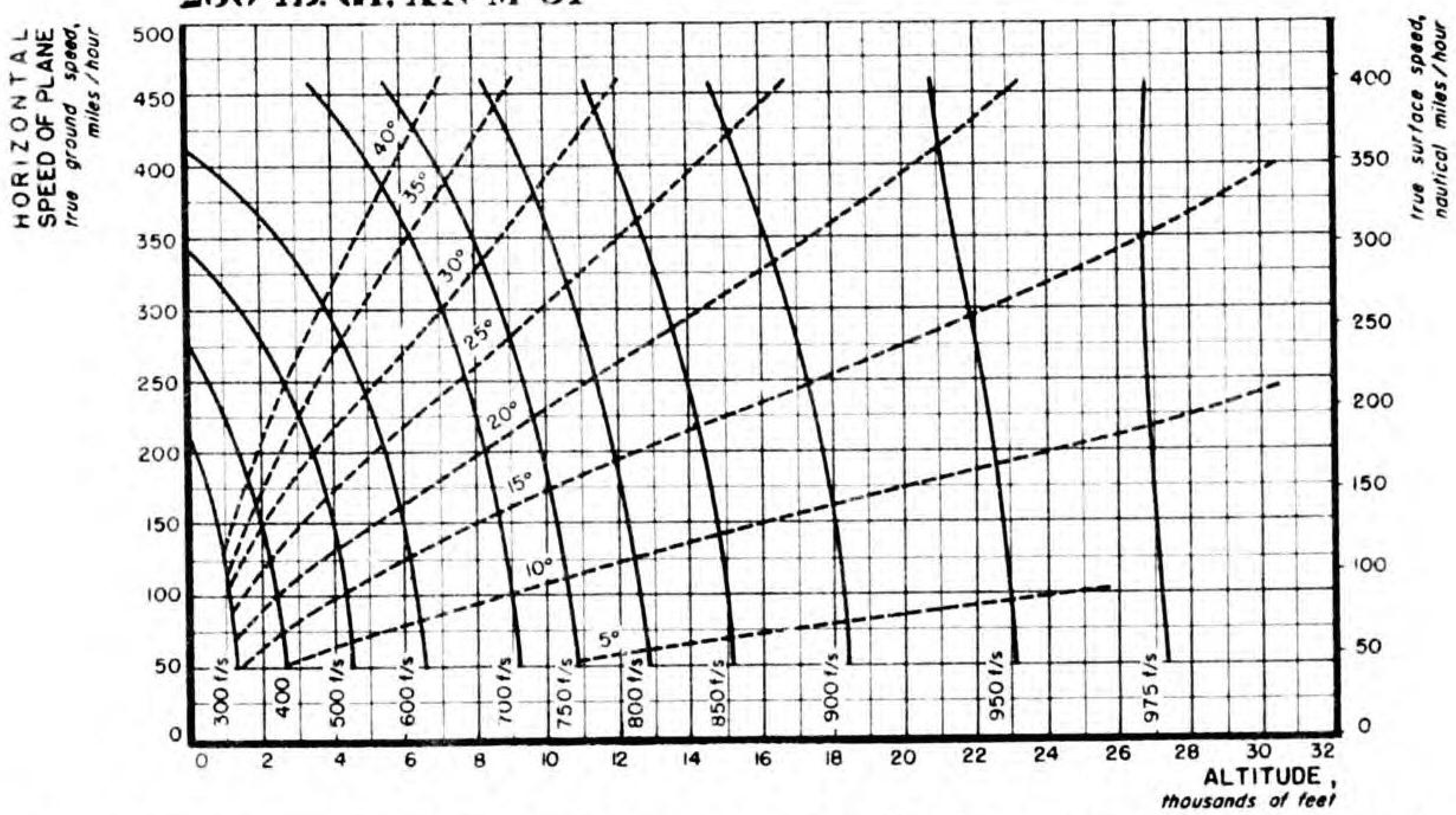
1 B 5* FLIGHT 100-lb GP; 250-lb GP

STRIKING VELOCITY AND ANGLE OF IMPACT: 100-lb GP, AN-M30 AND 250-lb GP, AN-M57

100-lb. GP, AN-M 30



250-lb. GP, AN-M 57



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Ballistic Research Laboratory Aberdeen Proving Ground, Maryland

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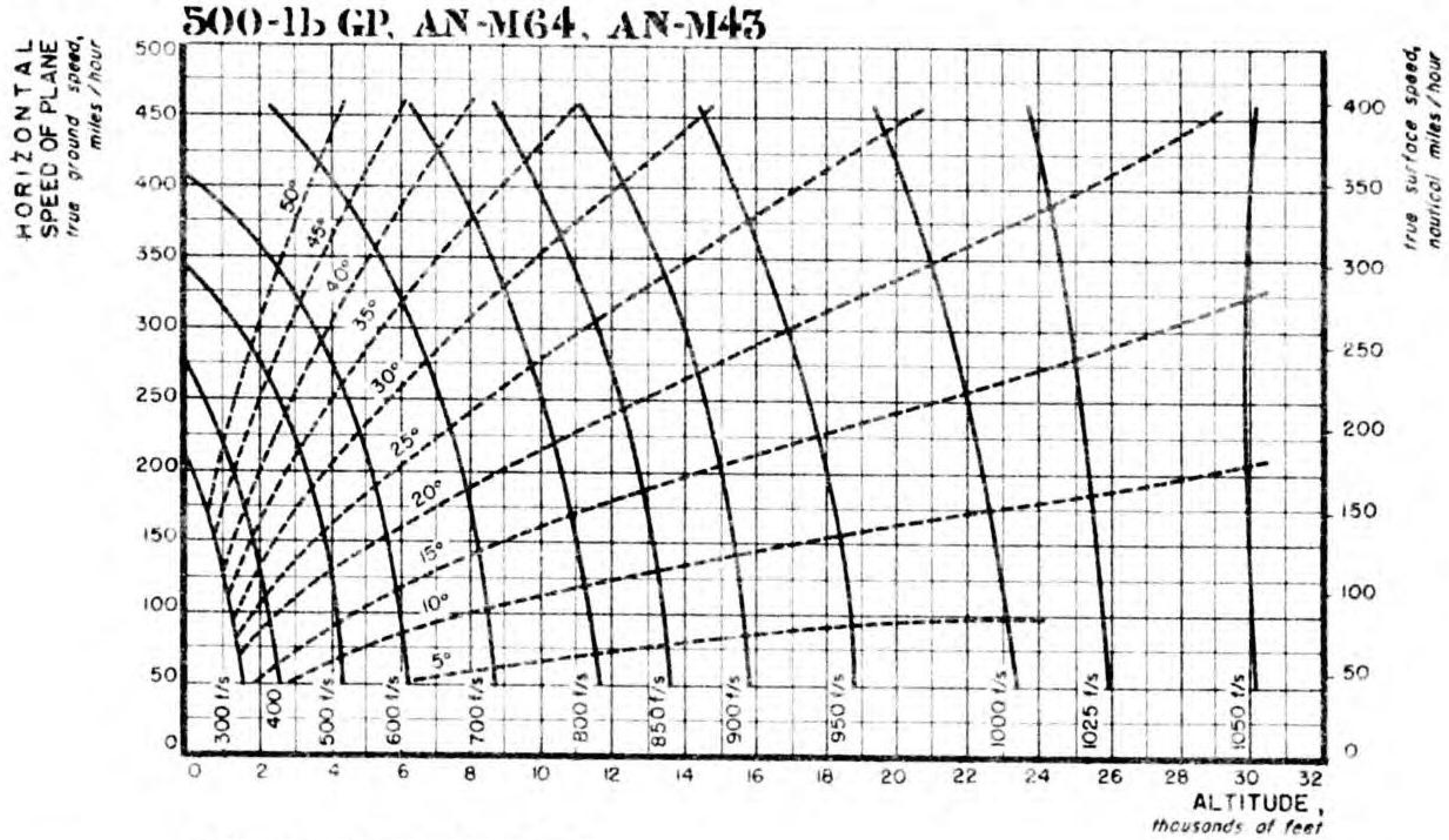
WEAPON DATA

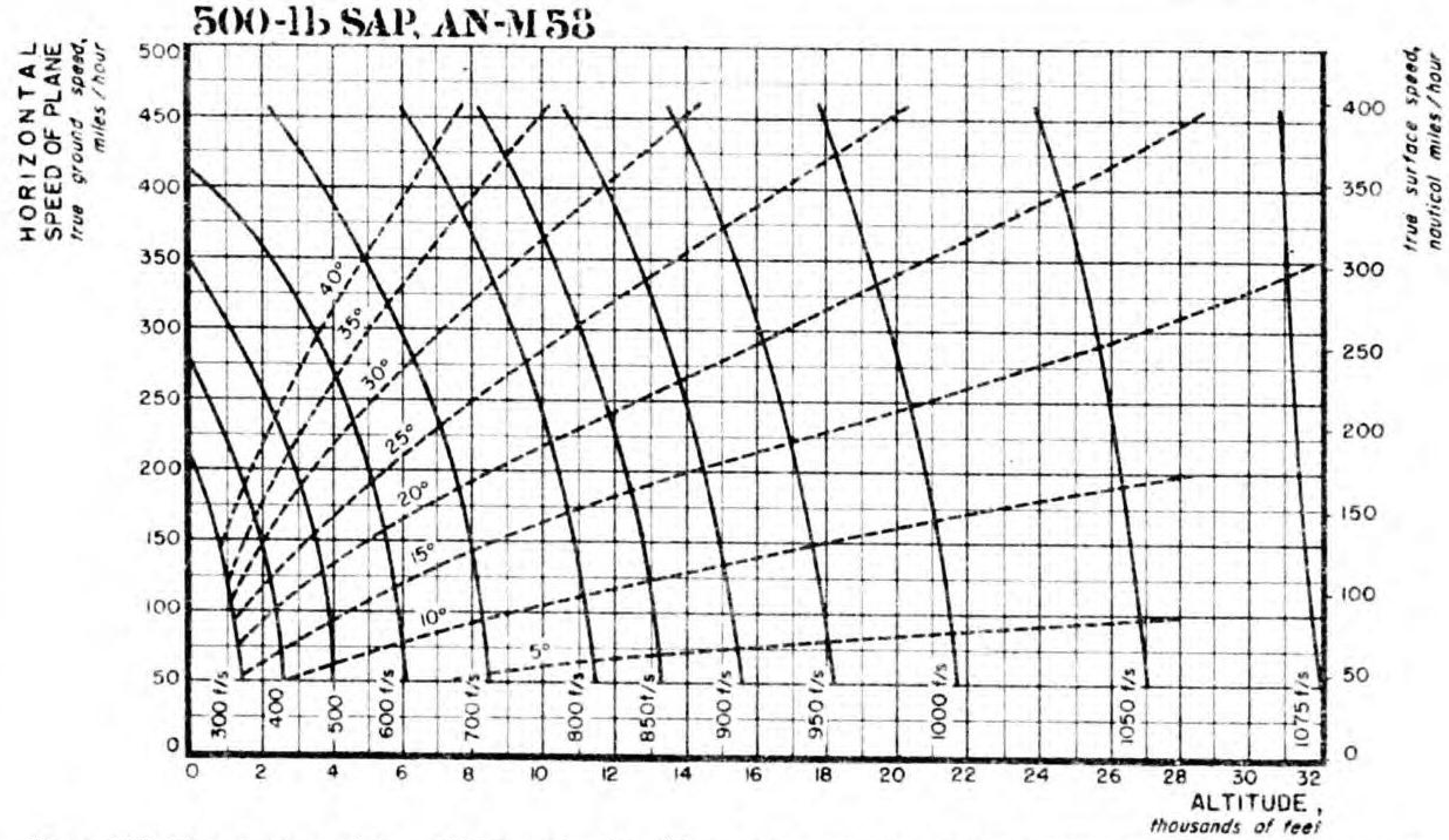
1 B 6* FLIGHT 500-lb GP; 500-lb SAP

STRIKING VELOCITY AND ANGLE OF IMPACT: 500-lb GP, AN-M64 AND 500-lb SAP, AN-M58

500-lb GP, AN-M64, AN-M43



500-lb SAP, AN-M 58



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland

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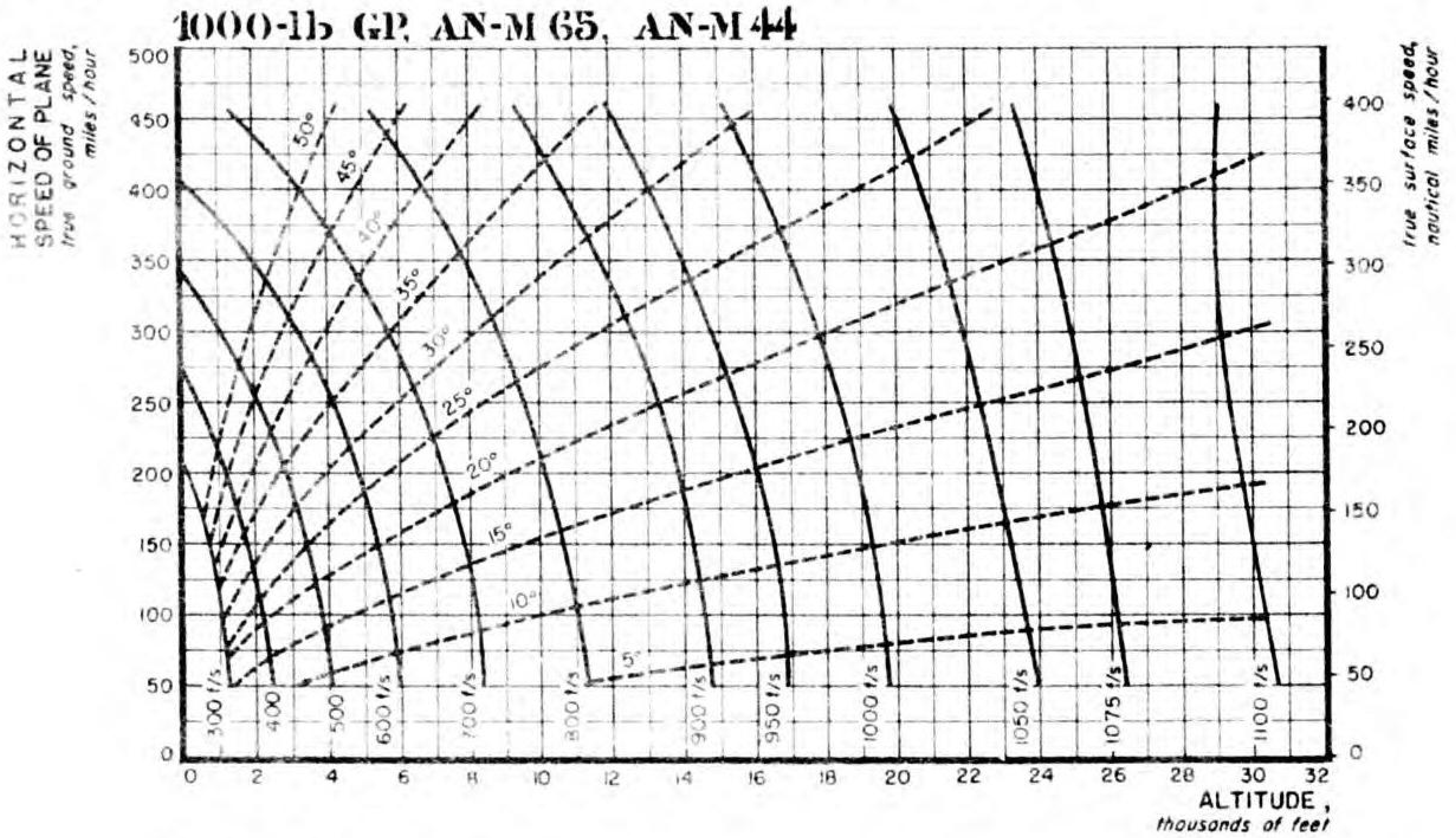
WEAPON DATA

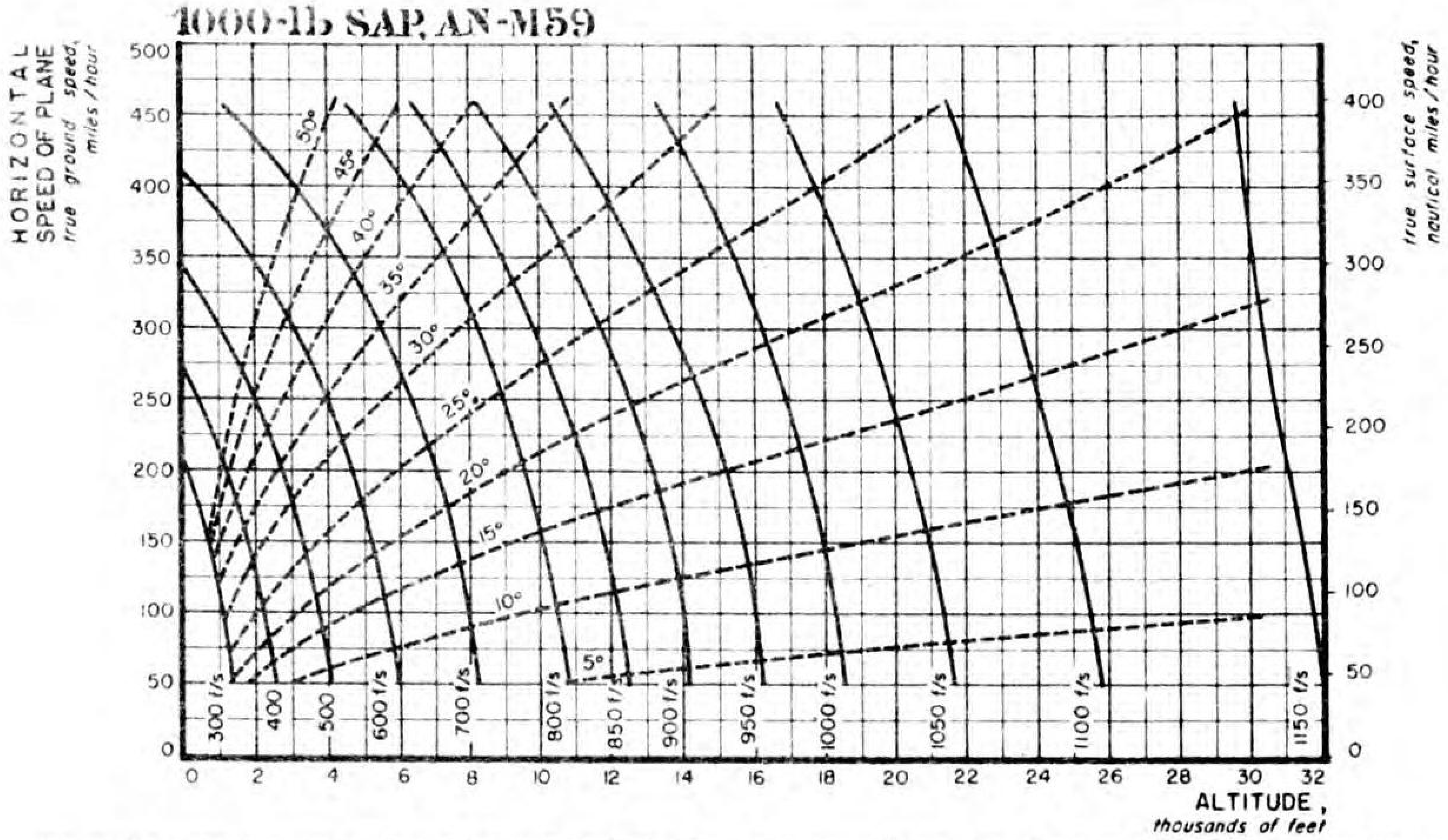
1 B7 ★
FLIGHT
1000-lb GP; 1000-lb SAP

STRIKING VELOCITY AND ANGLE OF IMPACT: 1000-lb GP, AN-M65 AND 1000-lb SAP, AN-M59

1000-lb GP, AN-M 65, AN-M44



1000-lb SAP, AN-M59



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

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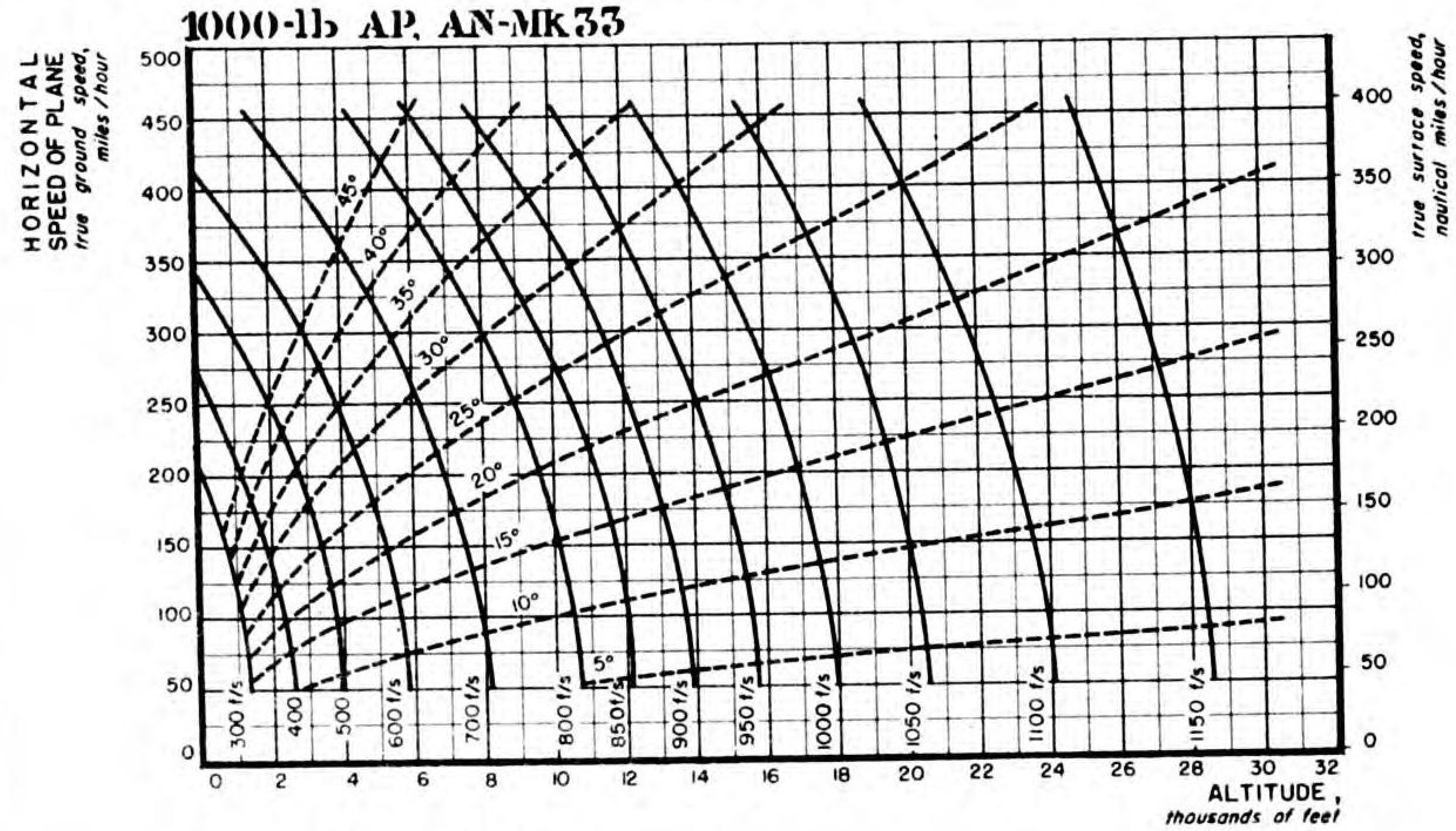
WEAPON DATA

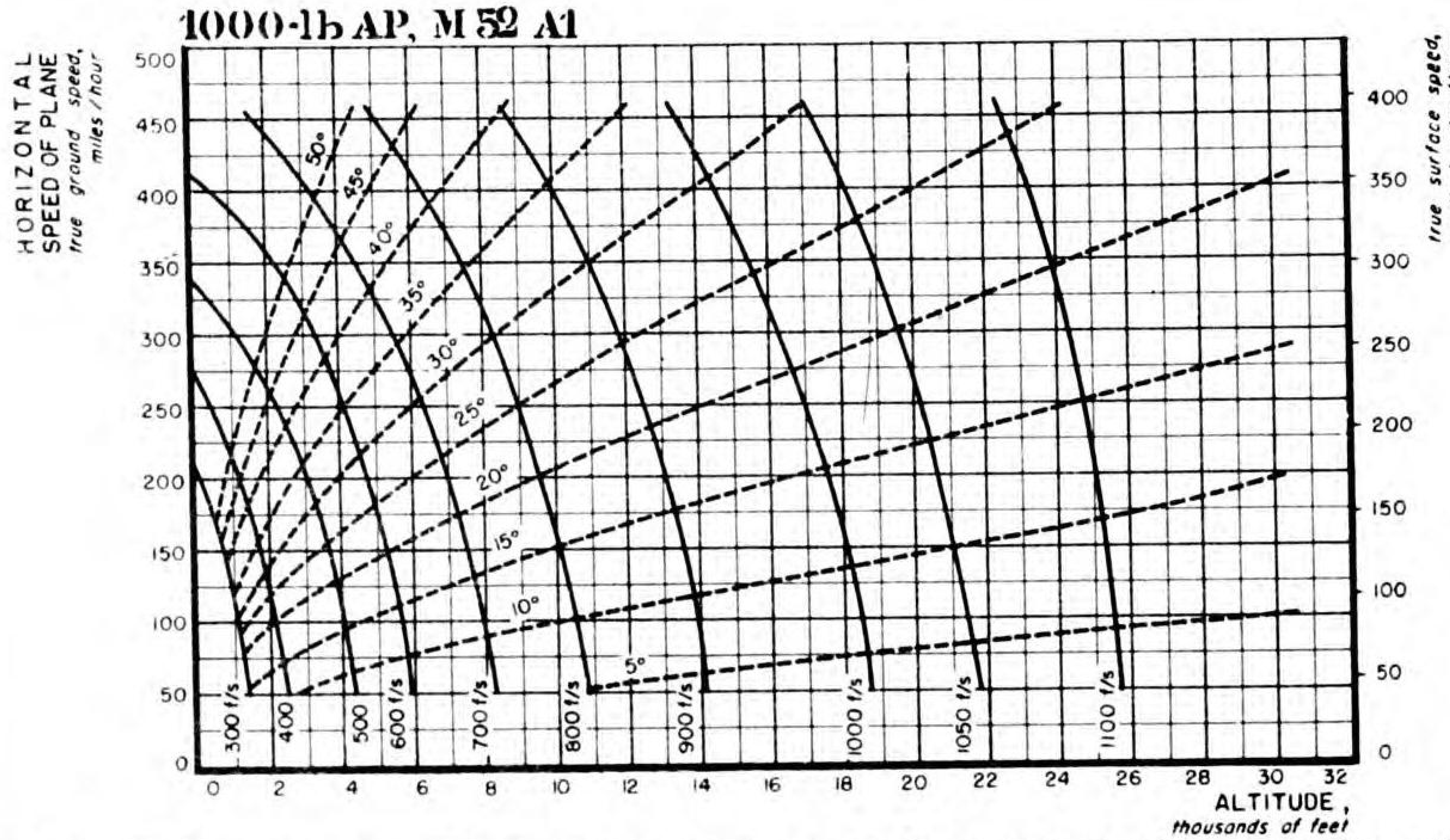
1 B8 ★
FLIGHT
1000-lb AP: Mk33, M52

STRIKING VELOCITY AND ANGLE OF IMPACT: 1000-lb AP, AN-Mk33 AND 1000-lb AP, M52 A1

1000-lb AP, AN-MK33



1000-lb AP, M 52 A1



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

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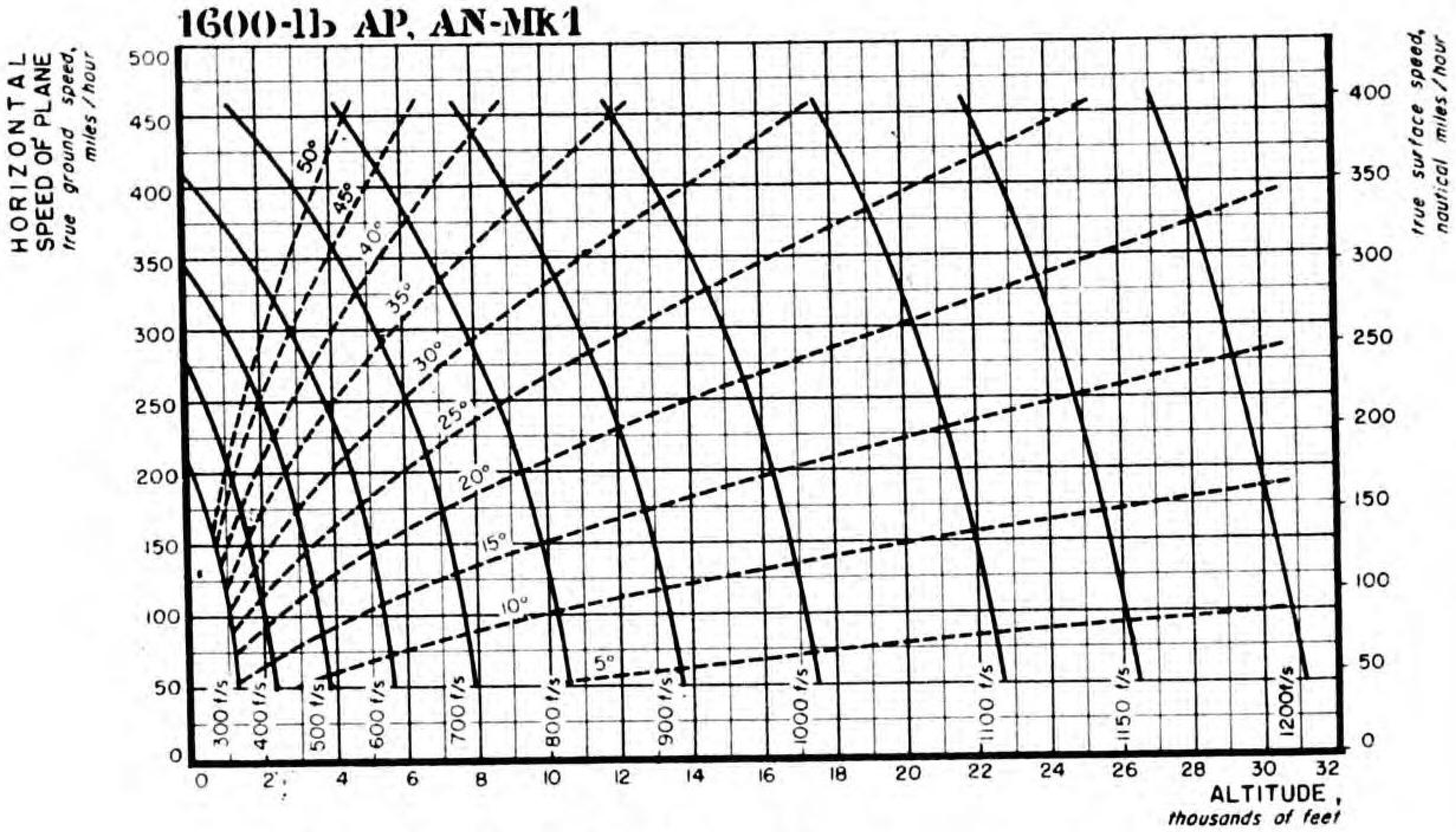
WEAPON DATA

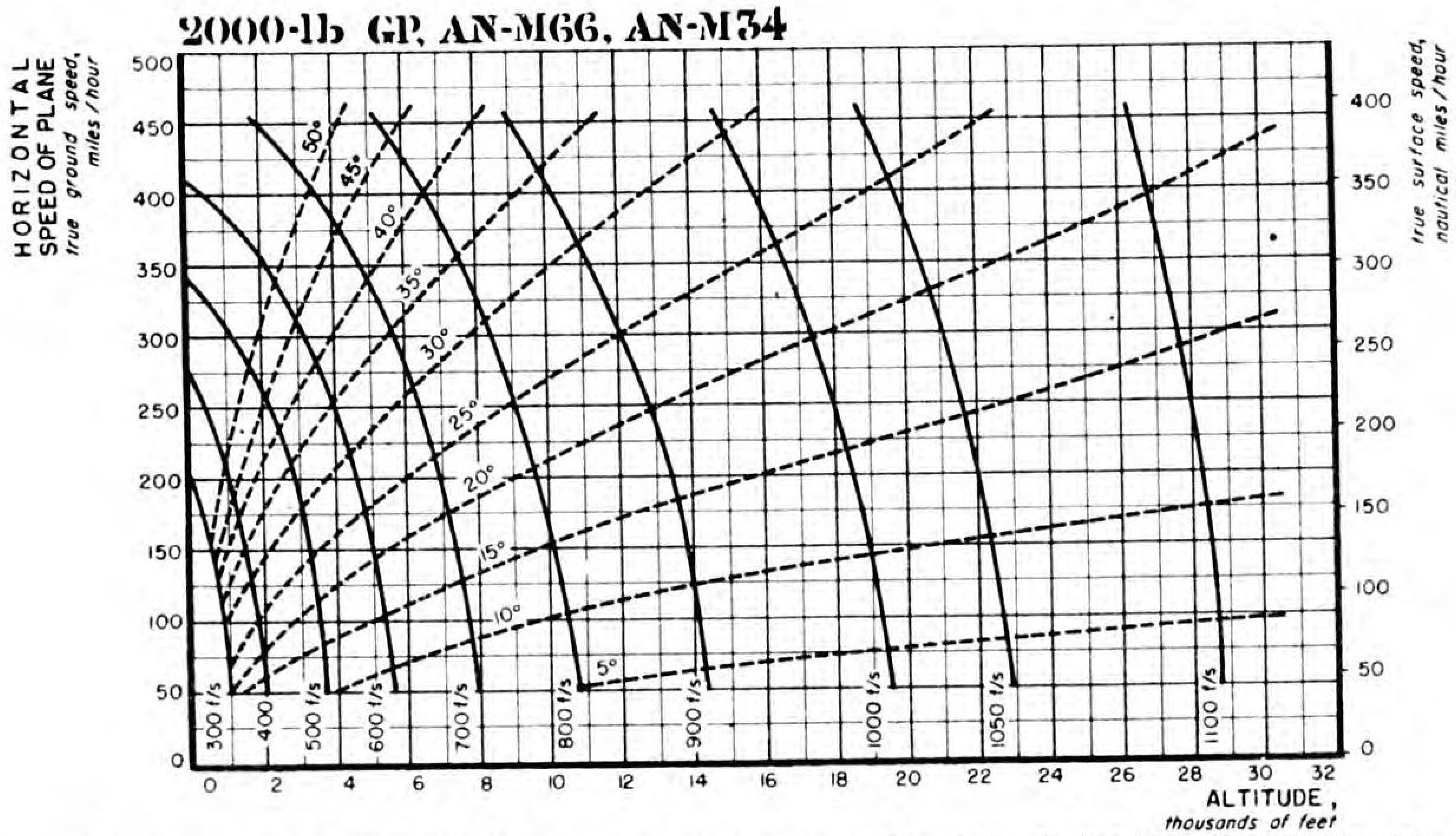
1 B 9 *
FLIGHT
1600-lb AP; 2000-lb GP

STRIKING VELOCITY AND ANGLE OF IMPACT: 1600-lb AP, AN-Mk1 AND 2000-lb GP, AN-M66

1600-lb AP, AN-Mk1



2000-lb GP, AN-M66, AN-M34



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland

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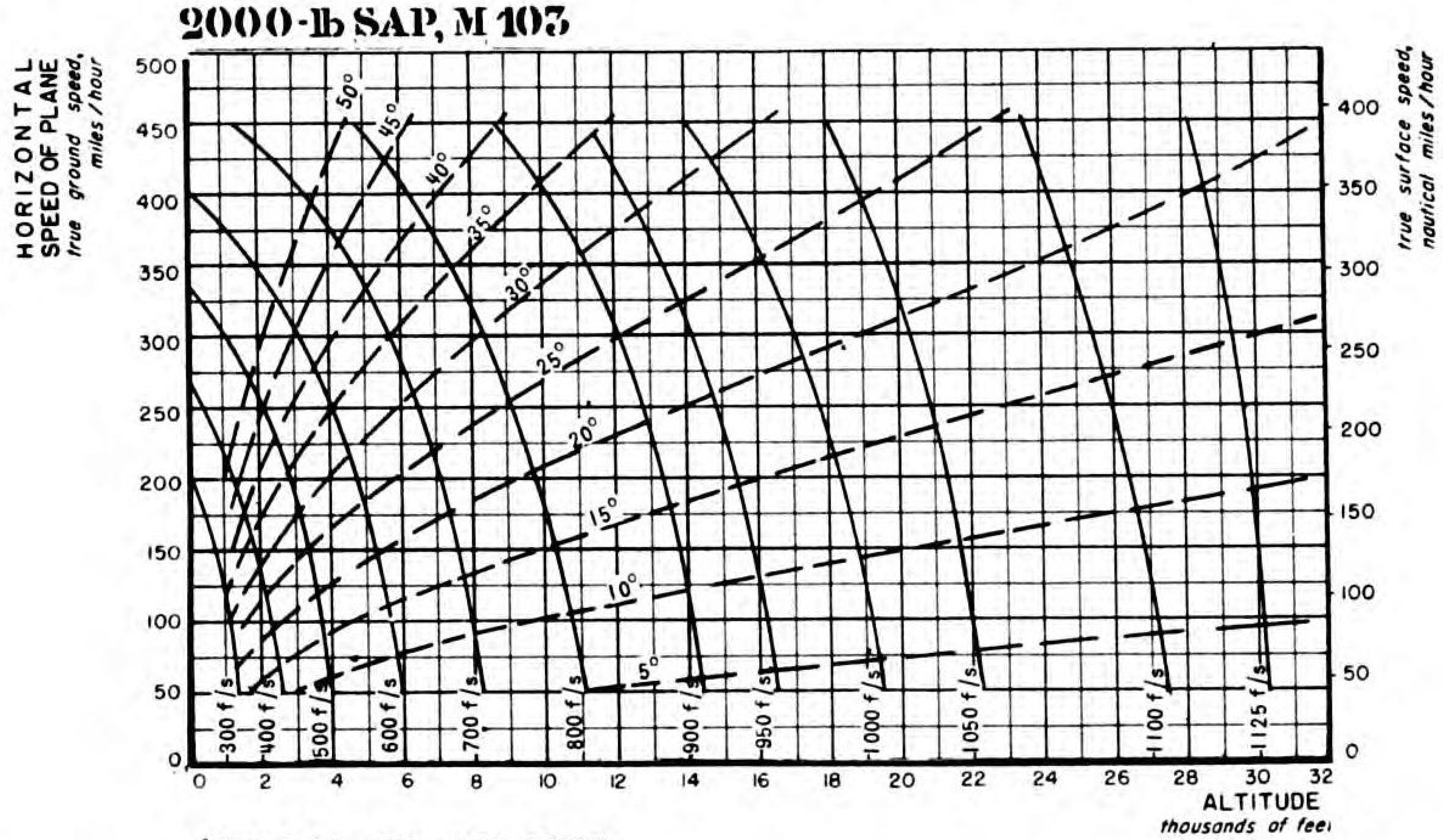
WEAPON DATA

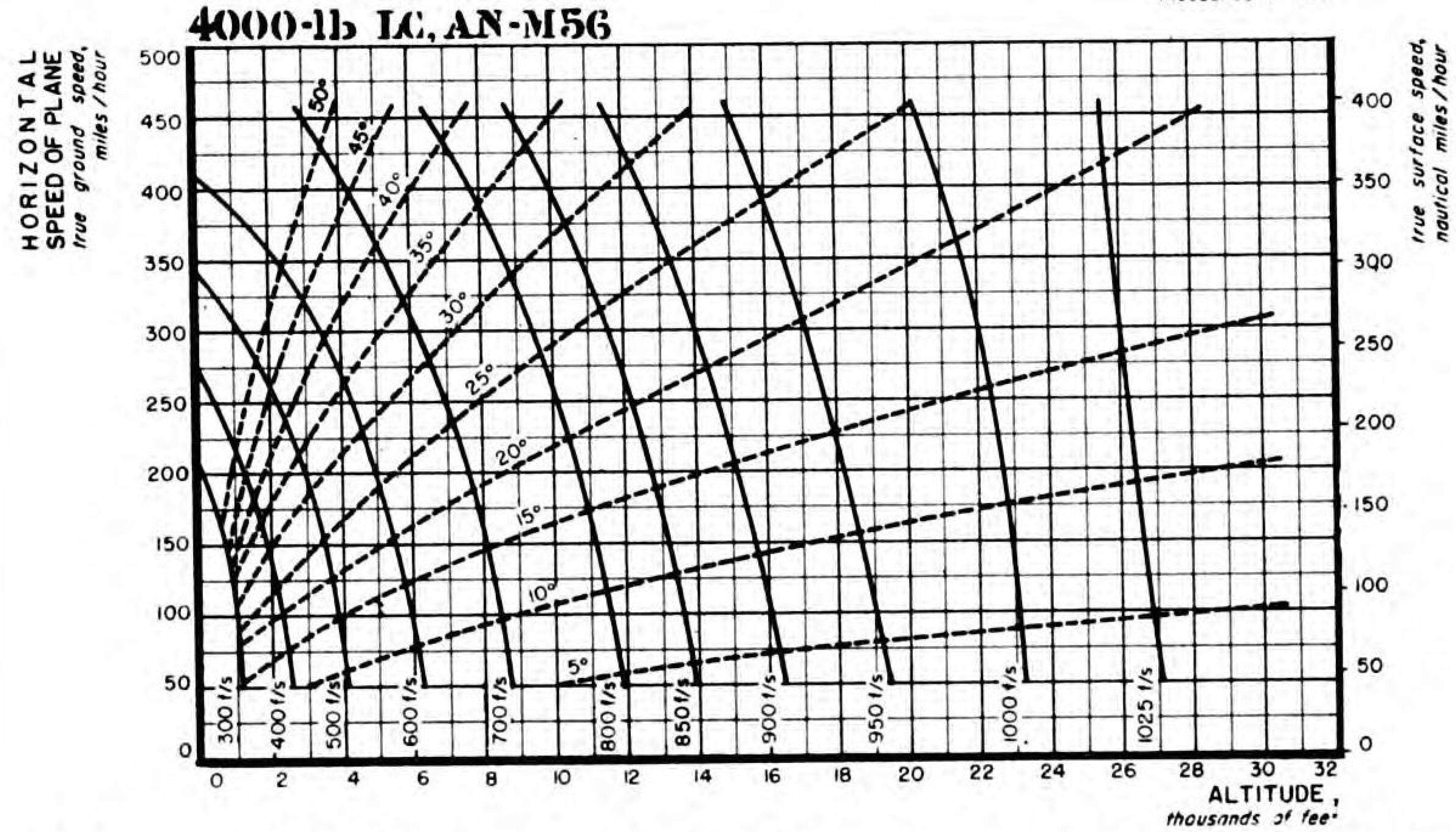
1 B10 *
FLIGHT
2000-lb SAP; 4000-lb LC

STRIKING VELOCITY AND ANGLE OF IMPACT: 2000-lb SAP, M103 AND 4000-lb LC, AN-M56

2000-lb SAP, M103



4000-lb LC, AN-M56



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Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland.

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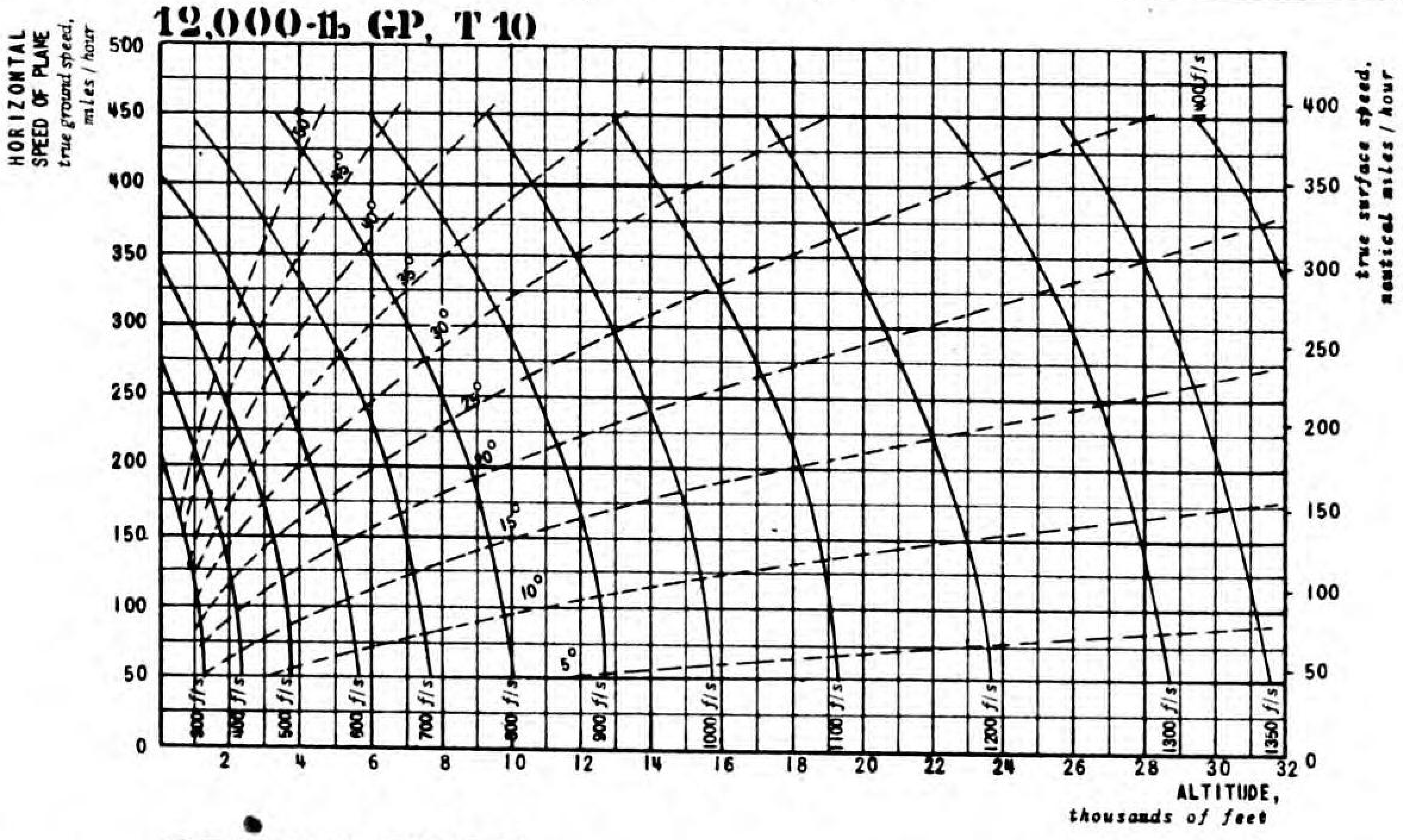
WEAPON DATA

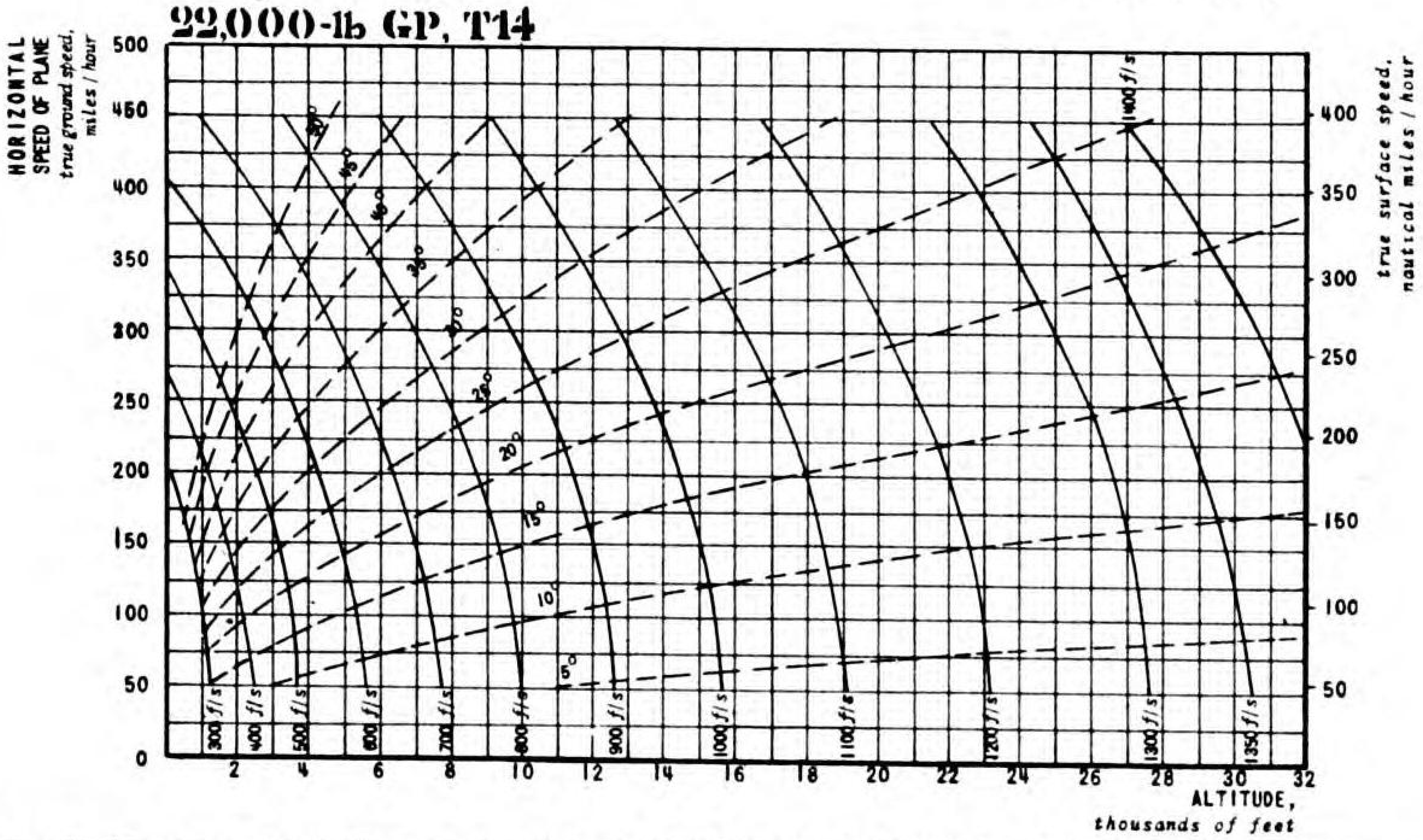
STRIKING VELOCITY AND ANGLE OF IMPACT: 12,000-lb GP, T10 AND 22,000-lb GP, T14

1 B 12
FLIGHT
12000-lb GP; 22000-lb GP

12,000-lb GP, T 10



22,000-lb GP, T14



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Office of the Chief of Ordnance, U. S. Army.

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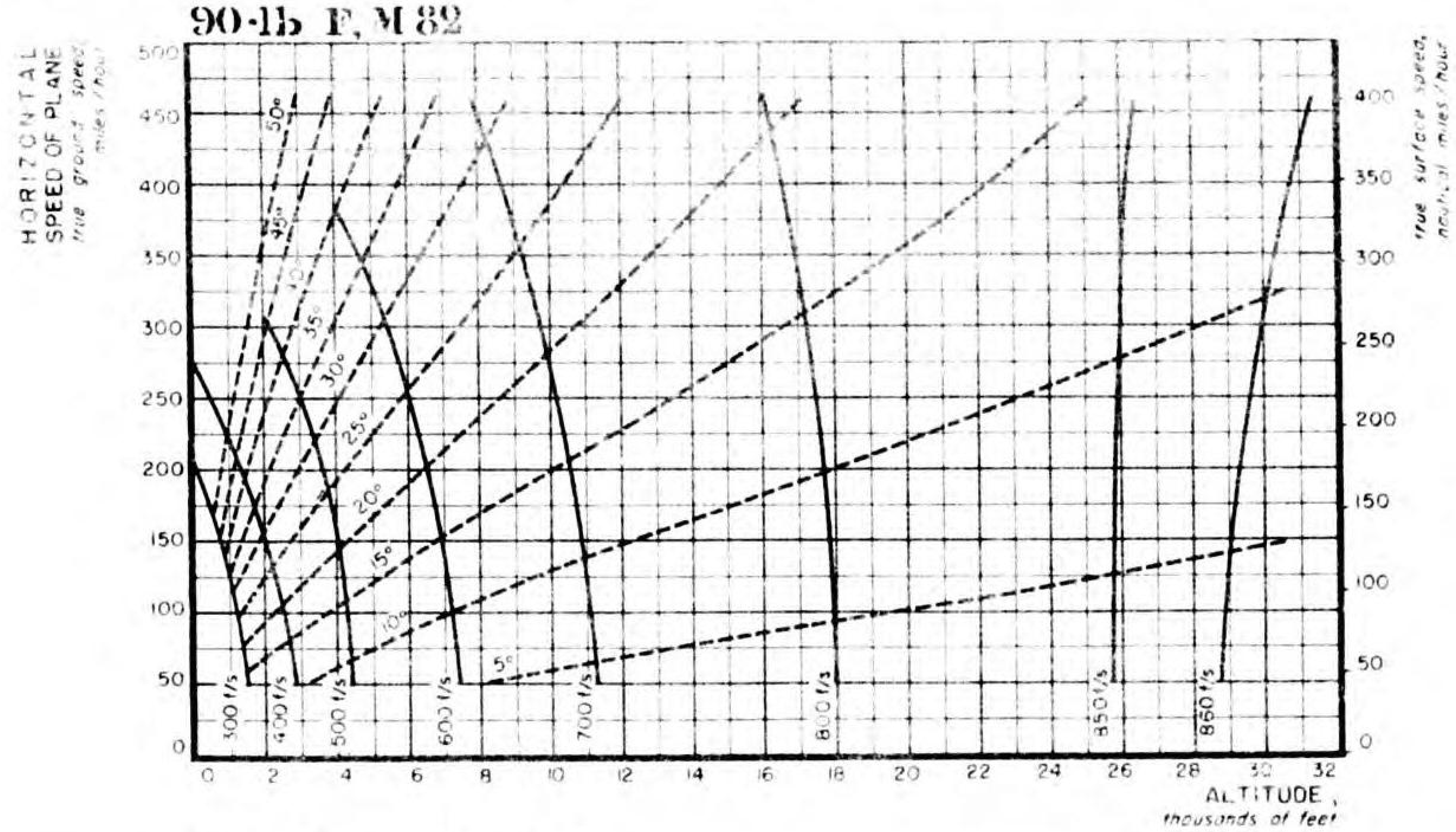
WEAPON DATA

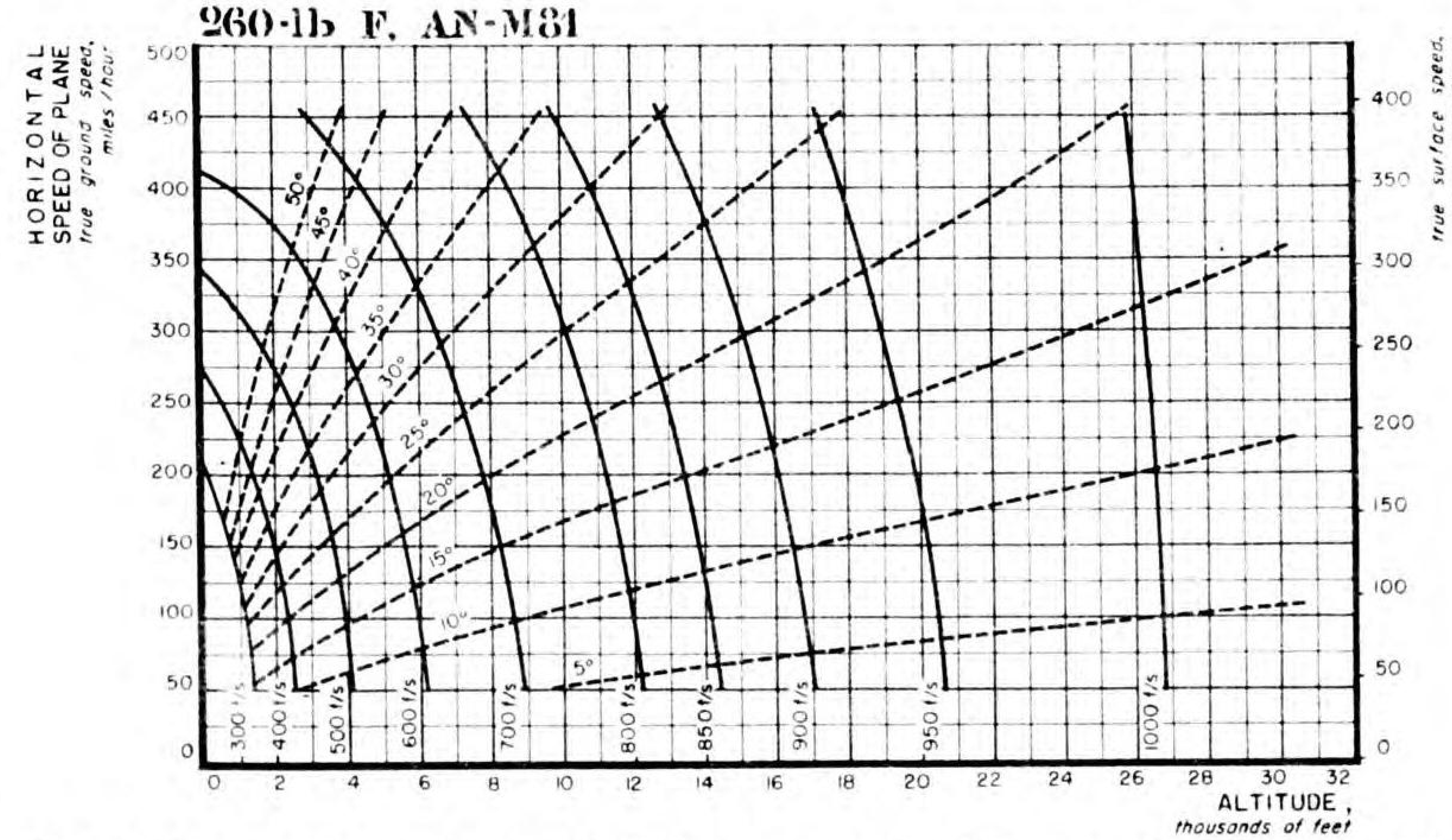
STRIKING VELOCITY AND ANGLE OF IMPACT: 90-lb FRAG. M82 AND 260-lb FRAG., AN-M81

1 B 15
FLIGHT
90-lb F; 260-lb F

90-lb F, M 82



260-lb F, AN-M81



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland

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C: TABULATION OF COMPARATIVE BALLISTIC DATA

1B20

(For true air speed of 250 mph. and zero range wind)

Altitude	BOMB DESIGNATION	AN-M69	AN-M50	AN-M69	AN-M47	AN-M69	AN-M50	AN-M30	AN-M76	AN-M64
	CLUSTER DESIGNATION	AN-M13	AN-M 7	E46		M18(E6R2)	AN-M17A1*			
	CLUSTER TYPE	QUICK-OPENING	QUICK-OPENING	AIMABLE opening at 5000 ft.		AIMABLE opening at 5000 ft.	AIMABLE opening at 5000 ft.			
	BOMBING TABLE: RT	6-A-2	4-B-1	500-Q-1	100-G-2	500-K-2	500-J-2	100-C-3	500-F-1	500-A-3
5,000 feet	RANGE, *feet*	2190	3920	-	5830	-	-	6070	6230	6330
	TRAIL, *mils*	1933	888	-	220	-	-	137	77	54
	TRAIL BEHIND AN-M64, *feet*	4140	2410	-	500	-	-	260	100	0
	RELEASE LAG AFTER AN-M64, *sec*	11.3	6.6	-	1.4	-	-	0.7	0.3	0
	DROPPING ANGLE, *degrees*	23.7	38.1	-	49.4	-	-	50.5	51.3	51.7
	TIME OF FLIGHT, *sec*	32.7	22.8	-	18.91	-	-	18.42	18.04	18.00
	STRIKING VELOCITY, *ft/sec*	230	375	-	530	-	-	575	620	625
10,000 feet	RANGE, *feet*	2440	4960	6720	7810	-	8100	8360	8680	8820
	TRAIL, *mils*	1752	819	859	233	-	259	138	78	61
	TRAIL BEHIND AN-M64, *feet*	6380	3860	2100	1010	-	720	460	140	0
	RELEASE LAG AFTER AN-M64, *sec*	17.4	10.5	5.7	2.8	-	2.0	1.3	0.4	0
	DROPPING ANGLE, *degrees*	13.7	26.4	33.9	38.0	-	39.0	39.9	41.0	41.4
	TIME OF FLIGHT, *sec*	54.4	35.8	41.7	27.64	-	29.1	26.57	25.79	25.71
	STRIKING VELOCITY, *ft/sec*	230	410	230	640	-	365	715	790	795
15,000 feet	RANGE, *feet*	2750	5750	8530	9240	-	9890	10,090	10,530	10,700
	TRAIL, *mils*	1638	766	642	233	-	215	136	78	63
	TRAIL BEHIND AN-M64, *feet*	7950	4950	2170	1460	-	810	610	170	0
	RELEASE LAG AFTER AN-M64, *sec*	21.6	13.5	5.9	4.0	-	2.2	1.7	0.5	0
	DROPPING ANGLE, *degrees*	10.4	21.0	29.7	31.6	-	33.4	33.9	35.1	35.5
	TIME OF FLIGHT, *sec*	73.4	47.1	49.5	34.74	-	35.7	33.07	31.90	31.77
	STRIKING VELOCITY, *ft/sec*	230	415	230	705	-	410	810	900	910
20,000 feet	RANGE, *feet*	3020	6460	9930	10,440	10,680	11,320	11,510	12,090	12.280
	TRAIL, *mils*	1546	722	530	230	379	195	135	78	65
	TRAIL BEHIND AN-M64, *feet*	9260	5820	2350	1840	1600	960	770	190	0
	RELEASE LAG AFTER AN-M64, *sec*	25.2	15.9	6.4	5.0	4.4	2.6	2.1	0.5	0
	DROPPING ANGLE, *degrees*	8.6	17.9	26.4	27.6	28.1	29.5	29.9	31.2	31.6
	TIME OF FLIGHT, *sec*	90.3	57.3	56.0	41.01	49.8	41.5	38.75	37.22	37.04
	STRIKING VELOCITY, *ft/sec*	230	420	230	745	230	440	860	965	980
25,000 feet	RANGE, *feet*	3370	7200	11,130	11,500	11,870	12,570	12,770	13,430	13,650
	TRAIL, *mils*	1467	687	463	226	329	187	134	80	68
	TRAIL BEHIND AN-M64, *feet*	10,280	6450	2520	2150	1780	1080	880	220	0
	RELEASE LAG AFTER AN-M64 *sec*	28.0	17.6	6.9	5.9	4.8	3.0	2.4	0.6	0
	DROPPING ANGLE, *degrees*	7.7	16.1	24.0	24.7	25.4	26.7	27.1	28.2	28.7
	TIME OF FLIGHT, *sec*	105.6	66.5	61.9	46.77	54.8	47.1	43.97	42.09	41.86
	STRIKING VELOCITY, *ft/sec*	230	425	230	765	230	465	890	1010	1025
30,000 feet	RANGE, *feet*	3740	7930	12,240	12,470	12,980	13,670	13,920	14,670	14,900
	TRAIL, *mils*	-	652	416	222	297	178	134	82	71
	TRAIL BEHIND AN-M64, *feet*	11,160	6970	2660	2430	1920	1230	980	230	0
	RELEASE LAG AFTER AN-M64 *sec*	30.4	19.0	7.3	6.6	5.2	3.4	2.7	0.6	0
	DROPPING ANGLE, *degrees*	7.1	14.8	22.2	22.6	23.4	24.5	24.9	26.1	26.4
	TIME OF FLIGHT, *sec*	-	74.9	67.4	52.17	59.7	51.8	48.92	46.71	46.44
	STRIKING VELOCITY, *ft/sec*	230	430	230	780	230	480	910	1030	1045

*Opening altitudes of 8,000 to 13,000 feet, instead of 5,000 feet, have recently been recommended for AN-M17A1 cluster

Note for all aimable clusters: (a) Trails given above are true trails. Trails given in bombing tables are fictitious trails for setting into bomb-sight with times of flight and disc speeds given in bombing tables in order to get proper range to target. (b) Trails (true) given above were calculated by the following formula:

$$\text{TRAIL} = \frac{\text{Aiming point offset upwind for each } 10^\circ \text{ of drift (trail setting zero)}}{\sin 10^\circ \times (\text{altitude} / 1000)}$$

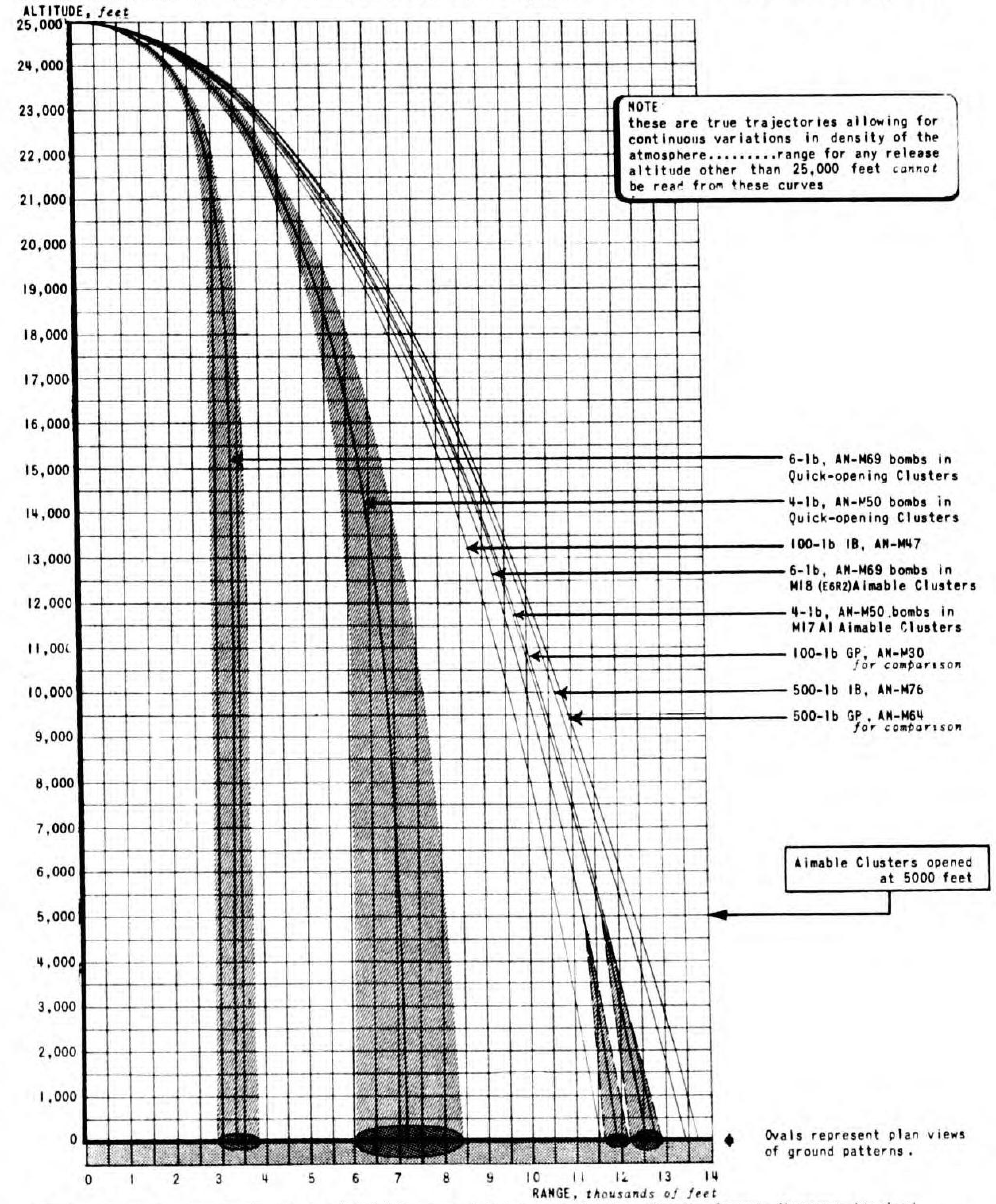
Times of flight were then calculated from trail and dropping angle by standard formula.

WEAPON DATA: INCENDIARIES

1B20
1 B FLIGHT
GENERAL

TRAJECTORIES AND BALLISTIC DATA FOR AMERICAN INCENDIARY BOMBS AND CLUSTERS

A: COMPARISON OF TRUE TRAJECTORIES FOR 25,000ft. RELEASE ALTITUDE & 250mph A.S.



SOURCE: Based on data supplied by the Ballistic Research Laboratory, Aberdeen Proving Ground, Aberdeen, Maryland

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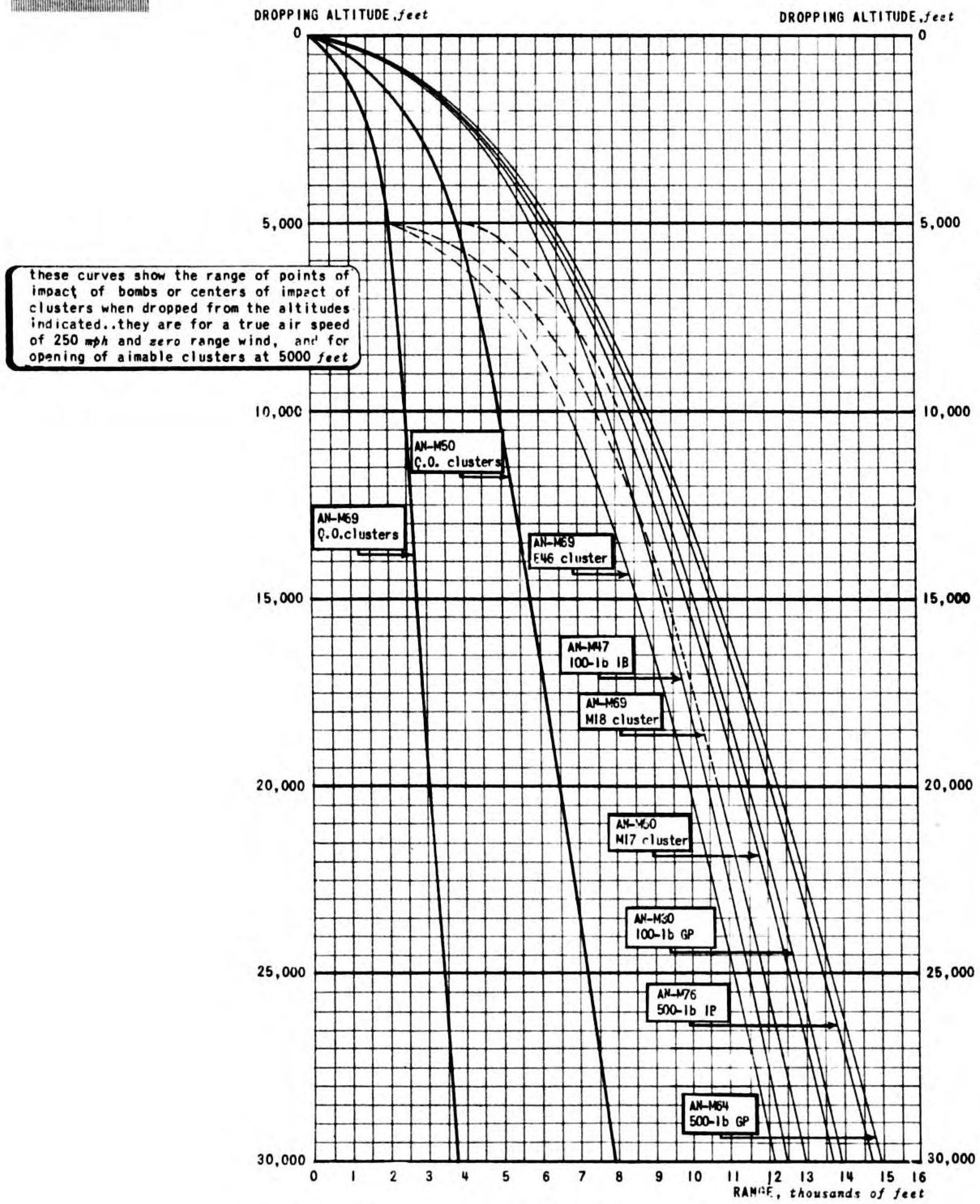
April 1945

B: GRAPH OF RANGE FOR ANY DROPPING ALTITUDE



SOURCE: Based on data in Ordnance Bombing Tables, U. S. Army

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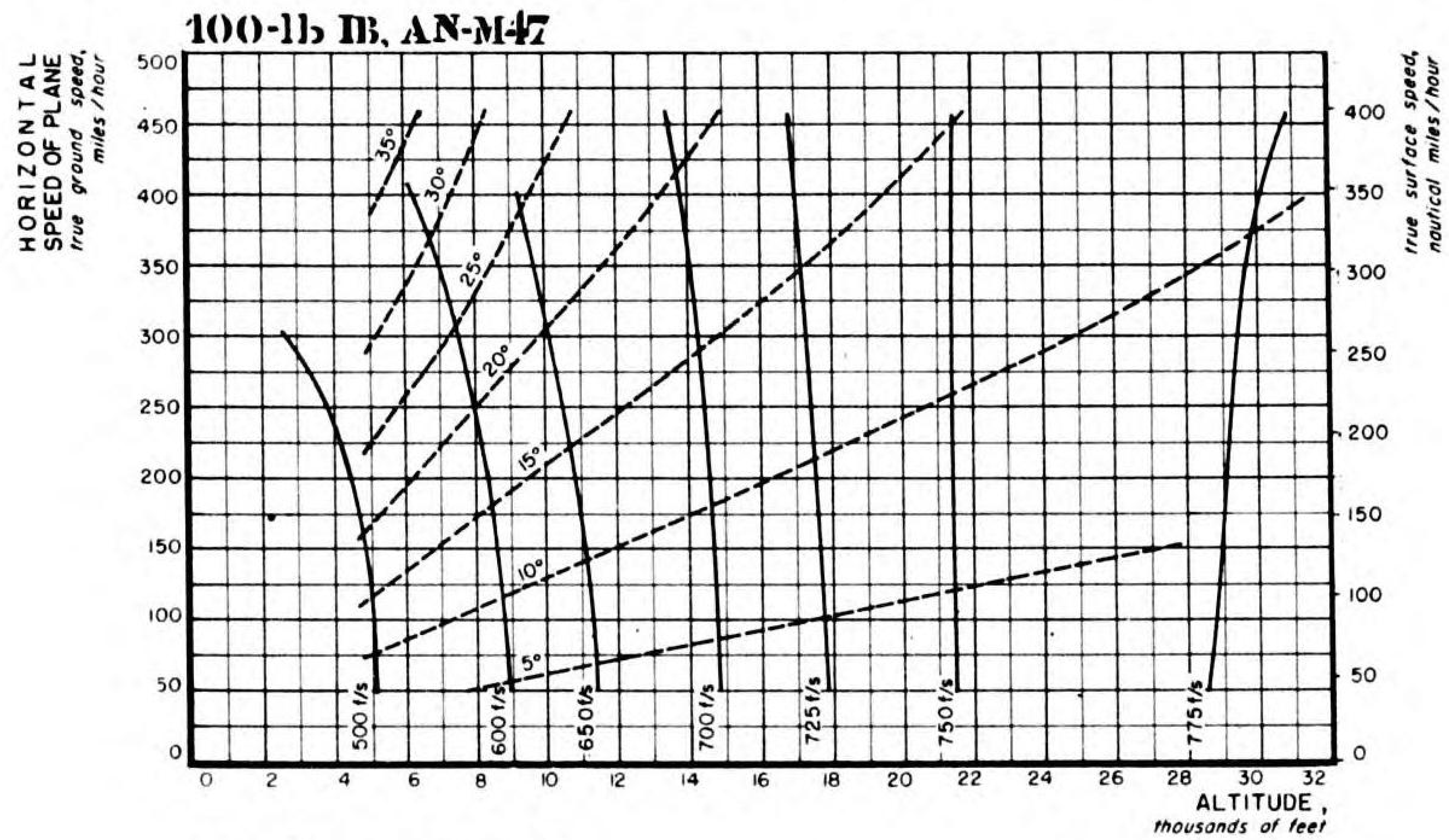
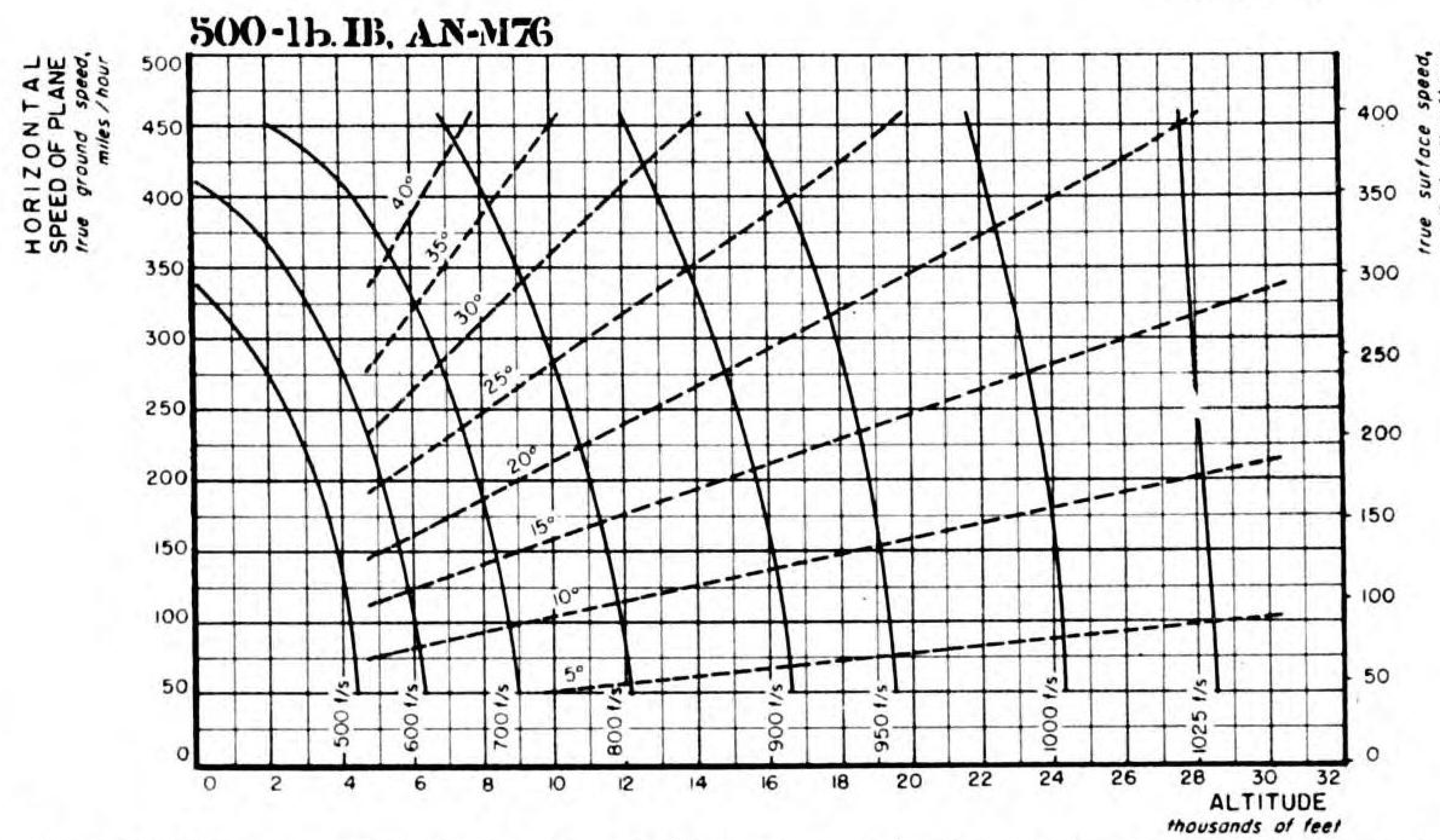
WEAPON DATA: INCENDIARIES

STRIKING VELOCITY AND ANGLE OF IMPACT: 100-lb IB, AN-M47 AND 500-lb IB, AN-M76

100-lb IB, AN-M47



500-lb IB, AN-M76



The solid line curves give striking velocity (feet per second) and the broken-line curves give angle of impact (degrees from the vertical) for bombs released from a plane in horizontal flight.

Locate a point by projecting upward from a given altitude and across from the given plane speed. Using this juncture, interpolate between curves to obtain striking velocity or impact angle.

Accuracy: Errors in striking velocity read from the graph will not exceed 15%; in impact angle, 4°.

Prepared from data supplied by the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland

NATIONAL DEFENSE RESEARCH COMMITTEE DIVISION 11, INCENDIARIES SECTION

December 1944

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WEAPON DATA: INCENDIARIES

1 C 1 AIRCRAFT LOADING

LOADING DATA FOR INCENDIARY BOMBS AND CLUSTERS

FOR MAXIMUM LOADING IN ALL CASES ON U.S. ARMY AIRCRAFT WITHOUT BOMB-BAY GAS TANKS OR OTHER SPECIAL EQUIPMENT IN BOMB-BAYS

PLANE	BOMB DESIGNATION →	AN-M47	AN-M50	AN-M50	AN-M52	AN-M69	AN-M69	M74	AN-M76
	CLUSTER DESIGNATION →	None	AN-M7	M17A1	AN-M11	AN-M13	E46	E48	None
	ACTUAL WEIGHT, pounds →	72	525	465	425	425	425	525	475
B-32	No. of clusters	-	40	40	40	40	40	40	-
	No. of bombs	-	5120	4400	7680	2400	1520	1520	40
	Total weight, Tons	-	10.5	9.30	8.50	8.50	8.5	10.15	9.50
	Total heat, million BTU	-	66.2	57.0	86.0	105.6	66.9	57.6	88.4
B-29	No. of clusters	-	40	40	40	32	40	40	-
	No. of bombs	144+	5120	4400	7680	1920	1520	1520	40
	Total weight, Tons	5.18	10.5	9.30	8.50	6.82	8.5	10.15	9.50
	Total heat, million BTU	96.4	66.2	57.0	86.0	84.5	66.9	57.6	88.4
B-24 Series	No. of clusters	-	12	12	12	12	12	12	-
	No. of bombs	52+	1536	1320	2304	720	456	456	12
	Total weight, Tons	1.87	3.15	2.79	2.55	2.55	2.55	3.15	2.85
	Total heat, million BTU	34.8	19.8	17.1	25.8	31.7	20.0	17.3	26.5
B-17 F.G.	No. of clusters	-	12	12++	12	12	12++	12++	-
	No. of bombs	42+	1536	1320	2304	720	456	456	12
	Total weight, Tons	1.51	3.15	2.79	2.55	2.55	2.55	3.15	2.85
	Total heat, million BTU	28.1	19.8	17.1	25.8	31.7	20.0	17.3	26.5
B-26** Series	No. of clusters	-	6	6	6	6	6	6	-
	No. of bombs	28+	768	660	1152	360	228	228	6
	Total weight, Tons	1.01	1.58	1.39	1.28	1.27	1.28	1.57	1.42
	Total heat, million BTU	18.7	9.9	8.5	12.9	15.8	10.0	8.6	13.3
B-25 Series	No. of clusters	-	6	6	6	6	6	6	-
	No. of bombs	24+	768	660	1152	360	228	228	6
	Total weight, Tons	0.87	1.58	1.39	1.28	1.27	1.28	1.57	1.42
	Total heat, million BTU	16.0	9.9	8.5	12.9	15.8	10.0	8.6	13.3
A-26* B	No. of clusters	-	6	6	6	4	6	6	-
	No. of bombs	16	768	660	1152	240	228	228	6
	Total weight, Tons	0.58	1.58	1.39	1.28	0.85	0.85	1.57	1.42
	Total heat, million BTU	10.7	9.9	8.5	12.9	10.6	10.0	8.6	13.3
A-20* C.G.H. J.K	No. of clusters	-	4	4	4	4	4	4	-
	No. of bombs	4	512	440	768	240	152	152	4
	Total weight, Tons	0.14	1.05	0.93	0.85	0.85	0.85	1.05	0.95
	Total heat, million BTU	2.7	6.6	5.7	8.6	10.6	6.7	5.8	8.8
A-36 P-51	No. of clusters	-	2	2	2	2	2	2	-
	No. of bombs	2	256	220	384	120	76	76	2
	Total weight, Tons	0.07	0.53	0.47	0.43	0.43	0.43	0.53	0.48
	Total heat, million BTU	1.3	3.3	2.8	4.3	5.3	3.3	2.9	4.4
P-47	No. of clusters	-	3	3	3	3	3	3	-
	No. of bombs	3	384	330	576	180	114	114	3
	Total weight, Tons	0.11	0.79	0.70	0.64	0.64	0.64	0.79	0.71
	Total heat, million BTU	2.0	5.0	4.3	6.5	7.9	5.0	4.3	6.6
P-40	No. of clusters	-	3	3	3	3	3	3	-
	No. of bombs	3	384	330	576	180	114	114	3
	Total weight, Tons	0.11	0.79	0.70	0.64	0.64	0.64	0.79	0.71
	Total heat, million BTU	2.0	5.0	4.3	6.5	7.9	5.0	4.3	6.6
P-38	No. of clusters	-	2	2	2	2	2	2	-
	No. of bombs	2	256	220	348	120	76	76	2
	Total weight, Tons	0.07	0.53	0.47	0.43	0.43	0.43	0.53	0.48
	Total heat, million BTU	1.3	3.3	2.8	4.3	5.3	3.3	2.9	4.4

* Internal loading only; for external loading add 4 - 100 lb. or 4 - 500 lb. clusters for A-20 G, H, J, K, and A-26B.
** Omitting aft bomb-bay.
\+ Multiple suspension using toggle wires.
\++ Minor interference on two bottom inboard stations might reduce loading from 12 to 10.

NATIONAL DEFENSE RESEARCH COMMITTEE — DIVISION 11, INCENDIARIES SECTION

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A D D E N D A

TO

Weapon Data Sheets 2-A1, 2-B1, 2-C1

1. Scale S, representing compressive strength of the concrete, is based on tests of 6" x 12" cylinders. Many compressive strength tests, particularly in Great Britain, are made on 6" cubes. As suggested by British investigators, the relation between these tests may be taken to be approximately

$$\frac{\text{Strength of 6" x 12" cylinder}}{\text{Strength of 6" cube}} = \frac{3}{4};$$

i.e., a strength of 4000 psi by cube tests corresponds to a strength of 3000 psi by cylinder tests. This relation should be observed whenever the nomograms are to be used for concrete whose strength is specified by cube tests.

2. There has been some confusion regarding the terms "thickness scabbed" and "thickness perforated" as used on sheets 2-B1 and 2-C1. This means the thickness of the target which can be scabbed or perforated under the conditions assumed. For instance, if the thickness scabbed is given as 60", slabs 60" or less in thickness will have scab knocked off the back, while slabs of thickness greater than 60" will not have scab knocked off. This result, of course, is qualified by the estimated 15% accuracy of the chart.

March 1944

NOTE:- This may be inserted facing page 2-A1.

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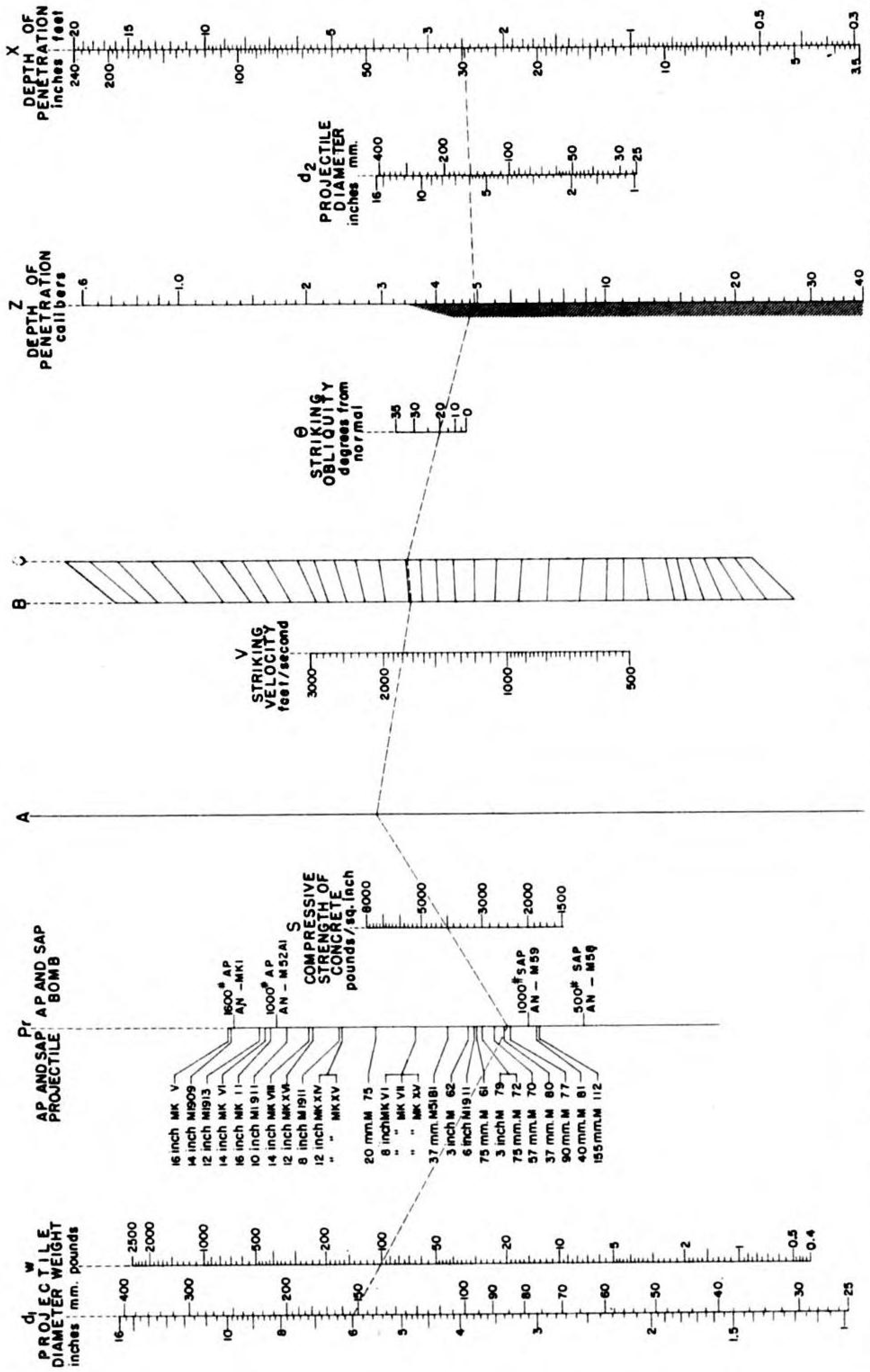
WEAPON DATA

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

2A1 CONCRETE PENETRATION

BASED ON DATA DEVELOPED FOR THE CHIEF OF ENGINEERS



DIRECTIONS: Determine the diameter and weight of that part of the projectile which penetrates the slab. (The total weight minus the weight of the windshield will usually be correct.) Draw a line through the proper points on the d_1 scale and w scale at the left of the chart to the Pr scale. (If the projectile is a type listed on this scale, the above may be omitted.) Continue from this point through the S scale to the A scale. From the A scale draw a line through the V scale to the B scale and follow the guide lines to the C scale. From the C scale draw a line through the θ scale to the Z scale. (If the point falls within the shaded area the projectile will probably stick in the target.) From the Z scale draw a line through the d_2 scale and read the depth of penetration (from the X scale. For oblique fire this depth is the maximum penetration normal to the target face. If the projectile or bomb causes scabbing (see 2B-sheet 1) the penetration will be somewhat more than shown here. The penetration for oblique fire at velocities above 2000 ft/sec may be somewhat more than shown here.

EXAMPLE: The dotted line shows a 6 inch, 100 pound projectile, striking 4,000 p.s.i. concrete with a velocity of 1,800 ft./sec. at an obliquity of 20°. The projectile will penetrate to a depth of 4.9 calibers or 29.4 inches. The projectile will probably stick in the target.

ACCURACY: This chart gives results accurate within 15%.

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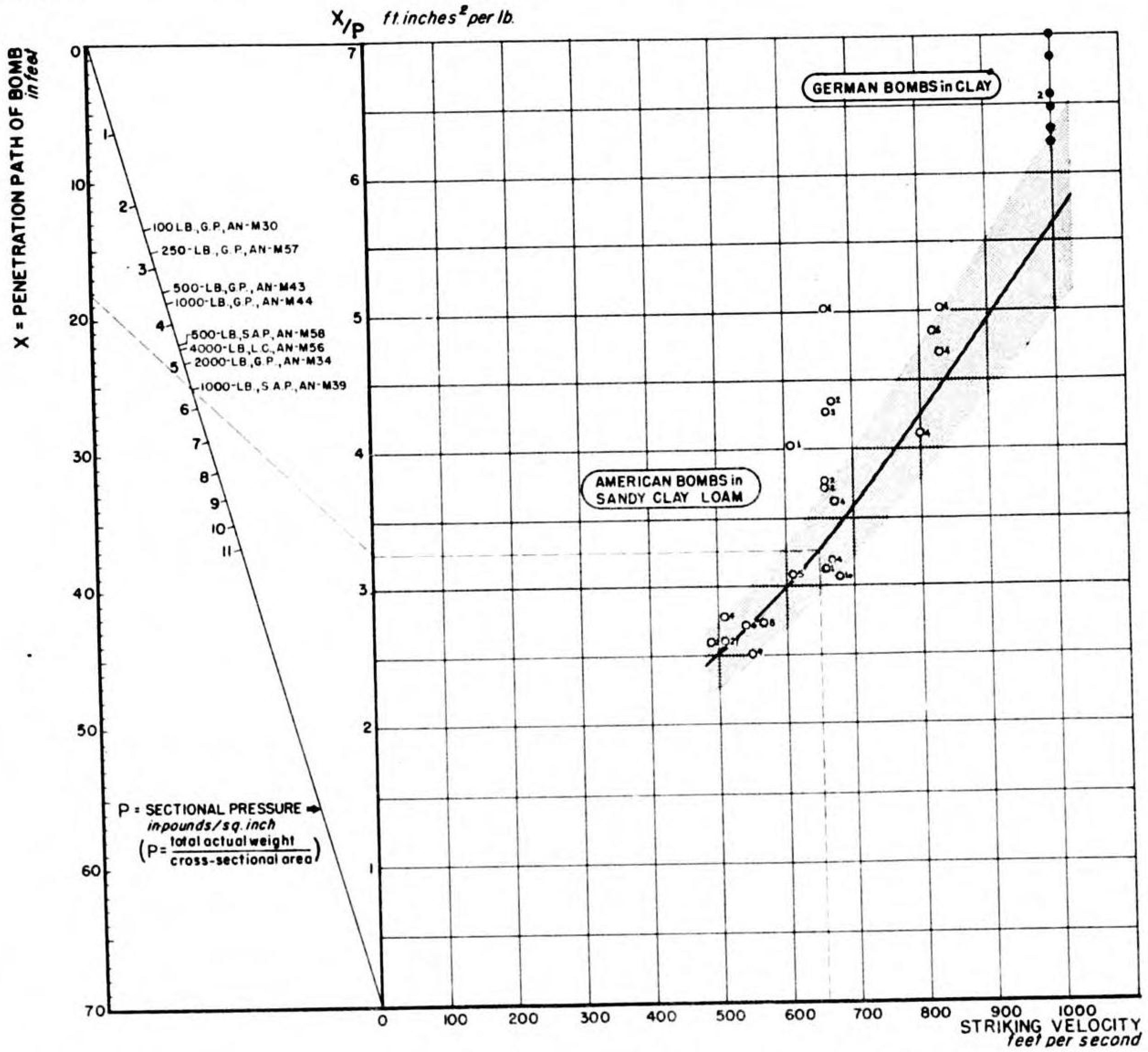
WEAPON DATA

PENETRATION OF BOMBS INTO SANDY CLAY LOAM

2 A2 EARTH PENETRATION

BASED ON DATA FOR 100-LB., 300-LB., & 500 LB. INERT BOMBS FROM ABERDEEN PROVING GROUND AND GERMAN BOMB DATA FROM BRITISH MINISTRY OF HOME SECURITY



THE GRAPH GIVES THE DISTANCE OF PENETRATION, MEASURED ALONG THE PATH, TO THE BASE OF THE BOMB. THE CURVE AND SHADED REGION IS USED FOR OBTAINING THE SECTIONAL PENETRATION CORRESPONDING TO A GIVEN STRIKING VELOCITY. THE NOMOGRAM SCALE WILL THEN PERMIT THE READING OF ESTIMATED PENETRATION DISTANCE.

BECAUSE OF UNPREDICTABLE CHANGES IN DIRECTION OF THE UNDERGROUND TRAJECTORY OF A BOMB, VERTICAL PENETRATION WILL OFTEN BE CONSIDERABLY LESS THAN THE LENGTH OF THE PATH - PERHAPS TWO-THIRDS OF THE LATTER OR EVEN LESS.

PENETRATIONS IN CHALK APPEAR TO BE ABOUT THE SAME AS VALUES TAKEN FROM THIS GRAPH, WHILE THOSE IN CLAY WOULD BE EXPECTED TO BE GREATER AS SHOWN BY THE GERMAN BOMBS.

AMERICAN EXPERIMENTAL DATA IS REPRESENTED BY OPEN CIRCLES, THE NUMBER BESIDE EACH BEING THE NUMBER OF TRIALS OF WHICH THE POINT IS AN AVERAGE. THE BRITISH DATA, OBTAINED FROM GERMAN BOMBS (250, 500, 1000, & 1800 kg. S.C. and 500, 1000, & 1400 kg. S.D. at an estimated velocity of 1000 ft./sec.) IS REPRESENTED BY SOLID CIRCLES.

EXAMPLE: The dotted line indicates that a 1000-lb. S.A.P., AN-M39, bomb striking at a velocity of 650 ft. per sec. will yield a penetration path length of about 18 feet.

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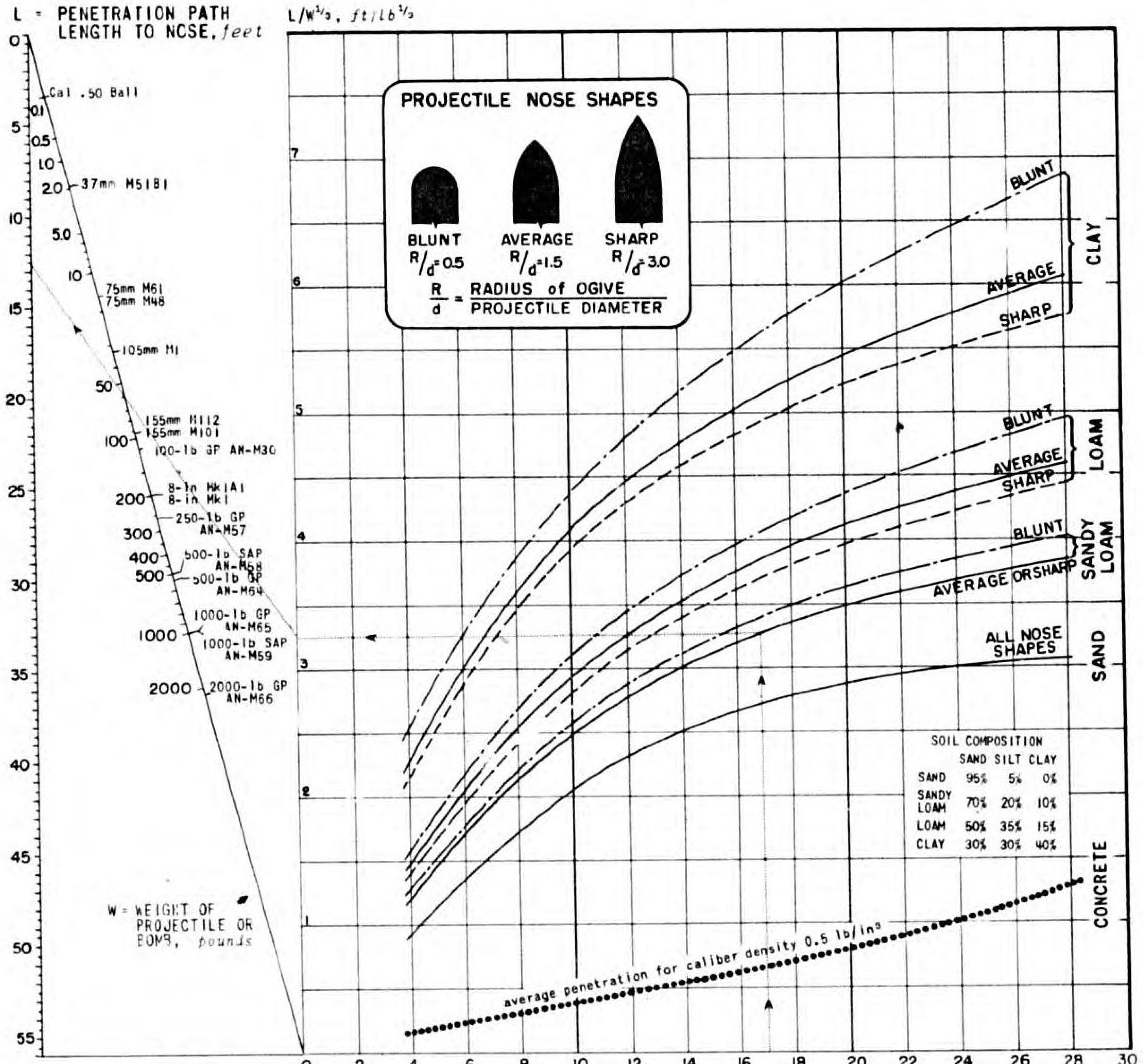
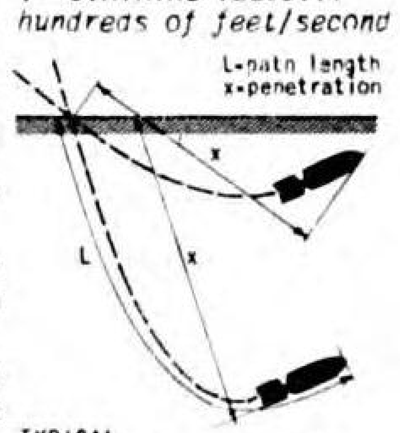
WEAPON DATA

2 A2* SOIL PENETRATION

PENETRATION OF BOMBS AND PROJECTILES INTO SOIL





TYPICAL UNDERGROUND TRAJECTORY

The graph and nomogram give the relation between striking velocity and penetration path length, measured to the nose, for projectiles or bombs of various weights penetrating into several soils. Curves marked *blunt, average,* and *sharp* are for projectiles of different nose shapes as sketched. Where no appreciable effect of nose shape on penetration has been observed only a single curve is drawn. The dependence of penetration path length on projectile weight, as given by the nomogram, agrees with observations for projectiles or bombs having caliber densities from 0.15 to 0.65 lb/in³. Most bombs and artillery projectiles have caliber density values (weight of projectile in pounds divided by the cube of the diameter in inches) within the above range.

Trajectories in soils are usually straight for two-thirds or more of the path length, but curve near the end of the path (see sketch). For this reason final distance from the surface is usually 10% to 30% less than the penetration path given here.

Curves given are for average soil types. Penetrations into rich plastic clay are approximately 30% greater than those observed in clay. The dotted curve at the bottom of the graph gives average penetration into good quality reinforced concrete, and is added here for rough comparison.

EXAMPLE: The dotted line shows that a projectile of average nose shape and weight of 60 lb striking sandy loam soil with a velocity of 1700 ft/sec will have a path length of approximately 12.5 ft, measured to the nose. Because of the curvature of the underground trajectory, the actual penetration from the surface will be somewhat less.

SOURCE: British and American tests with bombs and large caliber projectiles at velocities below 1100 ft/sec. Small caliber tests for the Corps of Engineers, U.S.A. extending over entire velocity range. The curves agree with measurements to ±20%.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

★ **Revision of 2 A2** dated September 1944

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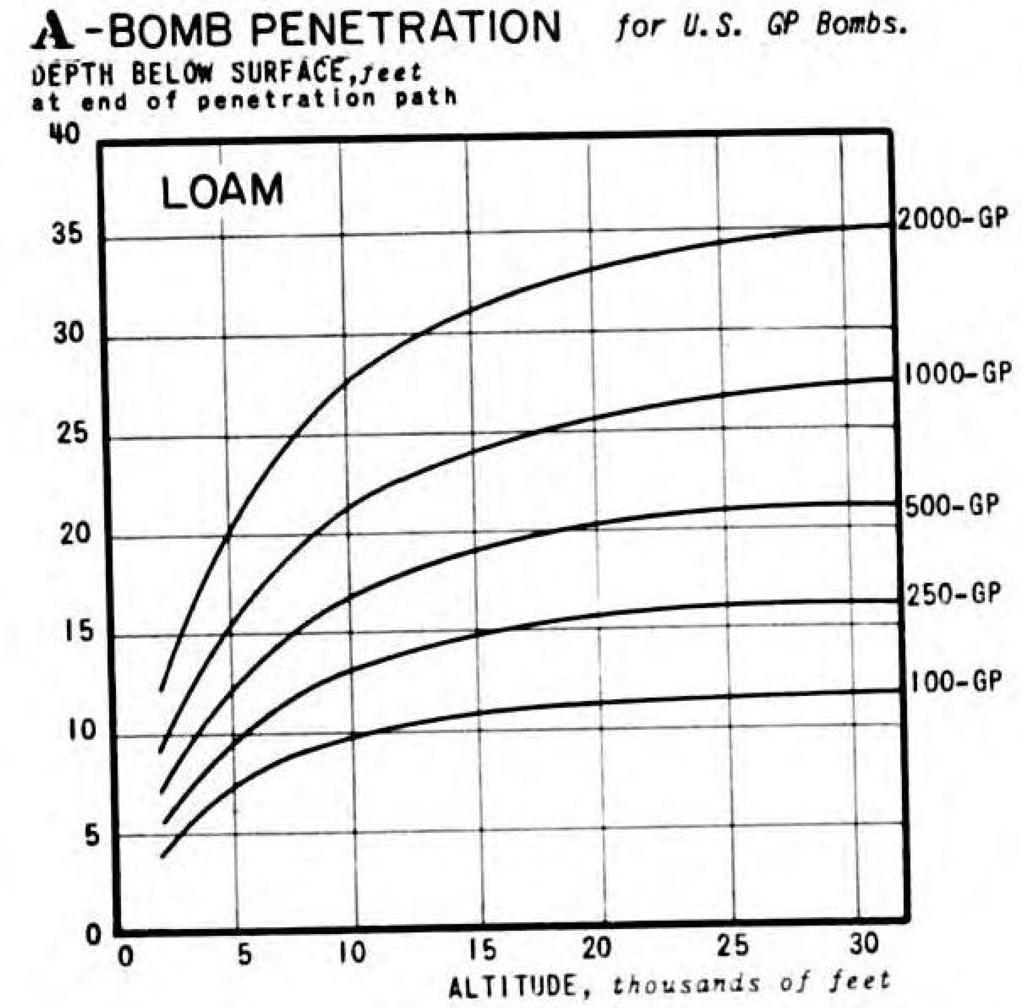
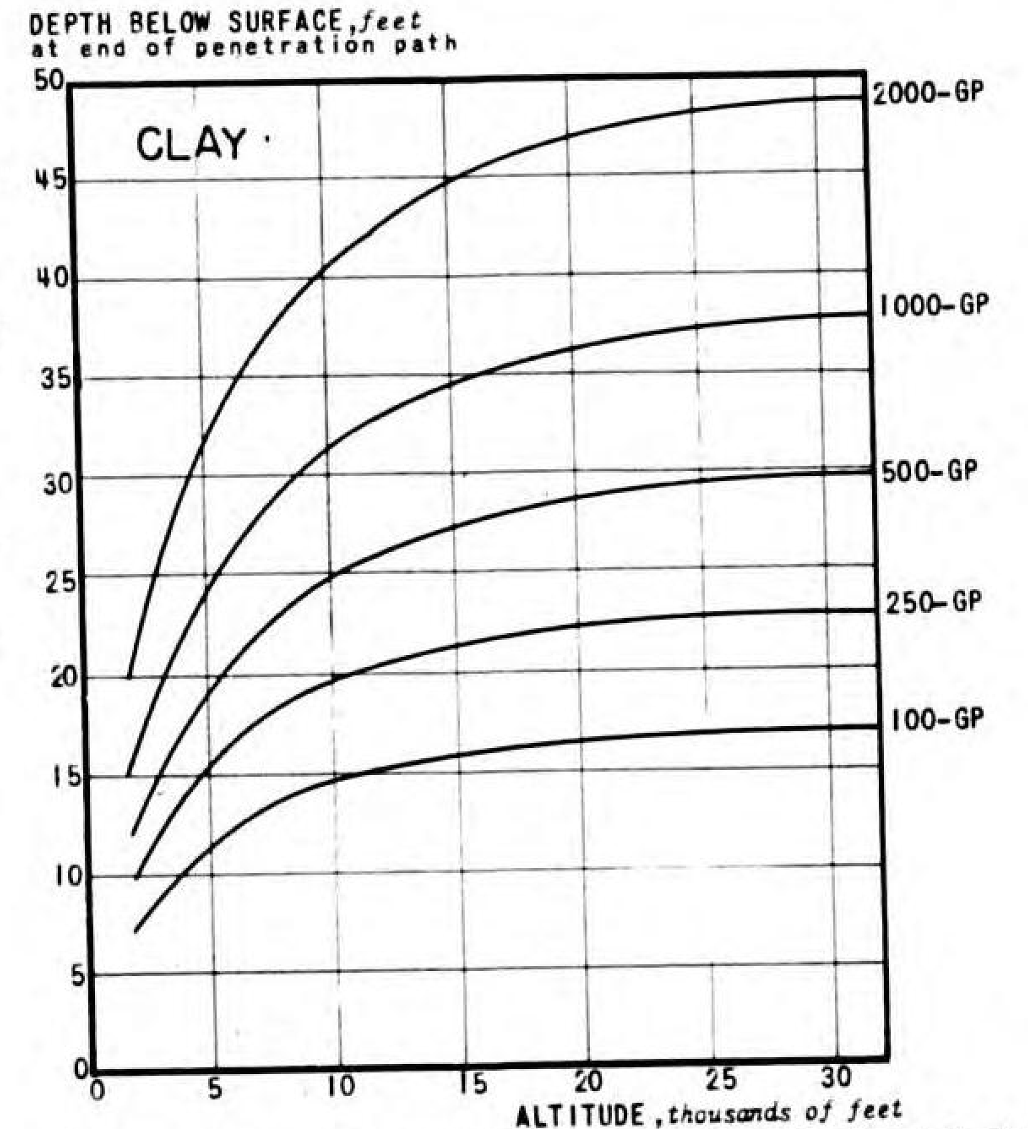
WEAPON DATA

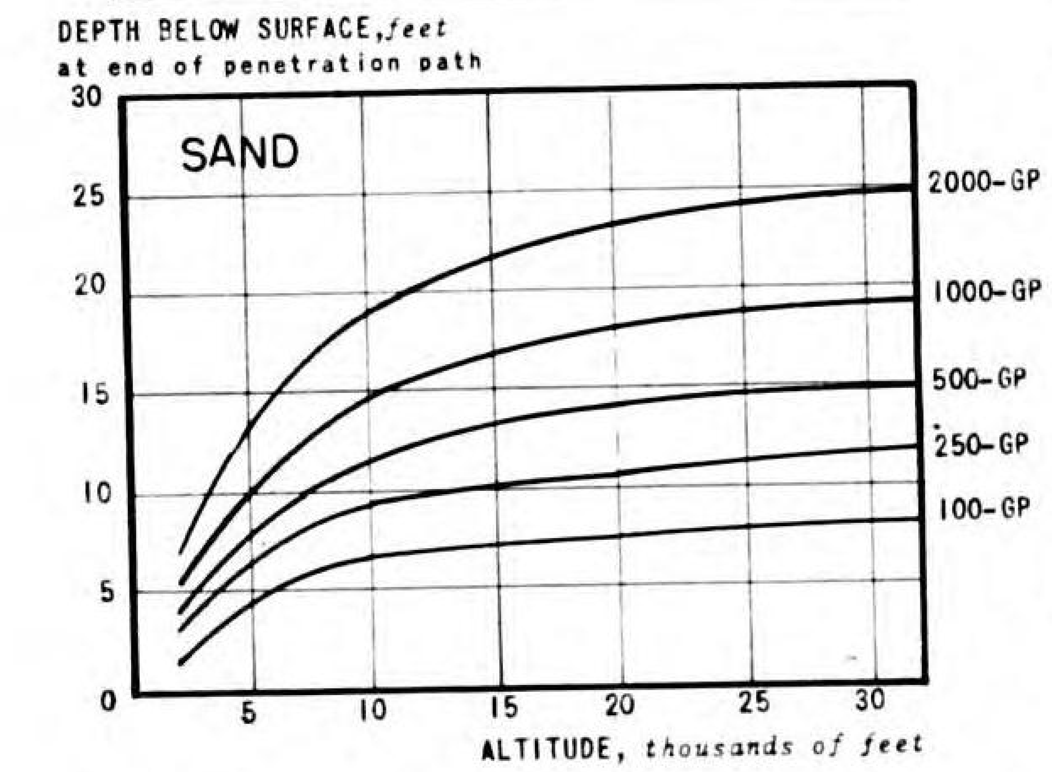
2 A2a SOIL PENETRATION

PENETRATION OF GP BOMBS AND SMALL CALIBER BULLETS INTO SOIL

A - BOMB PENETRATION *for U.S. GP Bombs.*







The curves give the depth below the surface for General Purpose bombs dropped from level flight at various altitudes. The depth is that measured from a level surface to the center of **the bomb, delay fuzed to permit full penetration.**

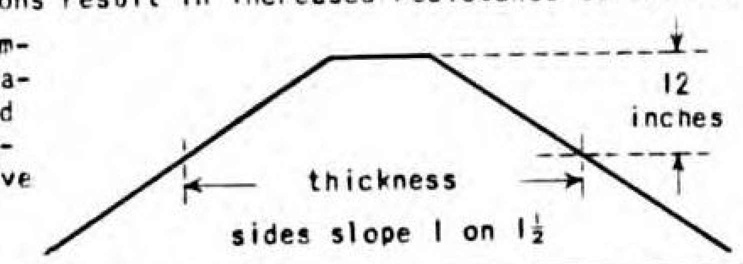
The designations clay, loam, and sand are for average soil types. For soils of other types interpolation should be made from these curves. For example, the depth in a sandy soil may be expected to be between the values given for sand and the values given for loam.

Bomb penetrations into soil vary due to the irregularities of curvature of the underground trajectory, and may vary appreciably due to inhomogeneities of the soil, water content of the soil, etc. The curves given here agree with the available data to within ± 20%.

B - SMALL CALIBER BULLETS

Penetration of small caliber jacketed bullets into soils is limited by the deformation of the soft tip at low velocities and stripping of the jacket from the core at high velocities. Such deformations result in increased resistance to motion.

The table gives penetration and perforation data for small caliber service ammunition with soft jacket and hard core. The maximum thickness of a soil parapet that can be perforated by a single hit at short range and the recommended minimum thickness of a soil parapet for protection against ten hits close together are given. The protection is adequate only for positions more than twelve inches (25 to 30 calibers) below the top of the parapet.



SOIL	U.S. CALIBER .30 AP				U.S. CALIBER .50 AP			
	Maximum Expected Penetration	Average Penetration, Short Range	Parapet Thickness Perforated	Parapet Thickness for Protection	Maximum Expected Penetration	Average Penetration, Short Range	Parapet Thickness Perforated	Parapet Thickness for Protection
LOOSE SAND	12 in	10 in	13 in	40 in	20 in	16 in	21 in	64 in
COMPACT SAND	9½ in	7½ in	12 in	30 in	15 in	12 in	19 in	46 in
LOAM	16 in	12 in	16 in	44 in	24 in	20 in	26 in	72 in
PLASTIC CLAY	23 in	20 in	23 in	65 in	40 in	30 in	36 in	100 in

SOURCE: The Bomb Penetration Curves are based on British and American tests with bombs and large caliber projectiles. The Small Caliber Bullet Tabulation is based on tests for the Corps. of Engineers, U.S.A.

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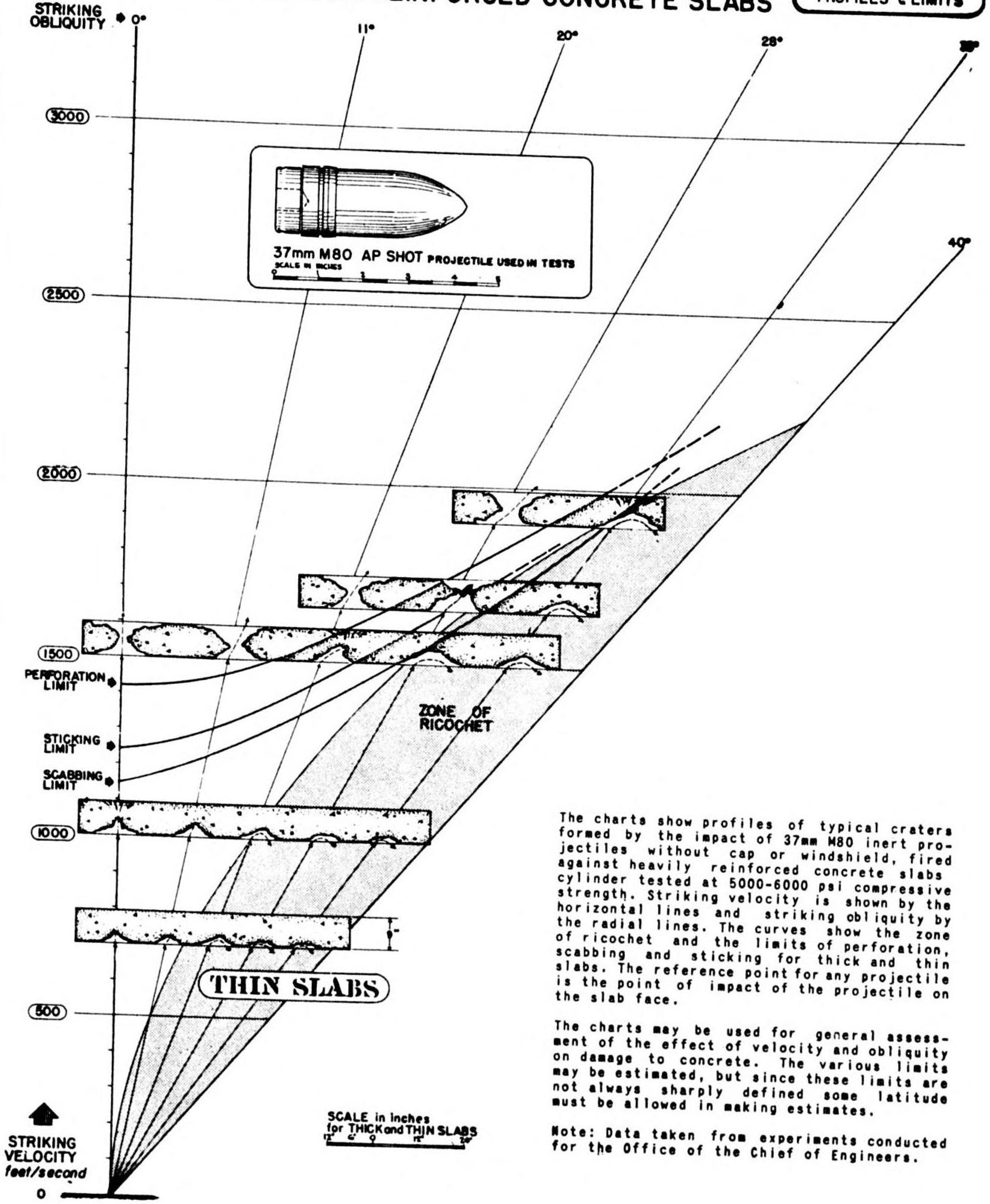
WEAPON DATA

2 A3 CONCRETE: PROFILES & LIMITS

PENETRATION PROFILES AND BALLISTIC LIMITS FOR REINFORCED CONCRETE SLABS



The charts show profiles of typical craters formed by the impact of 37mm M80 inert projectiles without cap or windshield, fired against heavily reinforced concrete slabs cylinder tested at 5000-6000 psi compressive strength. Striking velocity is shown by the horizontal lines and striking obliquity by the radial lines. The curves show the zone of ricochet and the limits of perforation, scabbing and sticking for thick and thin slabs. The reference point for any projectile is the point of impact of the projectile on the slab face.

The charts may be used for general assessment of the effect of velocity and obliquity on damage to concrete. The various limits may be estimated, but since these limits are not always sharply defined some latitude must be allowed in making estimates.

Note: Data taken from experiments conducted for the Office of the Chief of Engineers.

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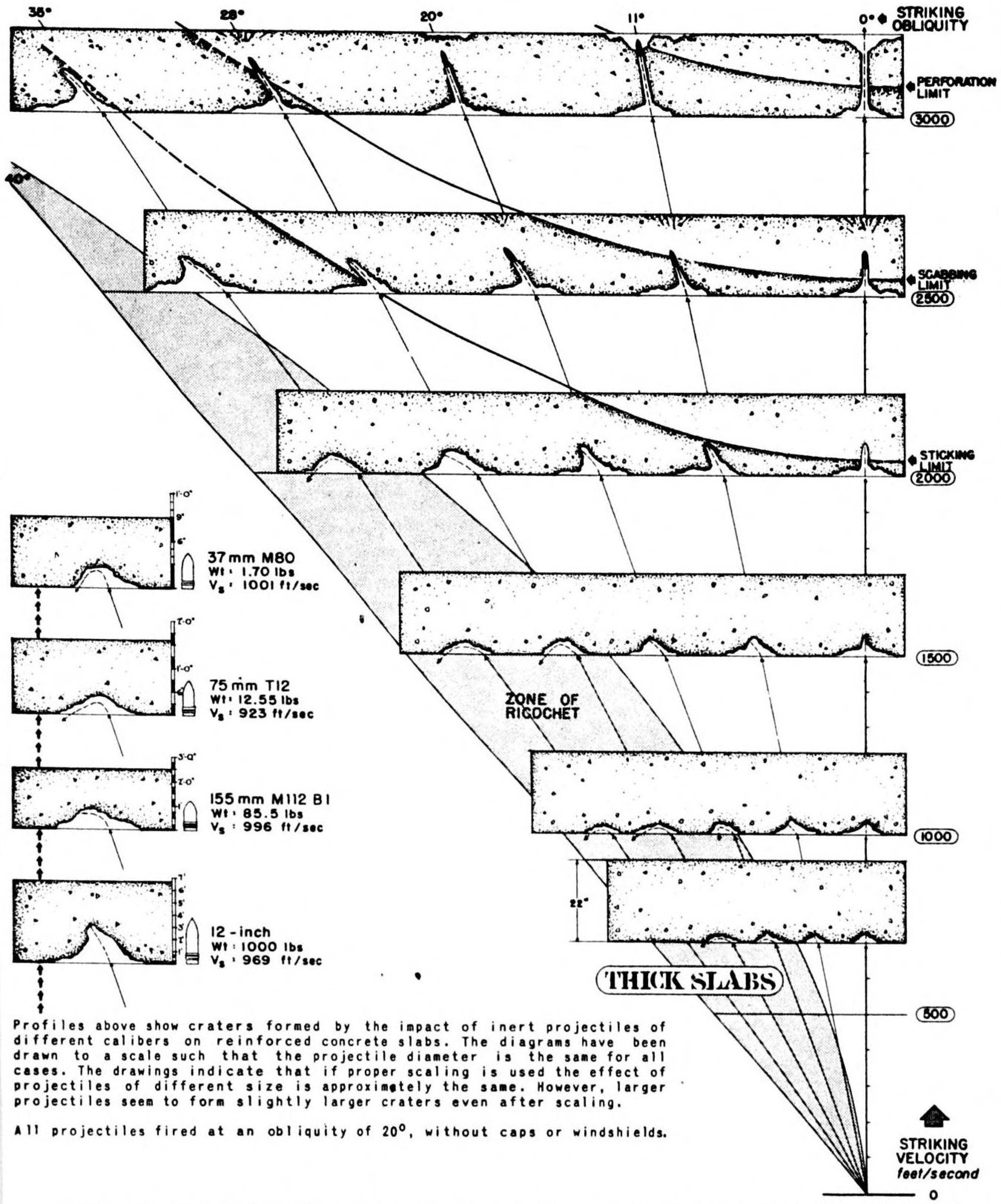

Profiles above show craters formed by the impact of inert projectiles of different calibers on reinforced concrete slabs. The diagrams have been drawn to a scale such that the projectile diameter is the same for all cases. The drawings indicate that if proper scaling is used the effect of projectiles of different size is approximately the same. However, larger projectiles seem to form slightly larger craters even after scaling.

All projectiles fired at an obliquity of 20°, without caps or windshields.

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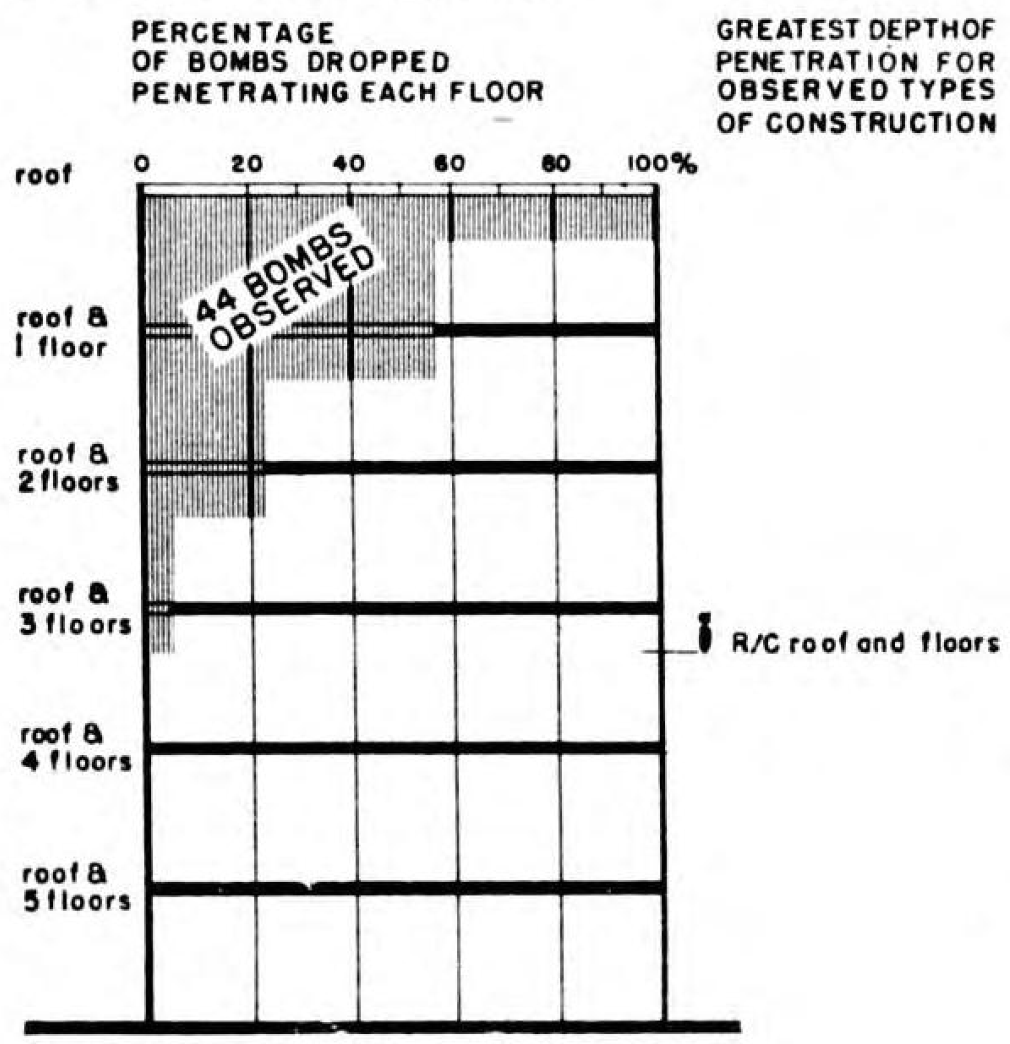
WEAPON DATA

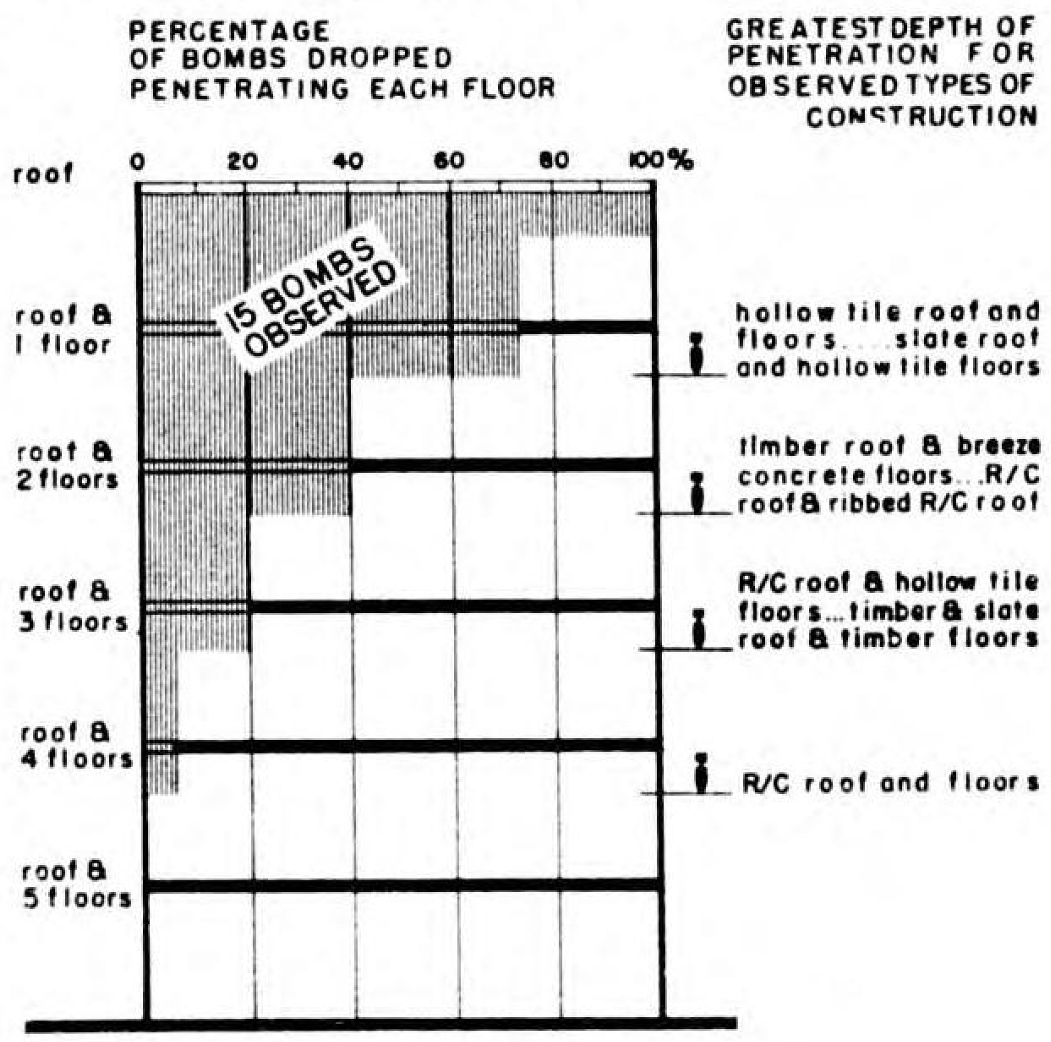
2 A 4
BUILDINGS
PENETRATION

PENETRATION OF GERMAN BOMBS INTO BUILDINGS

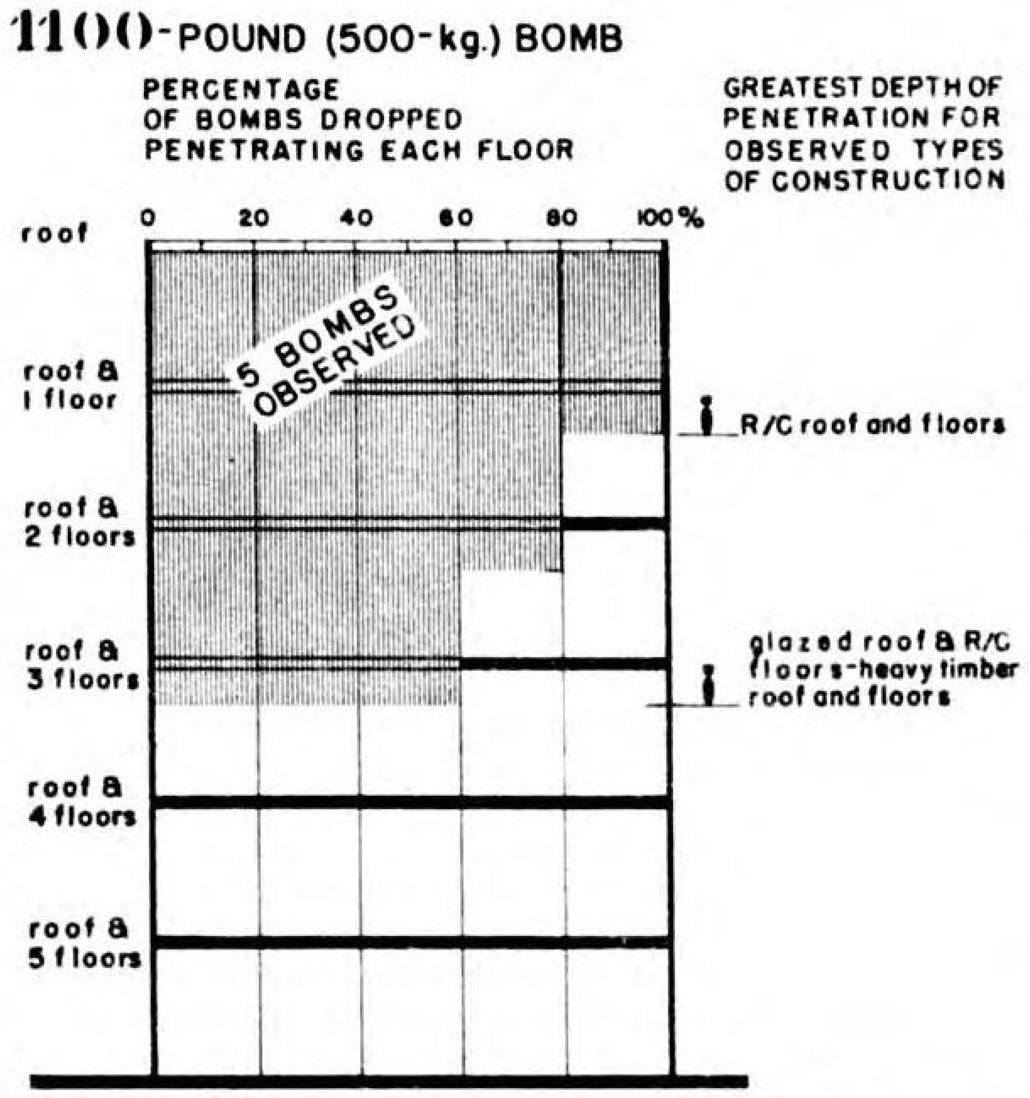
110-POUND (50-kg.) BOMB



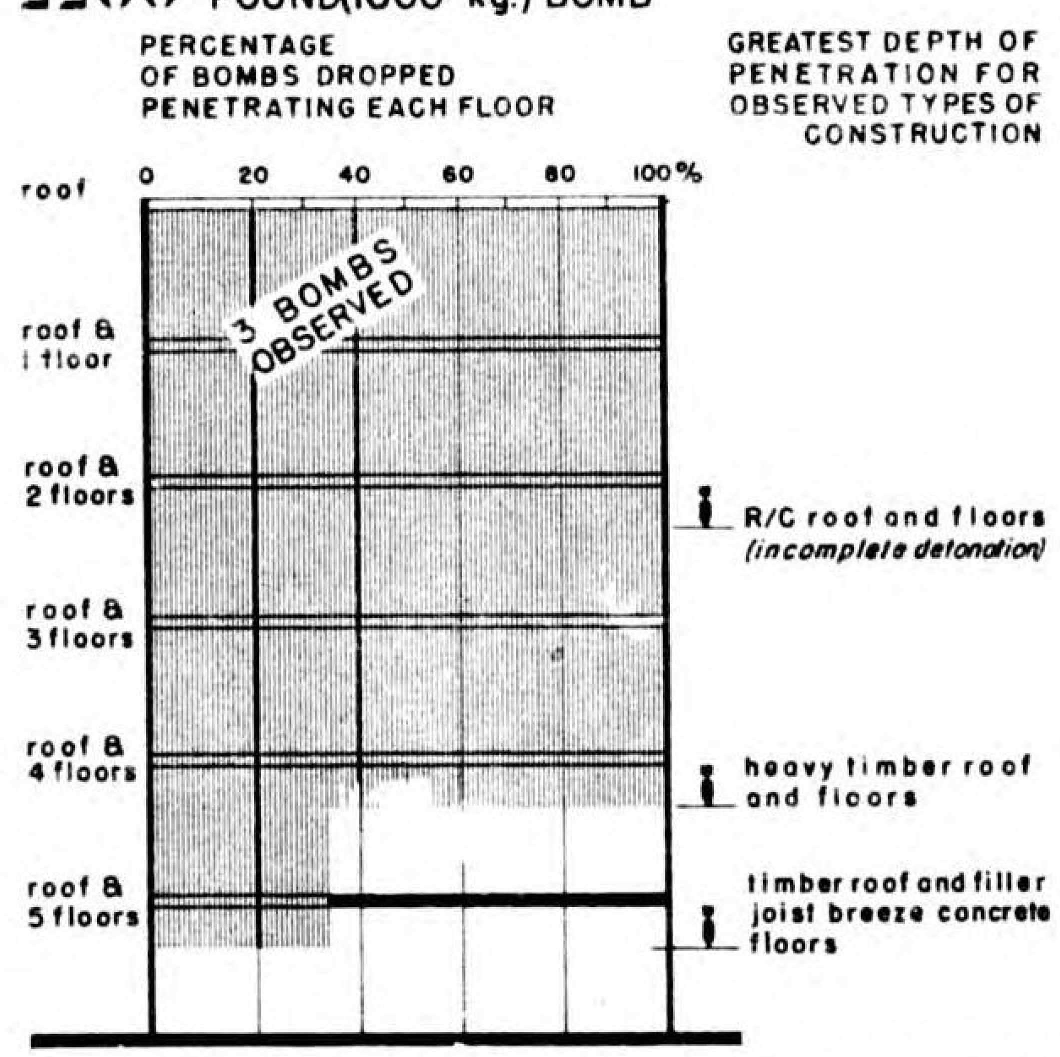
550-POUND (250-kg.) BOMB



1100-POUND (500-kg.) BOMB



2200-POUND (1000-kg.) BOMB



THE STRIKING VELOCITY AND FUZING FOR THE BOMBS OBSERVED AND REPRESENTED HERE ARE NOT KNOWN.... IN USING THIS DATA SHEET THIS FACT SHOULD BE CONSIDERED

FLOOR THICKNESS:
BECAUSE OF THE SMALL NUMBER OF INCIDENTS IT WAS NOT CONSIDERED FEASIBLE TO INVESTIGATE THE EFFECT OF FLOOR THICKNESS AND MATERIAL... INSTEAD ALL INCIDENTS WERE COMBINED IN MAKING UP THE GRAPHS

NOTE: DATA FOR THE 110-POUND BOMBS WERE PREPARED FROM BULLETIN A-4, EFFECTS OF BOMBING ON STRUCTURES BY J. D. BERNAL; AND FOR THE 550, 1100 AND 2200-POUND BOMBS FROM RE 4 BOMBING INCIDENT DAMAGE REPORTS

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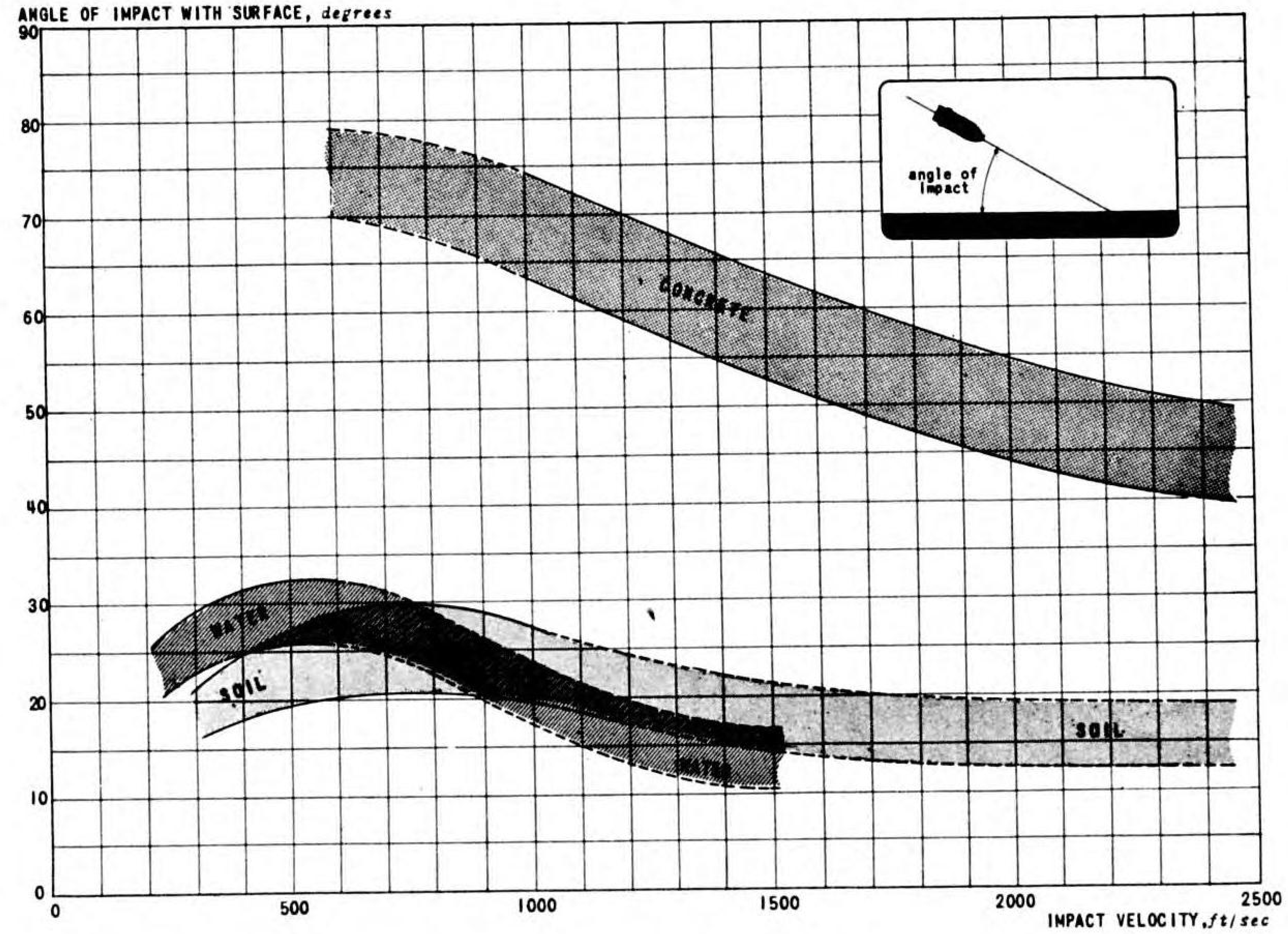
WEAPON DATA

2 A 5
RICOCHET

RICOCHET FROM WATER, SOIL AND CONCRETE



The graph gives the limiting angle separating ricochet and penetration for water, soil or massive concrete as a function of striking velocity. For armor or mild steel plate the limiting angle is different for each plate thickness; these are not treated here. The curves apply to ordinary projectiles and bombs, without special attachments or nose shapes.

The ricochet limits are represented in the form of bands, the width of each band including variation of many factors such as nose shape, moment of inertia, density of the projectile and density of the material. Each band on the graph separates two regions: ricochet occurs for combinations of striking velocity and impact angle below the band, no ricochet occurs for combinations above the band. The portions of each band with dotted edges are based on a small amount of data.

In general, missiles having sharp noses, long slender bodies or low densities will have ricochet limits in the upper part of each band, while those having blunt noses, short bodies or high densities will have ricochet limits in the lower part of each band. Increasing the surface regularity or the density of the target generally shifts ricochet limits toward the lower part of each band.

SOURCE: Soil and water ricochet data are from Aberdeen Proving Ground; concrete ricochet data are from the Office of the Chief of Engineers U. S. Army.

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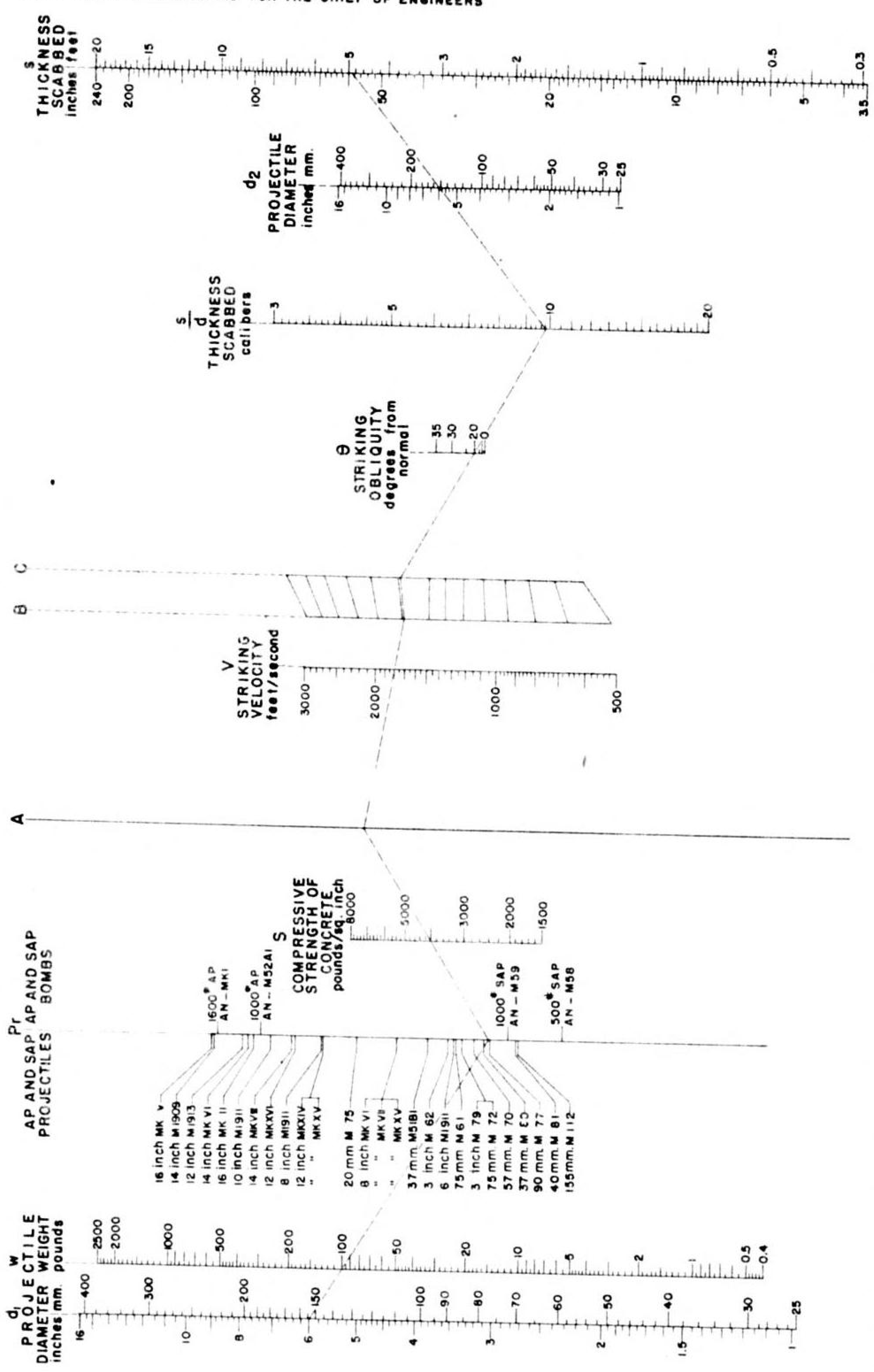
WEAPON DATA

2B1
CONCRETE: SCABBING

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

BASED ON DATA DEVELOPED FOR THE CHIEF OF ENGINEERS



DIRECTIONS: Determine the diameter and weight of that part of the projectile which penetrates the slab. (The total weight minus the weight of the windshield will usually be correct.) Draw a line through the proper points on the d_1 scale and w scale at the left of the chart to the Pr scale. (If the projectile is a type listed on this scale, the above may be omitted.) Continue from this point through the S scale to the A scale. From the A scale draw a line through the V scale to the B scale and follow the guide lines to the C scale. From the C scale draw a line through the θ scale to the s/d scale. From this point draw a line through the d_2 scale and read the thickness that will be scabbed from the s scale. The thickness scabbed by oblique fire at velocities above 2000 ft/sec may be somewhat more than shown here.

EXAMPLE:
The dotted line shows a 6 inch, 100 pound projectile, striking 4,000 p.s.i. concrete with a velocity of 1,800 ft./sec. at an obliquity of 20°. The projectile will scab a target 9.8 calibers or 58.8 inches.

ACCURACY:
This chart gives results accurate within 15%.

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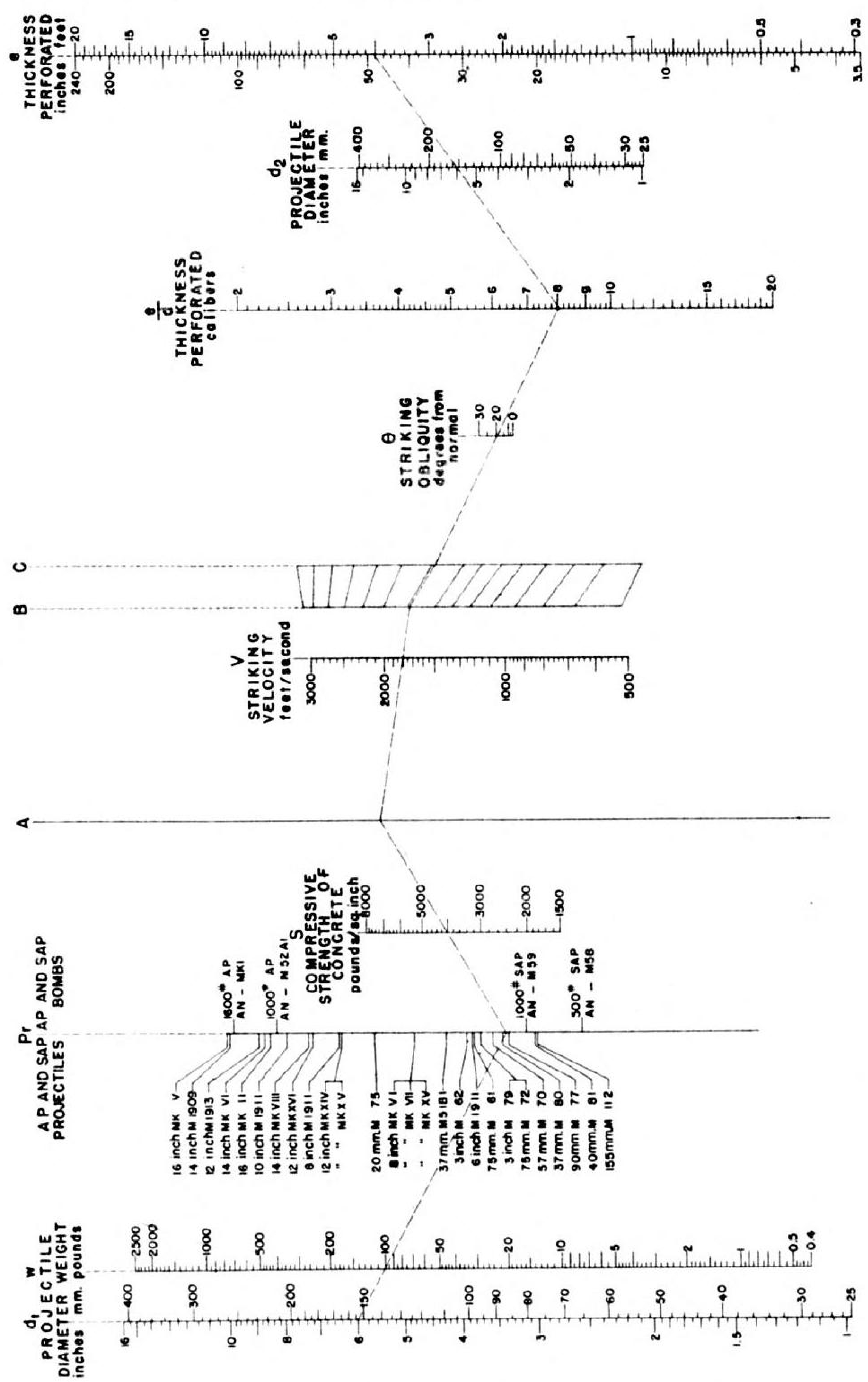
WEAPON DATA

9C1
CONCRETE PERFORATION

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

BASED ON DATA DEVELOPED FOR THE CHIEF OF ENGINEERS



DIRECTIONS: Determine the diameter and weight of that part of the projectile which perforates the slab. (The total weight minus the weight of the windshield will usually be correct.) Draw a line through the proper points on the d_1 scale and w scale at the left of the chart to the Pr scale. (If the projectile is a type listed on this scale, the above may be omitted.) Continue from this point through the S scale to the A scale. From the A scale draw a line through the V scale to the B scale and follow the guide lines to the C scale. From the C scale draw a line through the θ scale to the e/d scale. From this point draw a line through the d_2 scale and read the thickness that will be perforated from the e scale. The thickness perforated by oblique fire at velocities above 2000 ft./sec. may be somewhat more than shown here.

EXAMPLE:
The dotted line shows a 6 inch, 100 pound projectile, striking 4,000 p.s.i. concrete with a velocity of 1,800 ft./sec. at an obliquity of 20°
The projectile will perforate a target 8.1 calibers or 48.6 inches.

ACCURACY:
This chart gives results accurate within 15%.

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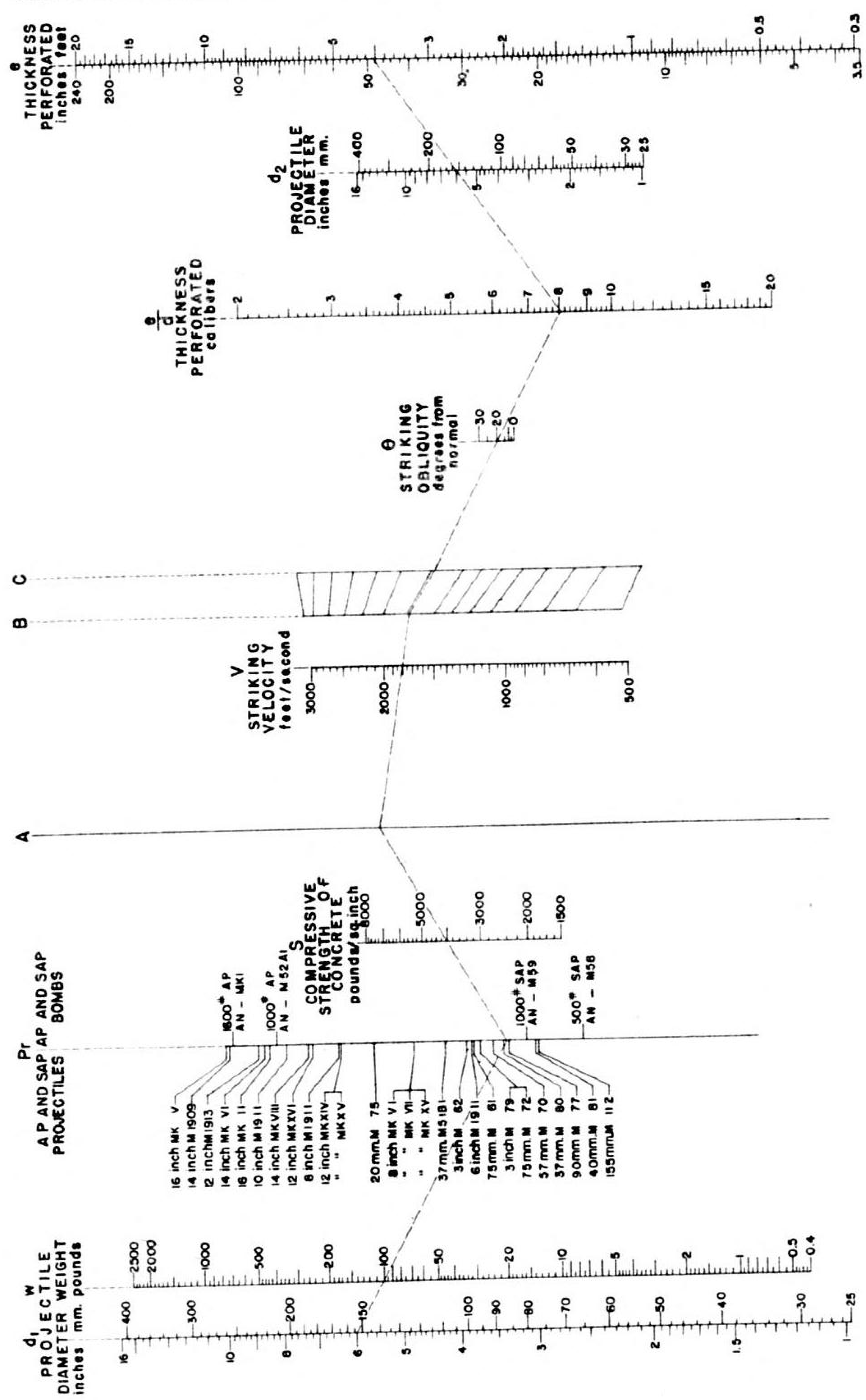
PERFORATION OF REINFORCED CONCRETE BY AP PROJECTILES AND AP AND SAP BOMBS

BASED ON DATA DEVELOPED FOR THE CHIEF OF ENGINEERS

2C1 CONCRETE: PERFORATION



DIRECTIONS: Determine the diameter and weight of that part of the projectile which perforates the slab. (The total weight minus the weight of the windshield will usually be correct.) Draw a line through the proper points on the d_1 scale and w scale at the left of the chart to the Pr scale. (If the projectile is a type listed on this scale, the above may be omitted.) Continue from this point through the S scale to the A scale. From the A scale draw a line through the V scale to the B scale and follow the guide lines to the C scale. From the C scale draw a line through the θ scale to the e/d scale. From this point draw a line through the d_2 scale and read the thickness that will be perforated from the e scale. The thickness perforated by oblique fire at velocities above 2000 ft./sec. may be somewhat more than shown here.

EXAMPLE:
The dotted line shows a 6 inch, 100 pound projectile, striking 4,000 p.s.i. concrete with a velocity of 1,800 ft./sec. at an obliquity of 20°. The projectile will perforate a target 8.1 calibers or 48.6 inches.

ACCURACY:
This chart gives results accurate within 15 %.

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WEAPON DATA

2 C1a PERFORATION OF R/C: SPECIFIC

PERFORATION OF REINFORCED CONCRETE BY SPECIFIC BOMBS AND ROCKETS

BOMB (delay fuzed)	ALTITUDE ft	CONCRETE PERFORATION, feet: 3000 psi	CONCRETE PERFORATION, feet: 5000 psi	SOIL PENETRATION, ft: Sand	SOIL PENETRATION, ft: Loam	CONCRETE PERFORATION, ft, WITH SOIL COVER OF VARIOUS THICKNESSES, ft: 2 ft	4 ft	6 ft	8 ft	10 ft	MINIMUM ALTITUDE ATTACK OF VERTICAL CONCRETE WALLS THICKNESS PERFORATED feet (By Bombs)
100-lb GP AN-M30	5000	1.0 ft limited by case strength	0.75 ft limited by case strength	5	8	0.7	0.5	-	-	-	
	10000			7	10	0.7	0.7	-	-	-	
	15000			7½	11	0.7	0.7	-	-	-	
	20000			8	11½	0.7	0.7	0.5	-	-	
	25000			8	11½	0.7	0.7	0.6	-	-	
250-lb GP AN-M57	5000	1.3 ft limited by case strength	1.0 ft limited by case strength	7	10	1.0	0.8	-	-	-	
	10000			9½	13½	1.0	1.0	0.8	-	-	
	15000			10½	15	1.0	1.0	1.0	-	-	
	20000			11	16	1.0	1.0	1.0	0.8	-	
	25000			11½	16	1.0	1.0	1.0	0.8	-	
500-lb GP AN-M43, M64	5000	1.7 ft limited by case strength	1.3 ft limited by case strength	8	12½	1.3	1.1	0.9	-	-	1.3
	10000			12	17	1.3	1.3	1.3	1.1	-	
	15000			13½	19	1.3	1.3	1.3	1.2	-	
	20000			14½	20½	1.3	1.3	1.3	1.2	1.1	
	25000			15	21	1.3	1.3	1.3	1.3	1.2	
1000-lb GP AN-M44, M65	5000	2.3 ft limited by case strength	1.7 ft limited by case strength	10½	16	1.7	1.7	1.3	1.1	-	1.5
	10000			15	22	1.7	1.7	1.7	1.7	1.3	
	15000			17	24	1.7	1.7	1.7	1.7	1.3	
	20000			18½	26	1.7	1.7	1.7	1.7	1.7	
	25000			19	27	1.7	1.7	1.7	1.7	1.7	
2000-lb GP AN-M34, M66	5000	2.9 ft limited by case strength	2.1 ft limited by case strength	13½	20½	2.1	2.1	2.1	1.9	1.7	2.0
	10000			19½	28	2.1	2.1	2.1	2.1	2.1	
	15000			22	31½	2.1	2.1	2.1	2.1	2.1	
	20000			24	33½	2.1	2.1	2.1	2.1	2.1	
	25000			24½	34½	2.1	2.1	2.1	2.1	2.1	
500-lb SAP AN-M58	5000	2.5	2.0	8	12½	1.7	1.4	1.1	-	-	1.5
	10000	3.0	2.7	12	17	2.4	2.1	1.7	1.3	-	
	15000	3.5	3.1	13½	19	2.7	2.4	2.1	1.8	-	
	20000	3.8	3.3	14½	20½	2.9	2.6	2.3	1.9	1.6	
	25000	4.1	3.5	15	21	3.2	2.8	2.5	2.2	1.8	
1000-lb SAP AN-M59	5000	3.0	2.7	10	16	2.4	2.1	1.8	1.5	-	2.0
	10000	3.9	3.5	15	22	3.2	2.9	2.5	2.2	1.9	
	15000	4.6	4.1	17	24	3.7	3.4	3.1	2.7	2.4	
	20000	5.1	4.4	18½	26	4.0	3.7	3.3	3.0	2.6	
	25000	5.5	4.7	19	27	4.3	4.0	3.7	3.3	3.0	
2000-lb SAP M 103	5000	3.3	3.0	13½	20½	2.7	2.4	2.1	1.8	1.5	CONCRETE PERFORATION BY ROCKETS: 5-inch HVAR Mk6 2.4 feet; 11.75-inch AR Mk2 4.5 feet
	10000	5.1	4.4	19½	28	4.1	3.8	3.5	3.1	2.8	
	15000	6.1	5.3	22	31½	4.9	4.6	4.3	4.0	3.6	
	20000	6.8	5.8	24	33½	5.4	5.1	4.7	4.4	4.0	
	25000	7.2	6.2	24½	34½	5.8	5.5	5.1	4.7	4.4	
1000-lb AP AN-Mk 33	5000	2.7	2.5	10½	16	2.2	1.9	1.7	1.1	-	
	10000	4.0	3.5	15	22	3.2	2.9	2.5	2.2	1.9	
	15000	5.2	4.3	17	24	3.9	3.6	3.2	2.9	2.5	
	20000	5.9	4.9	18½	26	4.5	4.1	3.7	3.3	2.9	
	25000	6.4	5.2	19	27	4.8	4.4	4.0	3.7	3.3	
1600-lb AP AN-Mk I	5000	3.4	3.0	12½	19	2.7	2.4	2.1	1.9	1.6	
	10000	4.8	4.2	17½	26	3.9	3.6	3.2	2.9	2.5	
	15000	6.2	5.2	20	28	4.9	4.5	4.1	3.8	3.3	
	20000	7.1	5.8	21½	30	5.4	5.0	4.6	4.3	3.9	
	25000	7.8	6.4	22	31	6.0	5.6	5.2	4.7	4.3	

The table gives the thickness of reinforced concrete and thickness of concrete with soil cover that can be perforated by GP, SAP, and AP bombs dropped from planes in level flight at 200 to 300 m.p.h. at various altitudes. The depth of penetratioh of the same bombs into soil is included for comparison.

Pombs should be fuzed 0.025 seconds delay or longer to insure perforation before detonation. The values given in the table apply to bombs with this fuze delay.

SOURCE: Based on Data Sheets 2A2*, 2C1, and Interim Memorandum No. M-13 of the Committee on Fortification Design.

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2 C2 PLASTIC PROTECTION PERFORATION

PERFORATION OF PLASTIC PROTECTION

DESCRIPTION

PLASTIC PROTECTION CONSISTS OF A MIXTURE, IN PROPORTIONS BY WEIGHT AS GIVEN, OF THE FOLLOWING MATERIALS: COARSE MINERAL AGGREGATE (exner gravel) - 60%; LIMESTONE DUST FILLER - 30%; MASTIC BITUMIN and/or COAL TAR PITCH - 10%. A LAYER OF THIS MIXTURE IS BACKED BY A 1/8-INCH TO 1/4-INCH THICK PLATE OF MILD STEEL. TO INCREASE THE STRUCTURAL STRENGTH AS WELL AS THE STOPPING POWER OF THE MATERIAL, CHICKEN WIRE OR EXPANDED METAL IS EMBEDDED IN THE PLASTIC MIXTURE AT THE CENTER OR NEAR THE FRONT SURFACE. OCCASIONALLY, A FRONT PLATE OF 20-GAUGE (or heavier) STEEL IS APPLIED.

EFFECTIVENESS

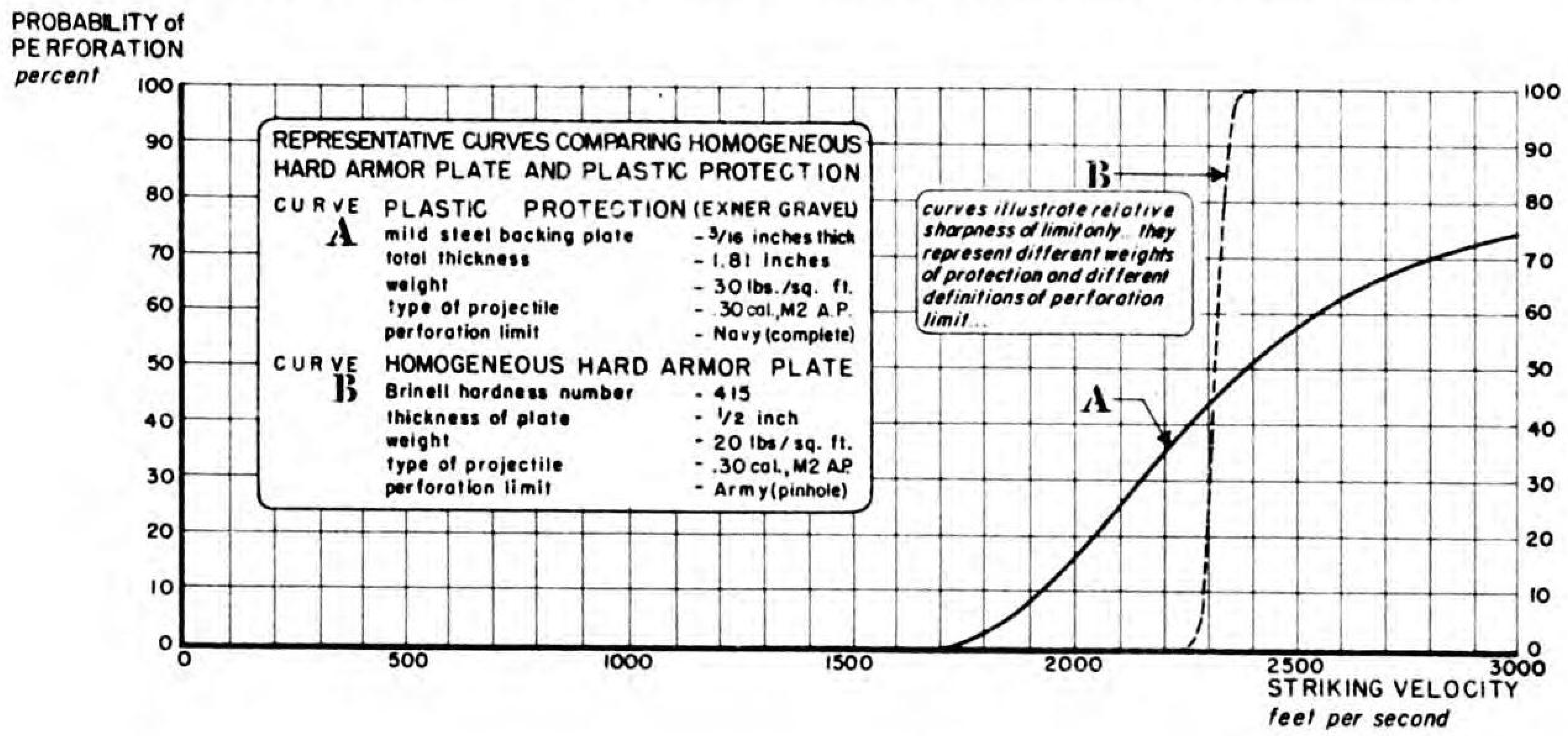
STOPPAGE OF THE PROJECTILE IS LARGELY DUE TO THE BREAKING-UP AND YAWING OF THE CORES BEFORE REACHING THE BACK PLATE. INASMUCH AS THIS PROCESS MAY OCCUR IN A LARGE NUMBER OF WAYS, THERE IS NO SHARPLY DEFINED LIMITING VELOCITY FOR A GIVEN THICKNESS OF THE MATERIAL SUCH THAT FOR HIGHER VELOCITIES ALL BULLETS WILL PERFORATE WHILE FOR LOWER VELOCITIES NONE WILL. IT MAY BE SAID ONLY THAT A CERTAIN PERCENTAGE OF PROJECTILES TRAVELING AT A GIVEN VELOCITY WILL BE STOPPED BY A GIVEN THICKNESS OF PLASTIC PROTECTION.

AMOUNTS OF PLASTIC PROTECTION, MILD STEEL AND SPECIAL TREATED STEEL REQUIRED FOR " ADEQUATE PROTECTION "

(5% PERFORATION AT NORMAL IMPACT AND CLOSE RANGE)

PROJECTILE	STRIKING VELOCITY ft./sec.	PLASTIC PROTECTION: t_B inches	PLASTIC PROTECTION: t inches	PLASTIC PROTECTION: W lbs./sq.ft.	MILD STEEL: t inches	MILD STEEL: W lbs./sq.ft.	SPECIAL TREATED STEEL: t inches	SPECIAL TREATED STEEL: W lbs./sq.ft.
British -.303inch, Mk VII, Ball	2440	1/8	1-1/8	20			1/4	10
American -.30 caliber Ball	2560	3/16	1-1/16	23				
British -.303inch AP	2440	3/16	2-1/4	34	1.04 *	42.4 *	.71 *	29 *
American -.30 cal., M-2 AP	2580	3/16	3-1/8	44	1 10	43.1	3/4	34
British -.55 inch AP	2400	1/4	5	72				
American -.50 cal., M-2 AP	2900	3/16	5to6	70to86	2.20 *	89.8 *	1-1/2	60
British -20 mm. AP	2750	1/4	7-7/8	110				
Splinter from U.S. 250-lb. G.P. Bomb at 37.5 feet	–	3/16	1-1/2	26	1.35	55.0	0.9	36

NOTES t_B - thickness of mild steel backing plate
t - total thickness (including backing plate)
W - total weight per unit area (including backing plate)
* these figures are estimates derived from the assumption that the thickness perforated is directly proportional to the mass of the projectile and to the square of the striking velocity and inversely proportional to the square of the caliber.



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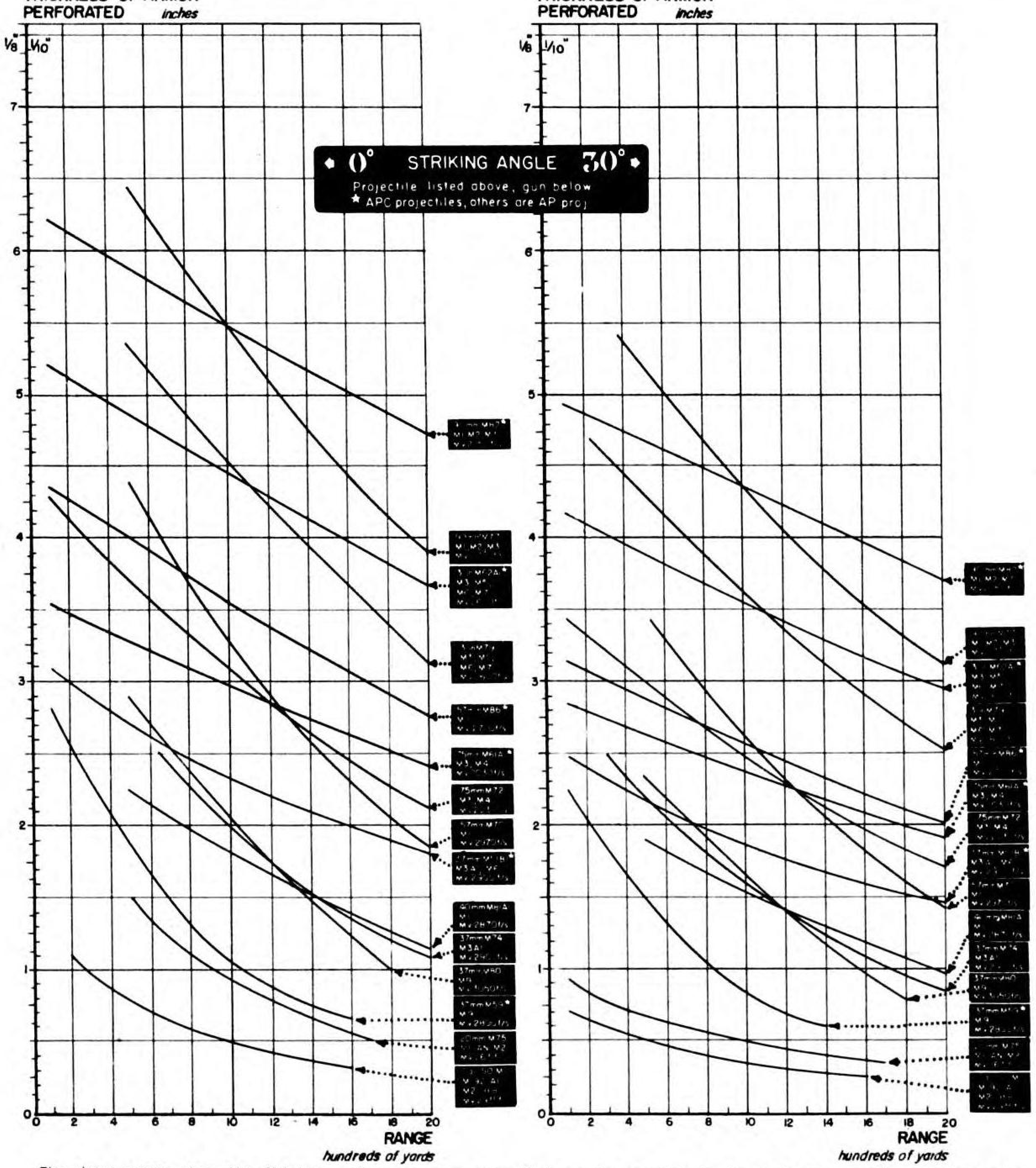
WEAPON DATA

2 C3a PERFORATION OF ARMOR-PROJECTILES

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

CURVES FOR INDIVIDUAL AP AND APC PROJECTILES



The above graphs show the thickness of homogeneous armor that can be expected to be perforated at 0° and 30° striking angles for various ranges by individual projectiles of known weight. The curves represent estimates based on data from actual firings or extrapolations of results of trials with other projectiles.

For information on perforation of homogeneous armor by other projectiles, see Data Sheet 2 C3.

SOURCE: Ballistic Section, Technical Division, Office of the Chief of Ordnance (U.S.).

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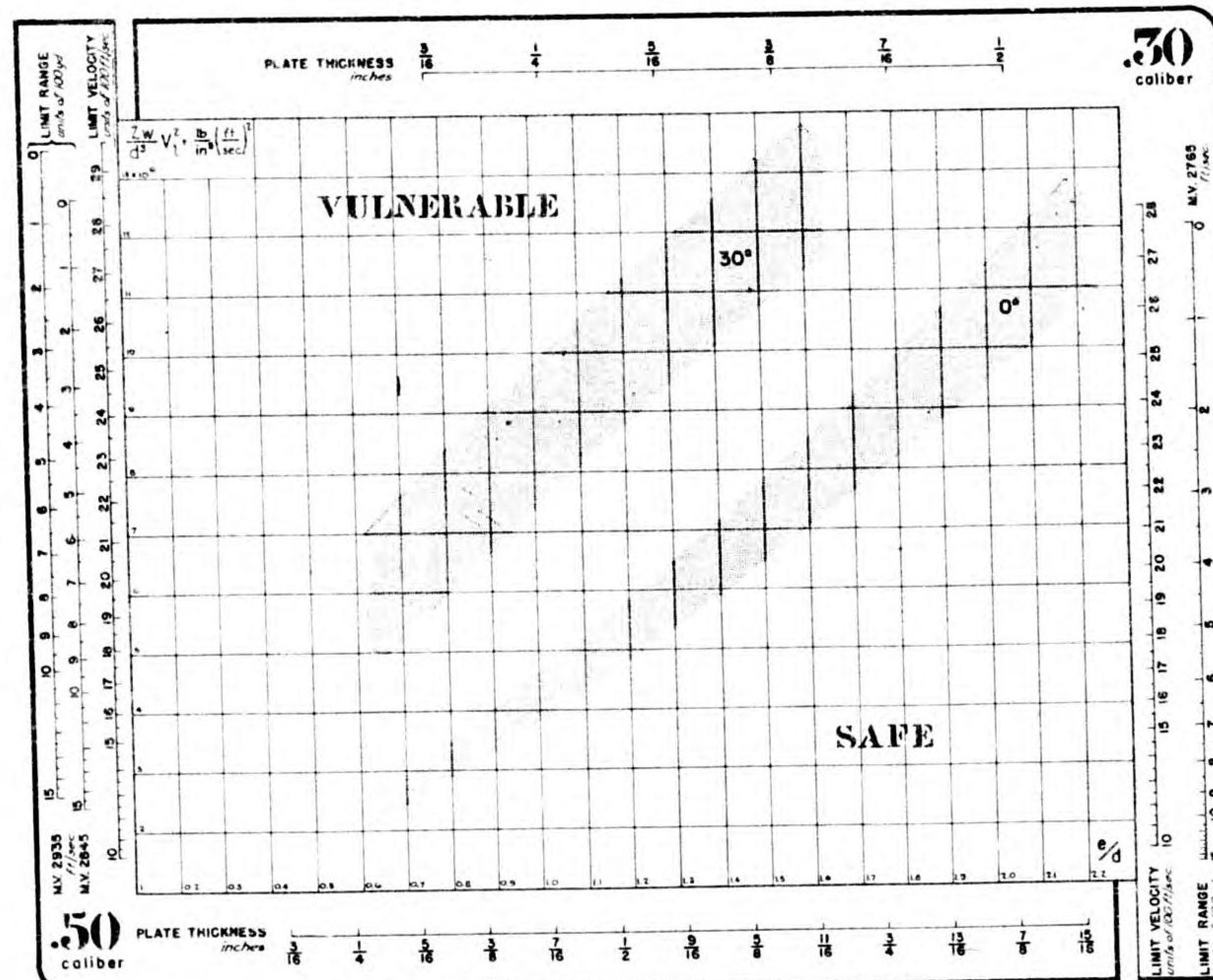
WEAPON DATA

2 C4 ARMOR PERFORATION

PERFORATION OF THIN HOMOGENEOUS HARD ARMOR BY SMALL CALIBER AP PROJECTILES



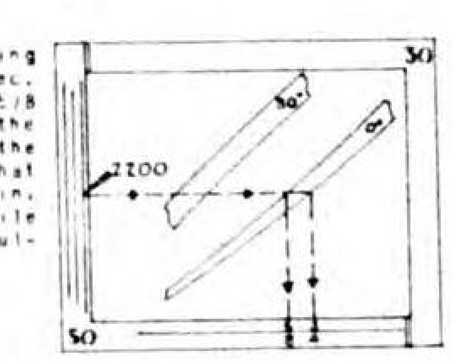
The graph shows the relation between perforation limit striking velocity (perforation limit range) and thickness of plate perforated for Caliber .50 M2 and Caliber .30 M2 AP projectiles fired against Homogeneous Hard Armor of BHN 350-450 at normal incidence and at an obliquity of 30°. The limit velocity concerned is that at which the projectile just passes completely through the plate (Navy Limit). Each value of limit velocity corresponds to a given range, depending on the M.V. of the gun. Range values for service muzzle velocities are given by the appropriate scales at each side of the chart.

Because of inherent scatter of the data, results are presented in the form of a band and may be looked upon as separating two regions of the graph: (a) "vulnerability" above and (b) "safety" below. The 0° band is drawn to include about 95% of the available firing data, while the 30° band includes 80% of the data for this angle.

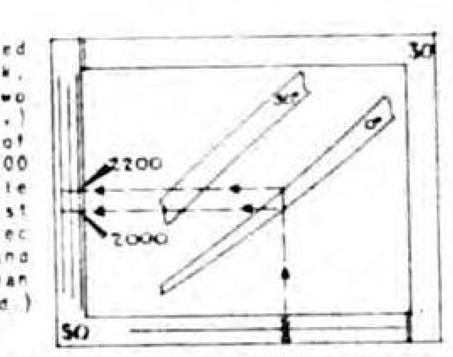
When thin Homogeneous Hard Armor in this Brinell range is used on aircraft, the limit velocity is considerably increased due to the tipping effect of the skin of the plane. The increase may amount to several hundred feet per second if the bullet is in a sidewise position when striking the armor.

EXAMPLES:

A Given a Cal .50 M2 AP projectile striking at 0° with a velocity of 2200 ft/sec, two values of plate thickness about 5/8 in. and 3/4 in. are read by following the line to each of the two borders of the band. It is reasonable to assume that plate thicknesses greater than 3/4 in. will be safe against the projectile, while thicknesses less than 5/8 in. will be vulnerable.



B Similarly, for same projectile fired normally at a plate 5/8 in. thick, two values of striking velocity (or two pairs of range values, depending on M.V.) result by reading to the two borders of the band, namely about 2000 & 2200 ft/sec or 700 and 520 yd. or 760 and 580 yd. The plate referred to is likely to be safe against striking velocities less than 2000 ft/sec (ranges greater than 700 or 760 yd.) and vulnerable to velocities greater than 2200 ft/sec (ranges less than 520 or 580 yd.)



BASED ON DATA FROM THE NAVAL RESEARCH LABORATORY, U.S. NAVAL PROVING GROUND, BALLISTIC RESEARCH LABORATORY, AND WATERTOWN ARSENAL

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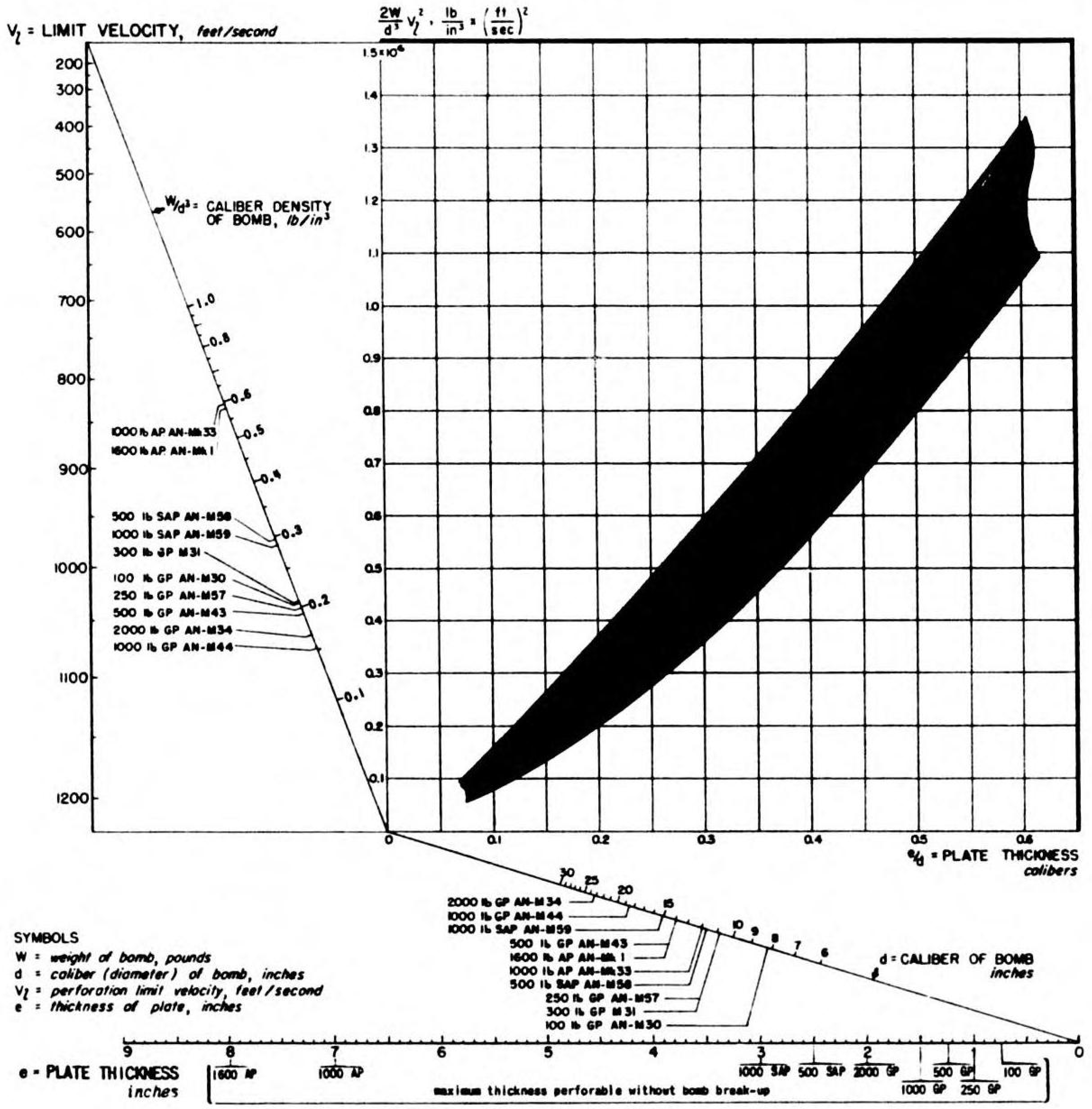
WEAPON DATA

2 C 5* PERFORATION OF ARMOR: BOMBS

PERFORATION OF HOMOGENEOUS ARMOR BY BOMBS



SYMBOLS
W = *weight of bomb, pounds*
d = *caliber (diameter) of bomb, inches*
V_l = *perforation limit velocity, feet/second*
e = *thickness of plate, inches*

The graph gives the relation between the striking velocity of a bomb and the thickness of homogeneous armor which it will perforate. Due to inherent scatter of the data, the relationship is represented in the form of a band, and strikes at obliquities from 0° to 30° are included in it.

EXAMPLE: Given a 1000-lb AN-Mk33 AP bomb striking with a velocity of 800 ft/sec; it can be expected to remain intact and to have a perforation limit thickness of 4½ to 6 inches of armor.

SOURCE:
Bureau of Ordnance, U.S.N., Sketch No. 124400 revision B and Woolwich Bomb Report A4700, Research Dept, Woolwich, England

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* Revision of Data Sheet 2 C5, dated July 1944

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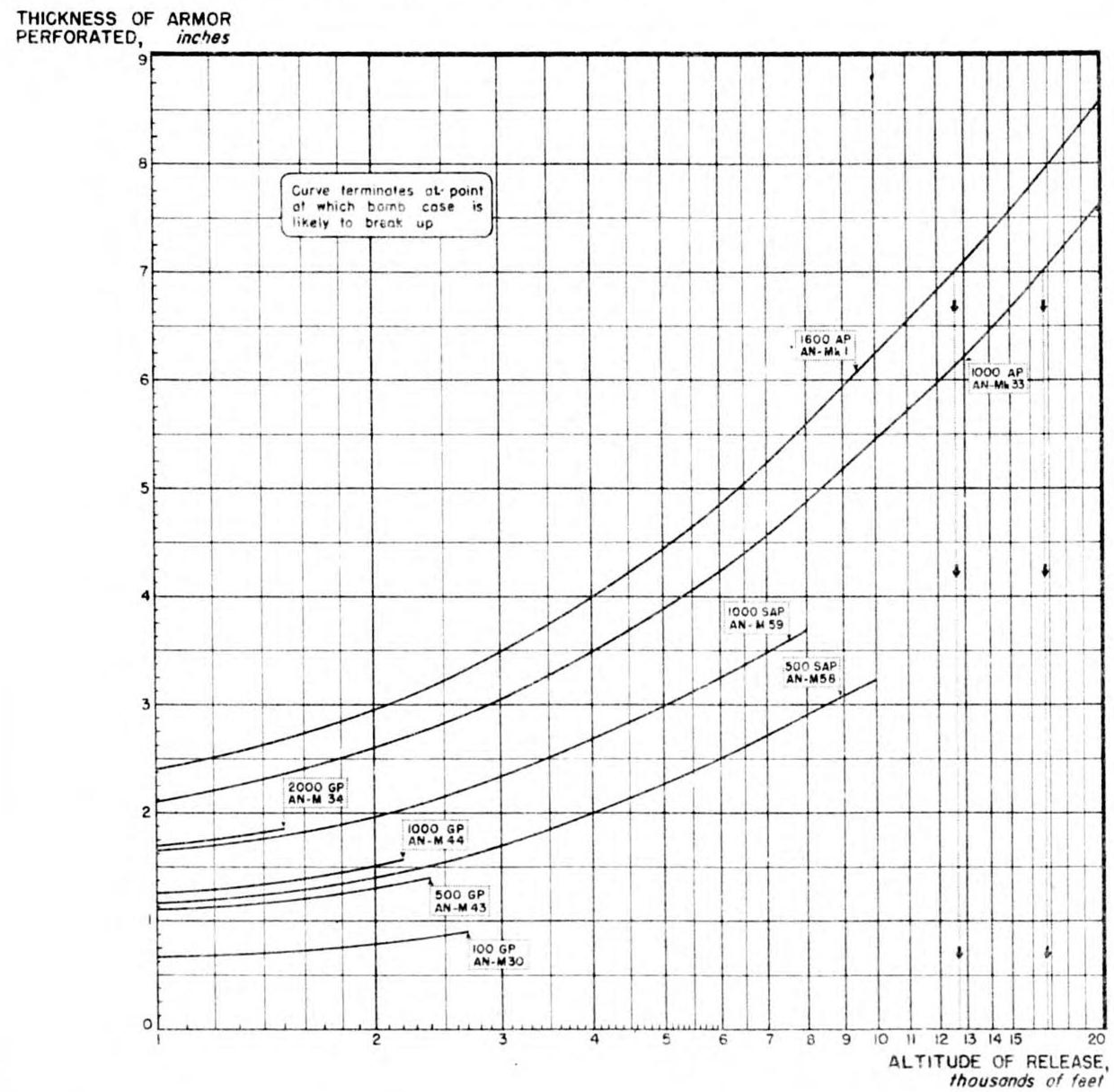
WEAPON DATA

2 C5a PERFORATION OF ARMOR: BOMBS

PERFORATION OF HOMOGENEOUS ARMOR BY BOMBS

CURVES FOR INDIVIDUAL BOMBS BASED ON DATA SHEET 2-C5



The curves give the thickness of homogeneous armor, in a horizontal position, perforated by a bomb released from a plane in horizontal flight at a ground speed of 200 to 300 m.p.h.

EXAMPLE: The dotted line indicates that in order to perforate 7 inches of armor the 1000-lb. AP bomb should be released above 17,000 feet and the 1600-lb. AP bomb at an altitude above 12,500 feet. All other bombs are likely to break up on striking armor of this thickness.

ACCURACY: Values read from the curves are estimated to be accurate to within 15%.

SOURCE: "Selection of Bombs and Fuses to be Used Against Various Targets", OpNav-16-V # A6, Office of the Chief of Naval Operations, and Woolwich Bomb Report A4700, Research Dept., Woolwich, England

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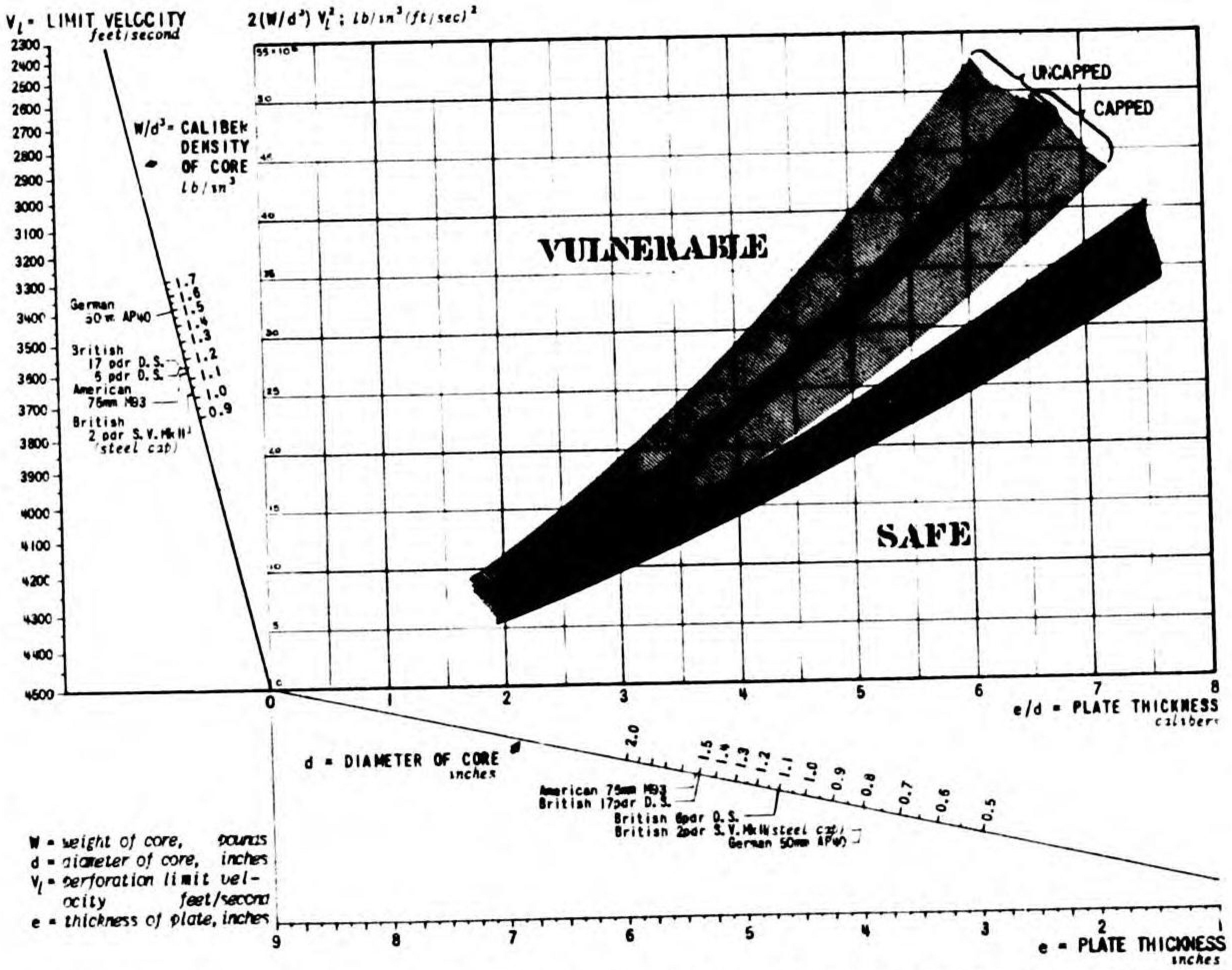
WEAPON DATA

2 C6 ARMOR PERFORATION

PERFORATION OF HOMOGENEOUS ARMOR BY TUNGSTEN CARBIDE CORED PROJECTILES

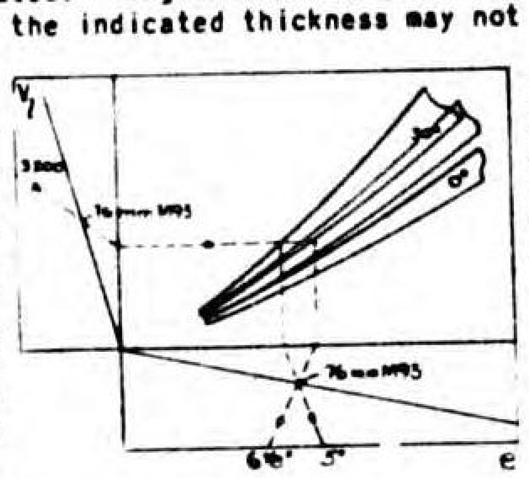


The chart shows the way in which limit velocity for complete perforation is related to thickness of homogeneous armor (BHN 220-330) perforated by capped and uncapped tungsten carbide cored projectiles striking at normal incidence and at 30° to the normal. The data represent projectiles having cores ranging from 0.65 to 1.52 inches in diameter. Indicated on the nomogram scales are projectiles with cores standardized for field use.

Because of inherent scatter of firing data, results are presented as bands. For each obliquity, the band was drawn to include 90% of the points. Capped and uncapped projectiles at 0° scatter randomly through the band; at 30° there is an evident separation as indicated. Tungsten carbide cores usually break up on impact. If there is complete disintegration of the core, perforation of the indicated thickness may not be attained.

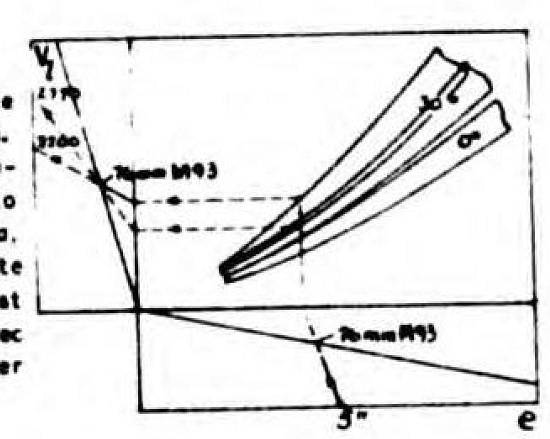
EXAMPLE A

Given an uncapped American 76 mm M93 projectile striking at 30° with a velocity of 3200 ft/sec, two values of plate thickness, about 5 inches and $6\frac{1}{8}$ inches, are read by following the line to each of the two borders of the band. It is reasonable to assume that plate thicknesses greater than $6\frac{1}{8}$ inches will be safe against this projectile, while thicknesses less than 5 inches will be vulnerable.



EXAMPLE B

Similarly, for the same projectile (see Example A) fired at a plate about 5 in. thick, two values of the striking velocity are read by following the line to each of the two borders of the band, namely 3200 and 2770 ft/sec. The plate referred to is likely to be safe against striking velocities less than 2770 ft/sec and vulnerable to velocities greater than 3200 ft/sec.



SOURCE: Based on experiments by American, British and Canadian military establishments.

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WEAPON DATA

2 C7 PERFORATION OF ARMOR: GERMAN PROJECTILES

PERFORATION OF HOMOGENEOUS ARMOR BY GERMAN PROJECTILES

GUN Cal. mm	GUN Model	PROJECTILE Type	PROJECTILE Weight pounds	PROJECTILE M.V. f/s	THICKNESS OF HOMOGENEOUS ARMOR PERFORATED, inches at RANGES, yards: 100	200	250	300	400	500	600	750	800	1000	1250	1500	2000	2500	Angle
20	KwK 30 KwK 38 KwK 38	APshell AP40	0.327 0.223	2625 3270	1.9 2.2	1.7 2.1		1.6 1.9	1.5 1.7										0°
28/20	SPzB41	AP41	0.287	4580	3.7	3.3		3.1	2.8	2.6	2.4		1.9						0°
42/28	Pak 41	AP41	0.79	4600		4.5				3.7		3.2		2.7					0°
37	KwK Pak(t) Pak(t)	APshell AP40	1.68 0.79	2500 3380	3.1	2.2 2.8		2.6	2.0 2.3	1.9	1.8								0°
47	Flak37 Pak(t)	AP36	3.64	2540	4.2	4.0			3.7		3.5		3.3	3.0 2.6		2.2			0°
50	KwK Pak 38 Pak 38 KwK	AP40 AP40 APC APC	1.95 1.95 4.54 4.54	3440 3930 2700 2240			4.6 5.6 3.5 2.6			3.9 4.7 3.1 2.3		3.2 3.9 2.7 2.1		3.3 2.4 1.8 5.9	2.8 2.1 1.5	1.9 1.4 5.3	4.6		0°
75/55	Pak 41	AP41		4123						6.7				6.7		5.7	4.8	4.1	0°
75	KwK 42 Pak 40 KwK 42	AP40 AP40 APCBC	10 9 15	3674 3250 3068			7.1			7.8 6.7 5.9		6.3		6.0 5.2	5.6	5.3 4.7	4.6 4.1	3.6	0°
76.2	Pak 36 Pak 36(r) Pak 36	AP40 APC APCBC/HE	9.25 16.7 14.33	2800 2430 2200		3.7 3.4			3.4 3.2	4.6	3.2 3.0		2.9 2.9	2.7 4.1 2.7	2.6	3.6 2.4	3.1	2.8	0°
88	Flak 41 Flak 41 Flak 36 Pak 43 Pak 43	AP40 APCBC APCBC APCBC AP40/43	16.1 22.45 21 22 16	3775 3400 2600 3280 3775						10.0 7.3 5.1				8.7 6.9 4.7 6.5		7.6 6.4 4.3 6.0	6.6 6.0 3.9 5.6	5.7 5.6 3.5	0°
105	Flak38-39 K 18 K 18 L FH 18 L FH 18	APC APCBC APCBC APCBC APCBC	57.4 34.62	2700 2370 1540 1280			6.7 5.8 3.4 2.7			6.5 5.6 3.3 2.6		6.2 5.3 3.1 2.6		6.0 5.1 3.0 2.5	5.8 4.9 2.9 2.4	5.6 4.8 2.8 2.3			0°
20	KwK 30 KwK 38 KwK 38	APshell AP40	0.327 0.223	2625 3270	1.2 1.9	1.1 1.8		1.1 1.6	1.0 1.5										30°
28/20	SPzB41	AP41	0.287	4580	2.7	2.6		2.4	2.2	2.1	1.9		1.6						30°
42/28	Pak 41	AP41	0.79	4600		3.7				3.0				2.2					30°
37	KwK Pak(t) Pak(t)	APshell AP40	1.68 0.79	2500 3380	2.7	1.7 2.4		2.2	1.5 1.9	1.4	1.3								30°
47	Flak 37 Pak(t)	AP36	3.64	2540										1.7	1.3				30°
50	KwK Pak 38 Pak 38 KwK	AP40 AP40 APC APC	1.95 1.95 4.54 4.54	3440 3930 2700 2240			3.3 4.3 2.6 2.1			2.6 3.4 2.4 1.9		2.1 2.7 2.3 1.7		2.2 2.0 1.5 5.1	1.7 1.8 1.4	1.6 1.2 4.5		3.9	30°
75/55	Pak 41	AP41		4123						5.8				4.8		3.9	3.2	2.6	30°
75	KwK 42 Pak 40 KwK 42	AP40 AP40 APCBC	10 9 15	3674 3250 3068	5.7					6.1 5.0 4.8				4.0 4.3		3.9	3.5	3.1	30°
76.2	Pak 36 Pak 36(r) Pak 36	AP40 APC APCBC/HE	9.25 16.7 14.33	2800 2430 2200						3.7				3.2		2.9	2.5	2.2	30°
88	Flak 41 Flak 41 Flak 36 Pak 43 Pak 43	AP40 APCBC APCBC APCBC AP40/43	16.1 22.45 21 22 16	3775 3400 2600 3280 3775	8.0 9.3					7.9 6.3 4.3				6.5 5.9 4.1 6.5 7.6		5.4 5.5 3.7 5.8 6.7	4.4 5.1 3.4	3.7 4.8 3.2	30°
105	Flak38-39 K 18 K 18 L FH 18 L FH 18	APC APCBC APCBC APCBC APCBC	57.4 34.62	2700 2370 1540 1280			5.7 4.9 2.9 2.3			5.5 4.7 2.7 2.2		5.3 4.5 2.6 2.1		5.5 5.1 4.4 2.5 2.1	4.9 4.2 2.4 2.0	5.1 4.8 4.0 2.3 1.9	4.7 4.4 3.7 2.1 1.9		30°

The table gives the thickness of homogeneous armor (BHN from about 250 to 325) that is likely to be perforated at various ranges by German armor piercing projectiles. Data are given for striking angles of 0° and 30° (angle measured from line perpendicular to plate). Perforation values in most cases are estimates based either on actual firing data or on extrapolation of results of trials with other projectiles. It should be noted that the tapered bore guns and the tungsten carbide projectiles (AP40 and AP41) have only been in very limited production.

ABBREVIATIONS:

Projectiles-
- AP Armor Piercing
- APC Armor Piercing Capped
- APCBC Armor Piercing Capped with Ballistic Cap
- AP 40 Armor Piercing with Carbide Core
- AP 41 Armor Piercing used in tapered bore gun

Guns-
- KwK Tank Mounted gun
- Flak Anti-aircraft gun
- Pak Anti-tank gun
- Pak(t) Anti-tank gun (Czech)
- Pak(r) Anti-tank gun (Russian)
- FK 36 Field gun
- S Pz B41 Heavy anti-tank gun
- L FH 18 Light Field Howitzer
- K 18 Medium gun

SOURCE: "Tactical and Technical Trends", No. 17; Catalog of Enemy Ordnance Materiel, Office of Chief of Ordnance, U.S.A.; Proc. of the Ord. Bd. (Brit)

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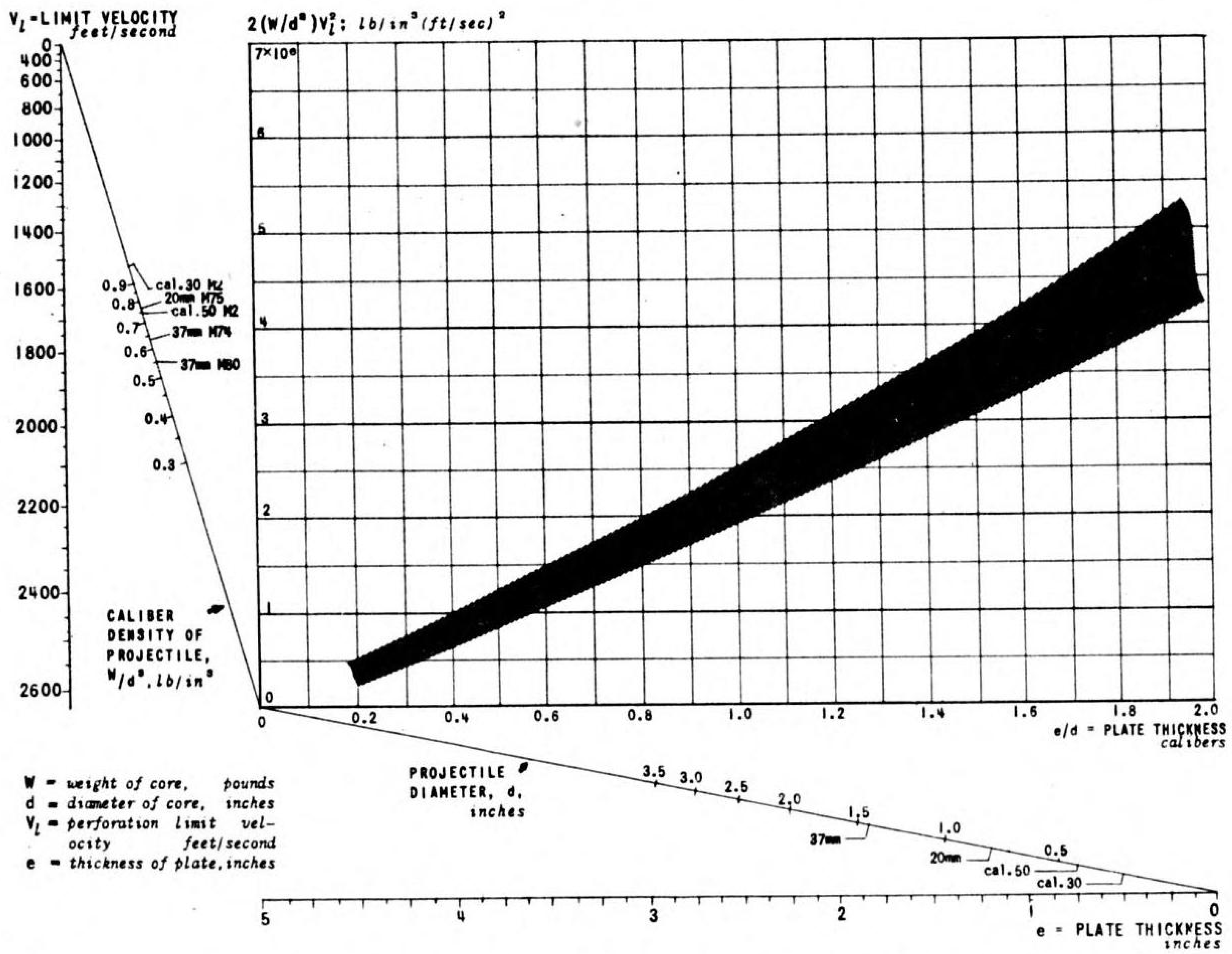
WEAPON DATA

2 C 8
MILD STEEL
PERFORATION

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

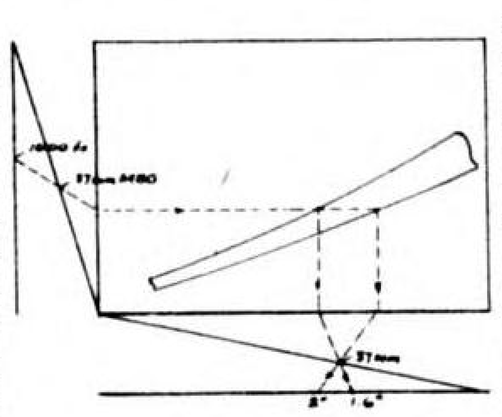


The graph shows the relation between perforation limit velocity and thickness of plate perforated. The limit velocity concerned is that at which the projectile just passes completely through the plate (Navy limit). The data represent armor piercing (AP) uncapped projectiles ranging from 0.30 inches to 1.45 inches, and caliber 0.30 and caliber 0.50 jacketed projectiles fired against mild steel armor BHN 100 - 150 at normal incidence.

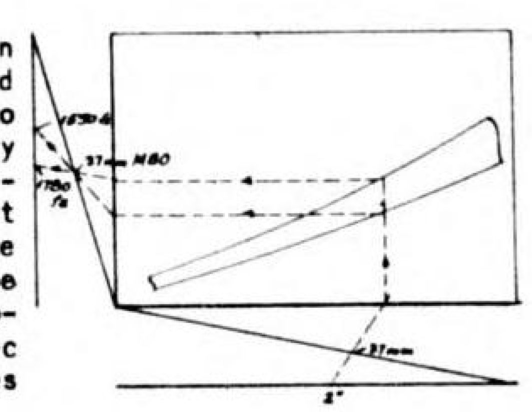
Because of inherent scatter of data, the results are presented in the form of a band. The band, therefore, may be looked upon as separating two regions of the graph, corresponding to vulnerability (above) and safety (below).

EXAMPLES:

A Given a 37mm M80 projectile striking with a velocity of 1600 ft./sec., two values of plate thickness about 1.6 in. and 2 inches, are read by following the line to each of the two borders of the band. It is reasonable to assume that plate thicknesses greater than 2 inches will be safe against the given projectile, while thicknesses less than 1.6 inches will be vulnerable.



B Similarly, for the given projectile (example A) fired at a plate 2 inches thick, two values of the striking velocity result by reading the two borders of the band, namely about 1550 and 1780 ft/sec. The plate referred to is likely to be safe against striking velocities less than 1550 ft/sec and vulnerable to velocities greater than 1780 ft/sec.



SOURCE:

Graph includes data from the Naval Research Laboratory, Bellevue, D. C., and the National Defense Research Committee, Princeton University.

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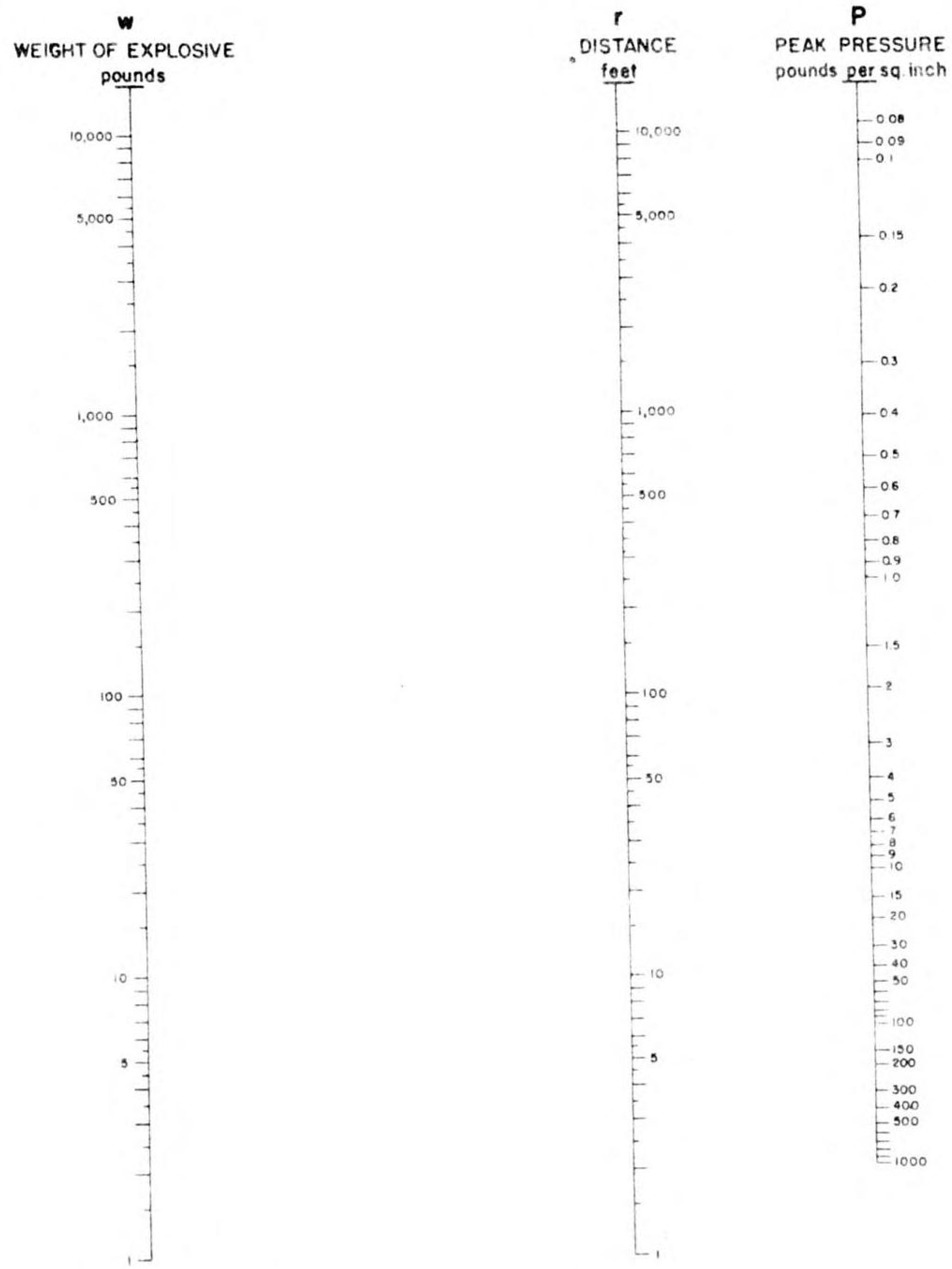
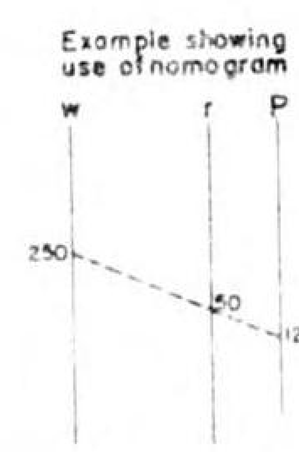
WEAPON DATA

3 A 1
PRESSURE

PEAK BLAST PRESSURE AS A FUNCTION OF DISTANCE AND WEIGHT OF EXPLOSIVE





VALUES INDICATED ARE ESTIMATED ACCURATE TO ABOUT 25 PERCENT AND ARE AVERAGES OF A LARGE NUMBER OF MEASUREMENTS ON ALL TYPES OF BOMBS AND EXPLOSIVES

Note: Readings taken with the gauge "side-on" to the blast wave; for "face-on" gauge, pressure values should be approximately doubled.

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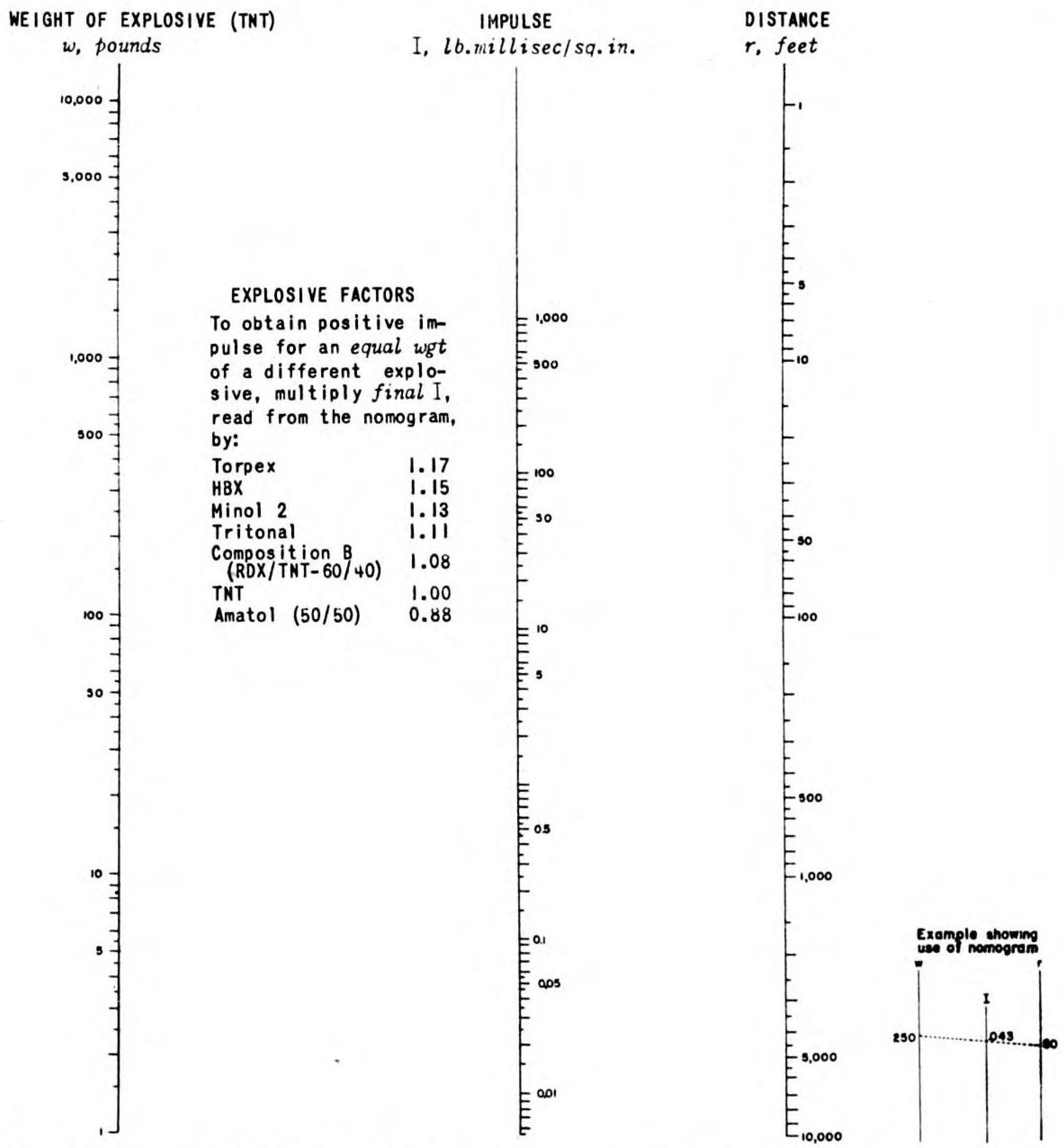
WEAPON DATA

3A2* POSITIVE IMPULSE

POSITIVE IMPULSE AS A FUNCTION OF DISTANCE AND WEIGHT OF EXPLOSIVE

FOR TNT FILLED GENERAL PURPOSE BOMBS



EXPLOSIVE FACTORS

To obtain positive impulse for an *equal wgt* of a different explosive, multiply *final* I, read from the nomogram, by:

Torpex	1.17
HBX	1.15
Minol 2	1.13
Tritonal	1.11
Composition B (RDX/TNT-60/40)	1.08
TNT	1.00
Amatol (50/50)	0.88

This sheet gives values of the positive impulse resulting from detonation of TNT-filled General Purpose (GP) bombs at ground level. Results refer to gauges placed *side-on* to the blast wave.

The nomogram represents the empirical relation $I = \frac{54\, w^{2/3}}{r}$

Where I is the positive impulse (lb-millisec/in²), based on pressure in excess of atmospheric, *r* is the distance from the explosion (ft) and *w* is the charge weight (lb). The constant in this equation is an average for American GP bombs. For other explosives, multiply final I, read from nomogram, by factors given in table; for other case weights (bomb types) use sheet 3A2a.

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WEAPON DATA

3A2a POSITIVE BLAST IMPULSE

BLAST IMPULSE DUE TO DETONATION OF BOMBS AT GROUND LEVEL

This sheet gives information on the magnitude of the positive air blast impulse resulting from detonation of bombs near the ground. Impulse values are based on readings of gauges placed *side-on* to the advancing blast wave.

The table gives a selection of impulse values for American bombs.

BLAST IMPULSE FROM PARTICULAR BOMBS: Positive Impulse per Unit Area, *lb-msec/in²*

	BOMB	FILLING	DISTANCE, *feet*														
			20	30	40	50	60	70	80	90	100	200	300	400	500	750	1000
	100-lb AN-M30	TNT	42	28	21	17	14	12	10	9.2	8.3	4.2	2.8	2.1	1.7	1.1	0.8
		Tritona	49	33	25	20	16	14	12	11	9.8	4.9	3.3	2.5	2.0	1.3	1.0
	250-lb AN-M57	TNT	69	46	35	28	23	20	17	15	14	6.9	4.6	3.5	2.8	1.9	1.4
		Tritonal	82	55	41	33	27	23	21	18	16	8.2	5.5	4.1	3.3	2.2	1.6
GP	500-lb AN-M43, M64	TNT	117	78	58	47	39	33	29	26	23	12	7.8	5.8	4.7	3.1	2.3
		Comp.B	128	85	64	51	43	37	32	28	26	13	8.5	6.4	5.1	3.4	2.6
		Tritonal	138	92	69	55	46	40	35	31	28	14	9.2	6.9	5.5	3.7	2.8
	1000-lb AN-M44, M65	TNT			90	72	60	51	45	40	36	18	12	9.0	7.2	4.8	3.6
		Comp.B			101	81	67	58	50	45	40	20	13	10	8.1	5.4	4.0
		Tritonal			106	85	71	61	53	47	42	21	14	11	8.5	5.7	4.2
	2000-lb AN-M34, M66	TNT				119	99	85	75	66	60	30	20	15	12	8.0	6.0
		Comp.B				130	109	93	81	72	65	33	22	16	13	8.7	6.5
		Tritonal				141	118	101	88	78	71	35	24	18	14	9.4	7.1
LC	4000-lb AN-M56	TNT						205	180	160	144	72	48	36	29	19	14
		Comp.B						225	197	175	158	79	52	39	32	21	16
		Tritonal						243	212	189	170	85	57	42	34	23	17
SAP	500-lb AN-M56	TNT		43	32	26	21	18	16	14	13	6.4	4.3	3.2	2.6	1.7	1.3
	1000-lb AN-M59	TNT			49	40	33	28	25	22	20	10	6.6	4.9	4.0	2.6	2.0

Accuracy: It is estimated that the mean of a large number of tests will fall within 5% of the corresponding tabulated value.

The positive impulse in air due to detonation of an explosive charge on the surface of the ground is given by

$$I = E\, e^{S} \left(\frac{w^{2/3}}{r}\right);$$

where: I = Positive impulse per unit area, *lb-millisec/in²*.
w = Weight of explosive, *pounds*.
r = Distance from explosion, *ft*.
E = Explosive factor (values listed below).
S = Equivalent cylinder charge/weight ratio
e = 2.718... = base of natural logarithms.

The *equivalent cylinder charge/weight ratio*, S, is the ratio of the weight of charge to the total weight of an equivalent cylindrical bomb. An equivalent cylindrical bomb is defined to be one with the same weight of explosive as the actual bomb, enclosed in a cylindrical shell of the same material and with the same internal diameter and internal volume, closed at the ends, the thickness of the shell and ends being equal to the sidewall thickness of the actual bomb. S is given approximately by

$$S = \frac{1}{1 + 4\frac{t\rho_m}{D\rho_x}\left[1 + \frac{\pi\rho_x}{8\, w/D^3}\right]}$$

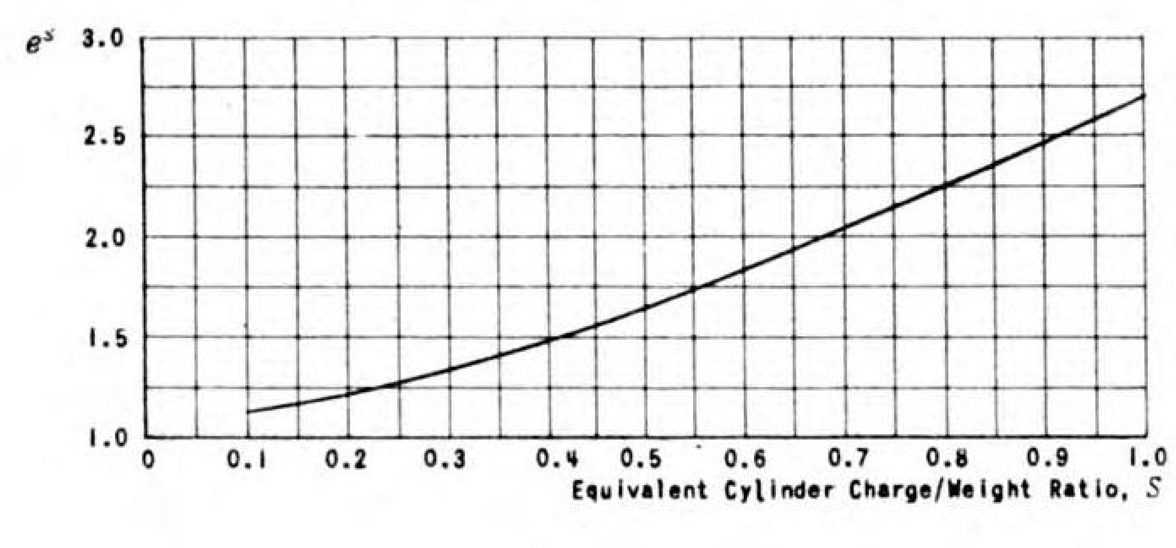
; for steel cased bombs filled TNT or Tritonal this becomes.......

$$S = \frac{1}{1 + \left[19 + \frac{0.44}{w/D^3}\right]\frac{t}{D}}$$

where: t = Bomb case thickness, *inches*.
D = Inside diameter of bomb body, *inches*.
ρ_m = Density of case material, *lb/in³*
ρ_x = Density of explosive filling, *lb/in³*

EXPLOSIVE FACTOR, E		E × e *
Torpex	35	94
HBX	34	92
Minol	33	90
Tritonal	33	89
Comp.B (RDX/TNT, 60/40)	32	86
TNT	29	80
Amatol	26	70

* For uncased charges, where: $S = 1$ and $I = E \times e \times \left(\frac{w^{2/3}}{r}\right)$



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Ref: AES-4, p51, (OSRD-4356)
AES-7, p9, (OSRD-4754)
August 1945

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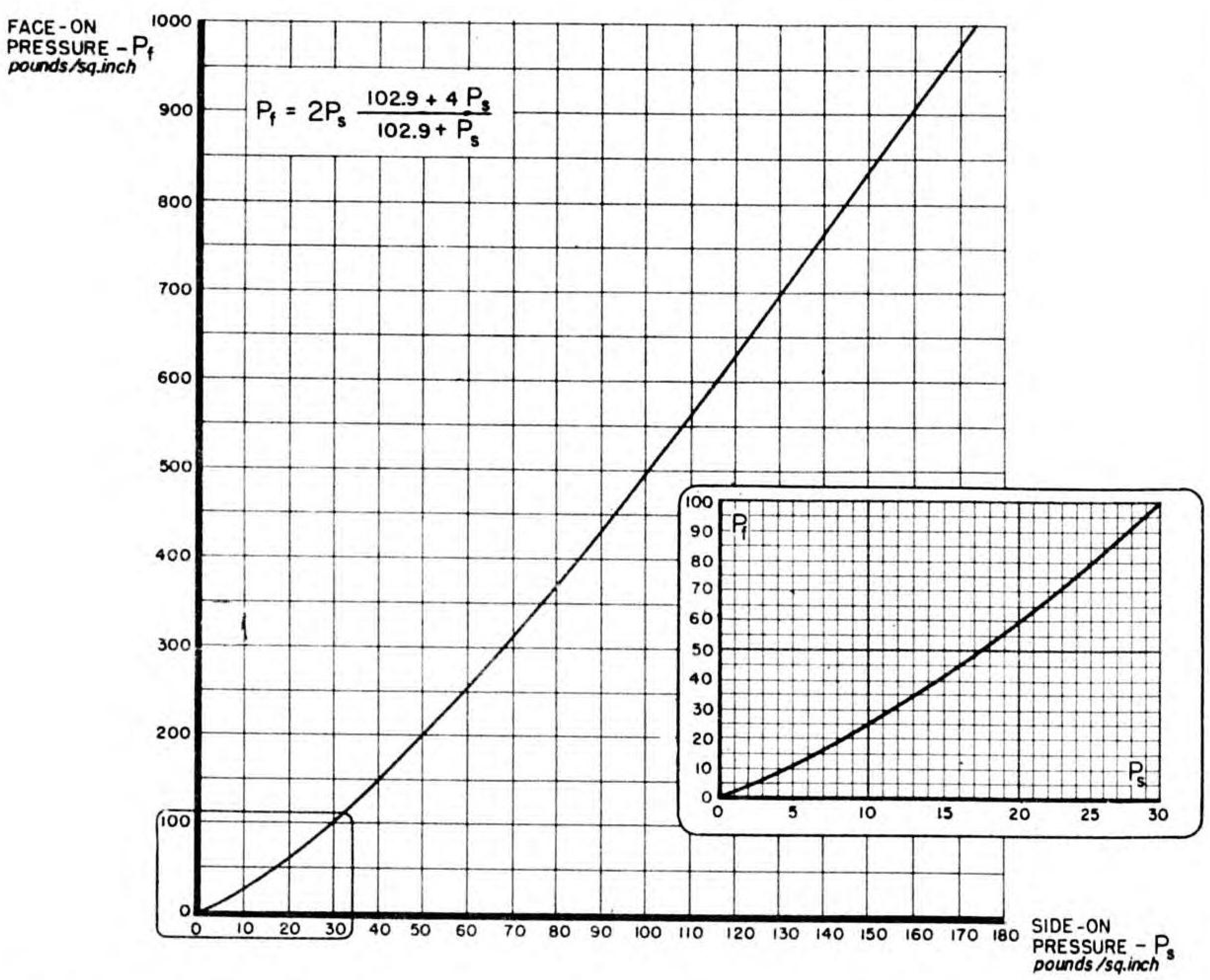
WEAPON DATA

3 A3 SIDE-ON *versus* FACE-ON

SIDE-ON AND FACE-ON BLAST PRESSURES IN AIR



The graph gives the relation between face-on pressure, P_f, recorded by a gauge fixed in an infinite rigid wall facing the blast, and side-on pressure, P_s, measured by a gauge whose face is parallel to the direction of motion of the blast wave.

All pressures indicated are in excess of atmospheric pressure.

This relationship is deduced from the Rankine-Hugoniot equations, assuming the incident blast wave to have a flat top. However, the curve will give the relation between the initial parts of the pressure-time curve obtained from an explosion, where P_s is initial peak pressure in the oncoming wave (as given by a gauge side-on) and P_f is initial peak in the wave reflected from any finite object such as a gauge alone.

If a side-on gauge were placed in front of an actual wall (i.e., one of finite extent and rigidity), and if another were set face-on in the wall, then the above relation would apply accurately to the initial phases of the blast pressure record obtained. However, if this relation were applied to the entire pressure-time curve it would predict face-on pressures that are too high at later stages of the record. The reason for the deviation is that the above formula does not consider any motion of the wall or diffraction of the wave around it.

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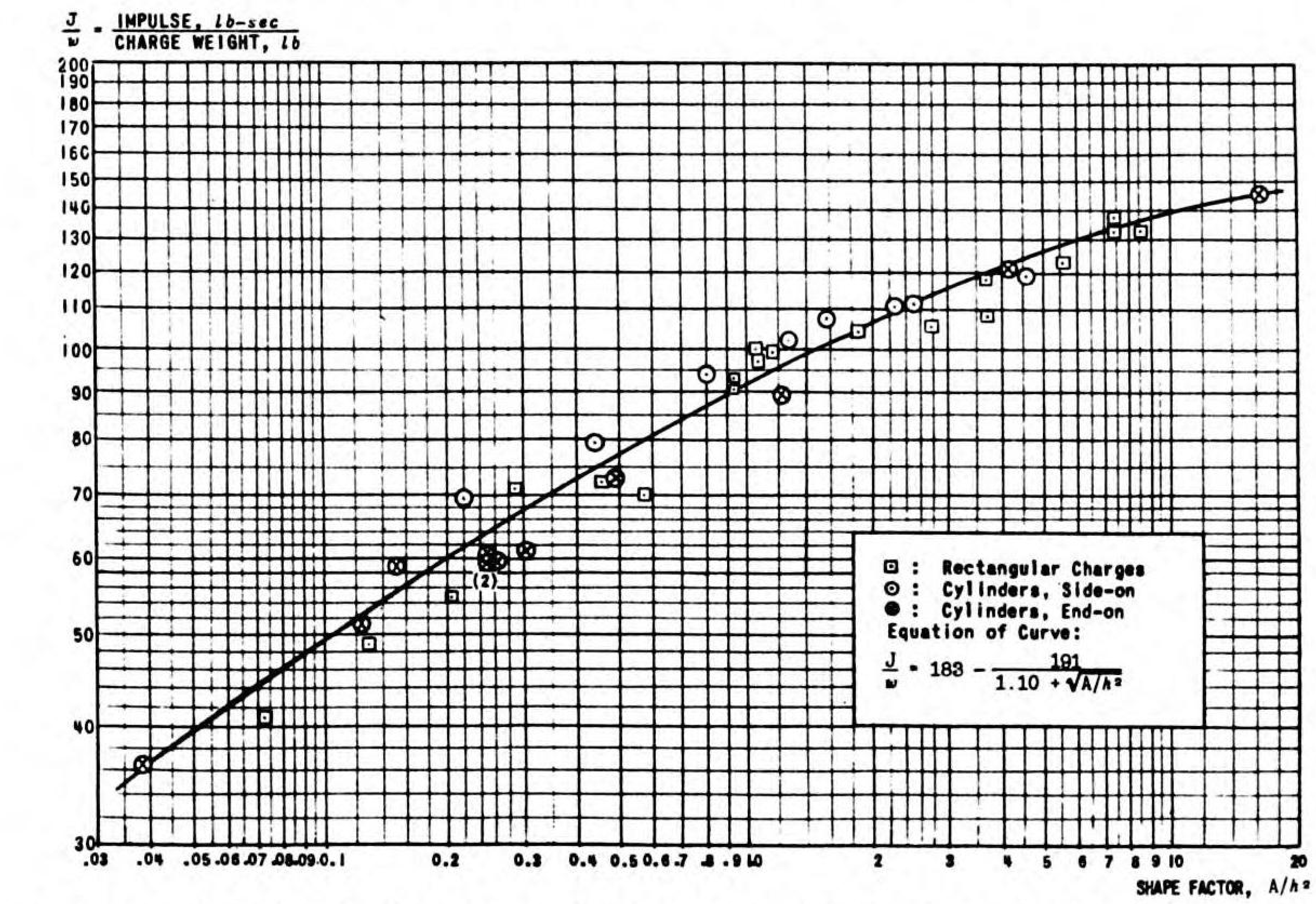
WEAPON DATA

3 A4 IMPULSE: CONTACT EXPLOSIONS

IMPULSE DELIVERED TO A PLANE SLAB BY A CONTACT EXPLOSION



The graph gives the total impulse delivered to an extended plane slab by detonation of a rectangular or cylindrical TNT charge in contact with it. For charges having either of the above forms, the impulse per unit weight can be correlated with the Shape Factor, A/h^2, given by the plan area of the charge divided by the square of its greatest measurement perpendicular to the slab (see sketches).

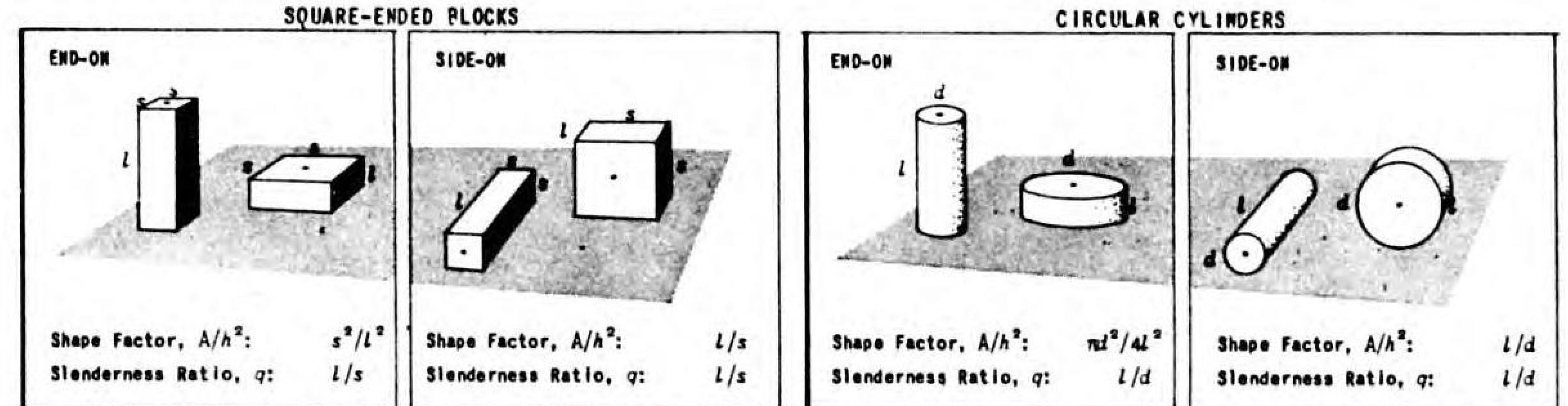
Measurements were made by means of the impulse pendulum (see source reference). Charges used in the tests varied in weight from ¼ to 2-lb, most weights being either ½ or 1-lb. Approximately 75% of the measured impulse values lie within ±8% of the empirical curve, which has the equation given in the graph above, where J is the impulse delivered to the plane slab *(lb-sec)*, *w* is the weight of charge *(lb)*, A is the plan area of the charge and *h* is the maximum extension of charge perpendicular to the slab. *All linear dimensions are measured in the same unit.* A brief series of tests indicates that the values of J/w given by the above relation for TNT should be multiplied by the following factors for other explosives: Tetryl 1.6: HBX-2, Minol-2, Comp.C-3 1.2; Pentolite, Comp.B, Tetrytol, Tritonal, cast TNT 1.1; Amatol 0.85.

For a charge having the form of a circular cylinder or a *square-ended* rectangular block, the ratio of the impulse delivered when the charge is placed *side-on* to the slab to that with the charge set *end-on* is given simply by

$$\frac{J_{side\text{-}on}}{J_{end\text{-}on}} = \frac{2}{3}\left(q + \frac{1}{2}\right)$$

Here q is the *Slenderness Index* of the charge, conveniently taken to be the length/diameter ratio in the case of a cylinder, or the length-to-side ratio for a square ended block (see sketches). The linear relation is a good approximation for q between 1 and 4.

SQUARE-ENDED BLOCKS | CIRCULAR CYLINDERS



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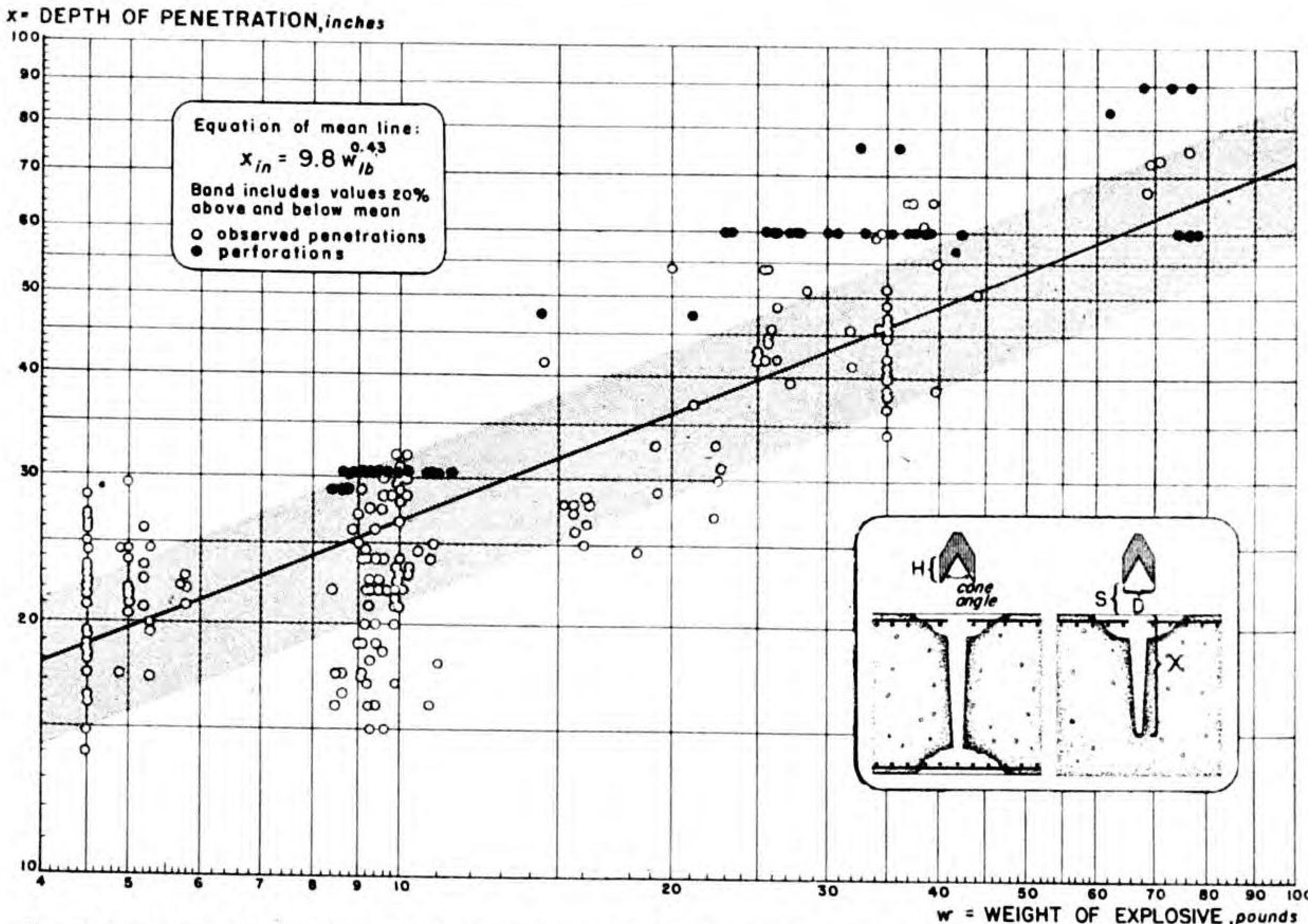
WEAPON DATA

3 A 5
CONE-END CHARGES
CONCRETE

PENETRATION OF CONCRETE BY DETONATION OF CONE-END CHARGES



The graph shows depth of penetration produced in concrete by a cone-end charge placed with axis perpendicular to the slab face. The mean line was determined by a least squares reduction; shaded band includes values 20% above and below mean.

Because of scabbing on rear face (see inset sketches) perforation often results even when slab thickness is greater than the penetration depth that would result in massive concrete.

TYPE OF EXPLOSIVE: Effects are not greatly dependent on explosive type provided charge is thoroughly compact and adequately primed.

BEST -	TNT/RDX	Plastic H.E.	GOOD -	Pentolite	Nobel 808	POOR - 60/40 Amatol
	TNT/PETN	Cyclotol		TNT	Picric Acid	P. A. G.
	TNT/CE	P.E.		Lyddite	Tetrytol	

CONE LINING: Dependence on material and thickness is not great.
Materials. BEST - Pressed steel. Forms large slug which may stick in hole, especially if cone angle is less than about 70°; may thus impair insertion of demolition charge.
GOOD - Glass. Hole somewhat shallower but of larger volume than with steel. Less debris is left in hole. Cast brass and cast manganese bronze also good.
Thickness: Various thicknesses used. Experiments indicate optimum value of about 0.1 inch (steel) for a charge of 6-inch diameter, and weighing approximately 10 lbs.

CONE ANGLE: Not extremely critical, but 60° to 80° usually adopted.

LENGTH-DIAMETER RATIO: Values of H/D (see sketches) between ½ and 1 are recommended.

STAND-OFF DISTANCE: The optimum stand-off, S, appears to be between about ½ and 1½ diameters.

CONCRETE STRENGTH: In general, slightly larger but not deeper holes result in softer concrete.

PILLBOX TESTS: Trials indicate that a 75-lb. charge will defeat a 5-ft. thick pillbox wall and throw scab capable of lethal or incapacitating effects on any occupants.

DATA FROM EXPERIMENTS BY U.S. ENGINEER BOARD AND BY BRITISH MINISTRY OF SUPPLY

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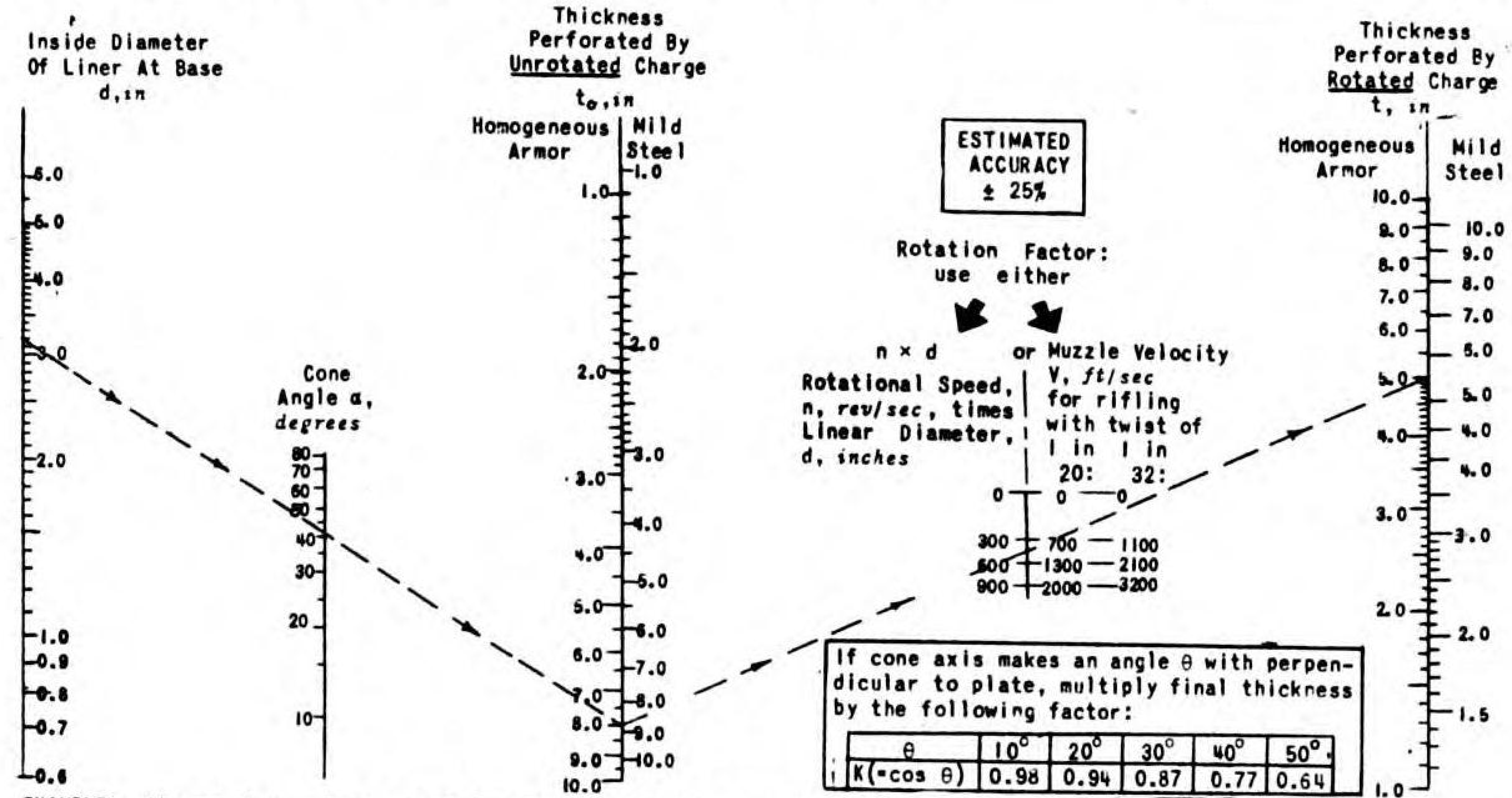
WEAPON DATA

3 A 6
ARMOR PERFORATION BY CONE-END WEAPONS

PERFORATION OF HOMOGENEOUS ARMOR BY WEAPONS WITH CONE-END CHARGES



If cone axis makes an angle θ with perpendicular to plate, multiply final thickness by the following factor:

θ	10°	20°	30°	40°	50°
K(=cos θ)	0.98	0.94	0.87	0.77	0.64

EXAMPLE: At normal incidence, an HEAT 105mm M67 having a muzzle velocity of 950 *ft/sec* and a twist of 1 in 20 will perforate about 5 *in* of armor, as shown by the index lines. At 30°, the performance will be about 5 x 0.87 = 4.3 *in*

The nomogram gives thickness of homogeneous armor perforated by Munroe jets from cone-end hollow charge projected weapons. The underlying empirical equation, deduced from performance records on actual weapons is

$$t = \frac{0.89\, d \cos\theta}{\sin(\alpha/2)} f(nd)$$

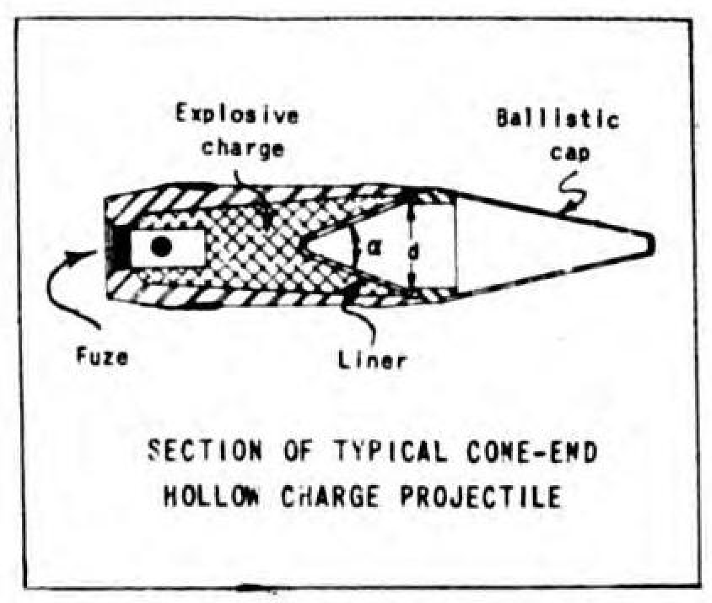
where $f(nd)$ = 1.0, 0.69, 0.57, 0.48, for nd = 0, 300, 600, 900 *r.p.s. x in* respectively. *(see notation on nomogram.)*

Factors such as thickness and material of liner, type and density of explosive, confinement of charge, stand-off distance, etc. are not included in the relation, although changes in these quantities are responsible for some variation in observed results. With the empirical relation used, scatter in the data precludes making a distinction between *depth of penetration* in massive plate and *thickness* of plate *perforated*. Thus the present relation will be useful in estimating performance of any weapon designed according to reasonable practice, but should be considered a rough guide to be used only in the absence of experimental data.

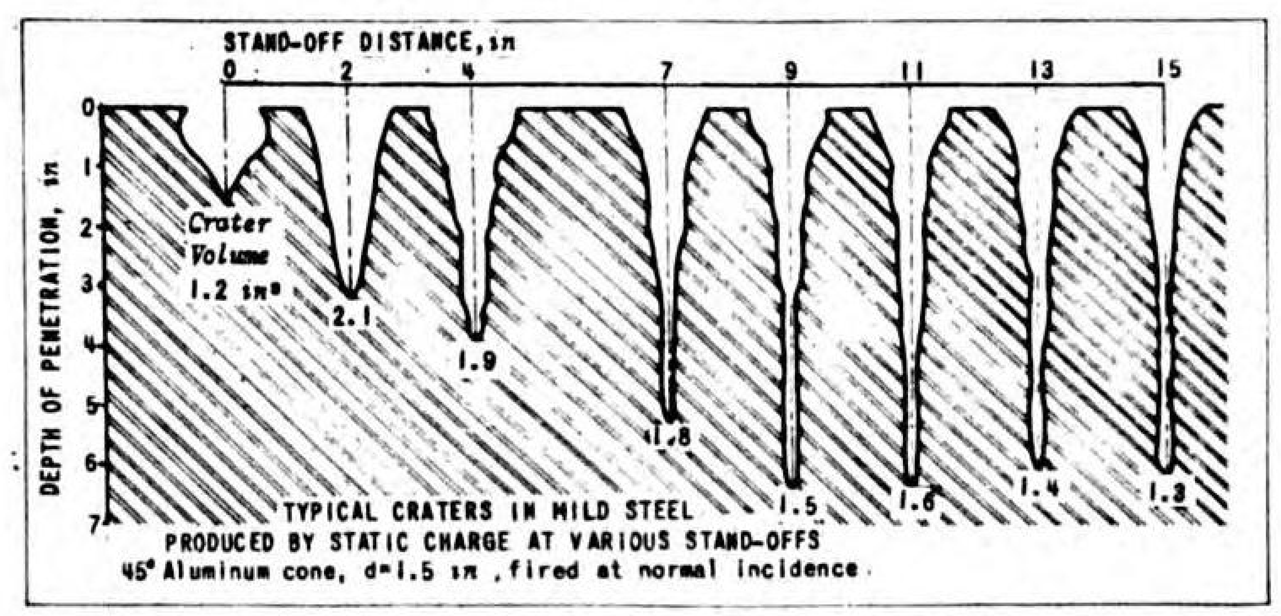
Basic data are mainly for projectiles having steel liners and filled Cyclotol or Pentolite. Explosives combining high power with high rate of detonation give greatest target damage. As the equation above shows, rotated projectiles generally form shallower craters; however, these are likely to be wider than the craters due to static detonation.

PERFORMANCE OF PARTICULAR WEAPONS:

Weapon	Thickness of Armor Perforated, *in* *(normal incidence)*
US - HEAT M6A3(Bazooka)	5.3
Grenade M9A1	4.0
HEAT 57mm T-20 E-2	3
HEAT 75mm M66	3.5
HEAT 105mm M67	4.8
Br - PIAT	3.8
HEAT 3.7-in & 95mm	5.0
Ger- Panzerfaust (30, 60 & 100)	8.0
Panzerschreck (Ger. Bazooka)	6.5
Jap- A.T. Conical Hand Grenade	2.8
A.P. Rifle Grenade	2



SECTION OF TYPICAL CONE-END HOLLOW CHARGE PROJECTILE



TYPICAL CRATERS IN MILD STEEL PRODUCED BY STATIC CHARGE AT VARIOUS STAND-OFFS
45° Aluminum cone, d=1.5 in, fired at normal incidence

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2
Ref: OTB-12f (OSRD-5350f)
August 1945

3A6

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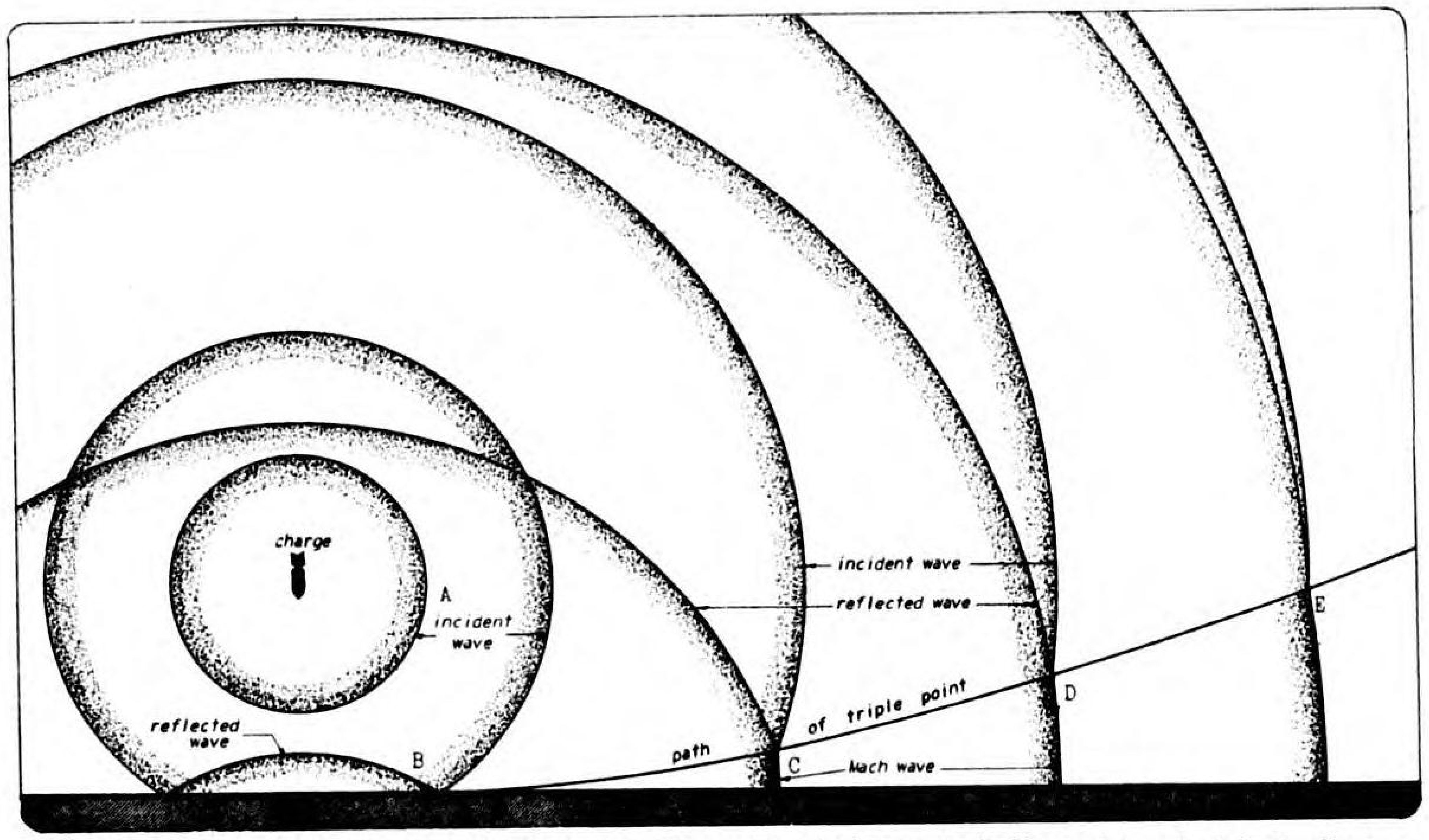
MACH REFLECTION



When a charge is detonated above ground a shock wave will spread out almost spherically as shown at A in the figure above, which is a section in a vertical plane passing through the charge. As this shock wave, called the incident wave, strikes the ground it is reflected and the situation is somewhat as shown at B. If the ground were infinitely rigid and if the shock wave were weak (that is, almost a sound wave) the reflected wave could be constructed by imagining that the ground is replaced by air and an equal charge, the so called image charge, detonating at the same time at an equal distance below the ground and in line with the actual charge. In an actual explosion the reflected wave differs from the one constructed in this manner, primarily because the incident wave is stronger than a sound wave.

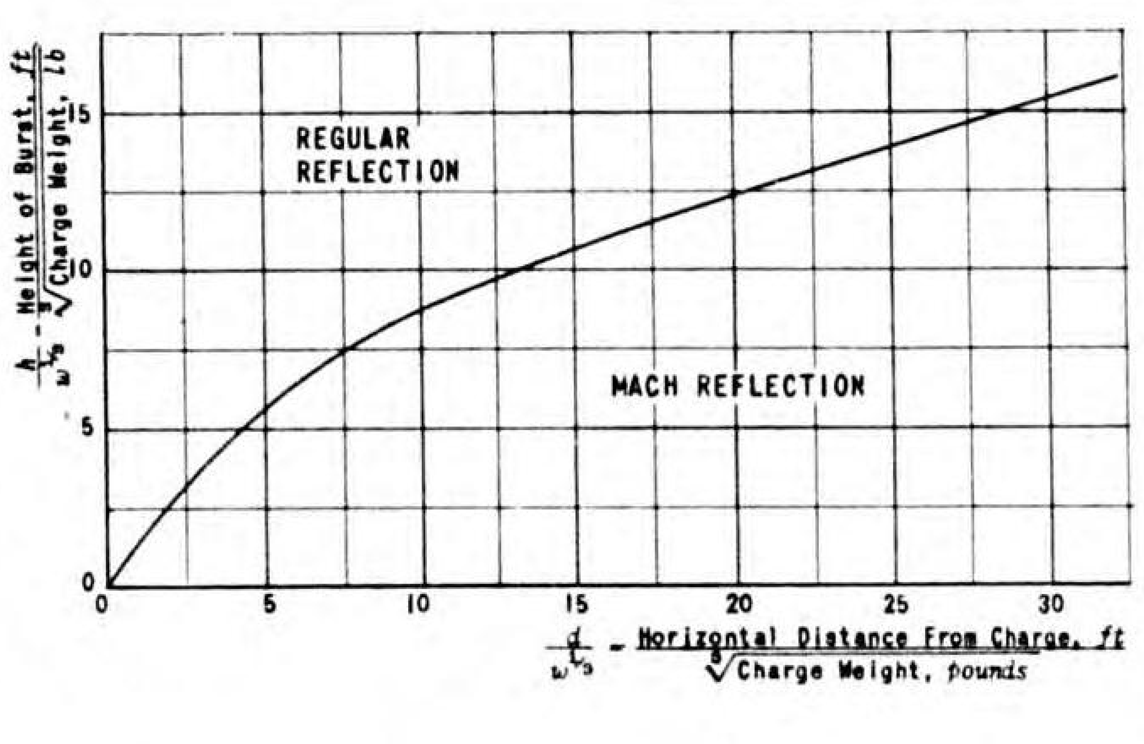
The angle between the normal to the wave front and the normal to the ground surface is called the angle of incidence. It has been found that for each ratio of the pressure in front of the shock wave to that immediately behind the wave front there is a critical angle of incidence beyond which reflection of the type shown at B is impossible. Thus there is some place along the ground where a new type of reflection called *Mach reflection* takes place. A new wave, called the Mach wave, is formed and the situation is as illustrated at C, D and E in the figure. The intersection of the incident wave, the reflected wave, and the Mach wave is called the triple point.

As the phenomenon progresses the Mach wave grows and the triple point describes a curve through the air. This path has been studied in detail experimentally and a typical path is shown in the figure above. Other paths are shown in the lower figure of sheet 3 A8.

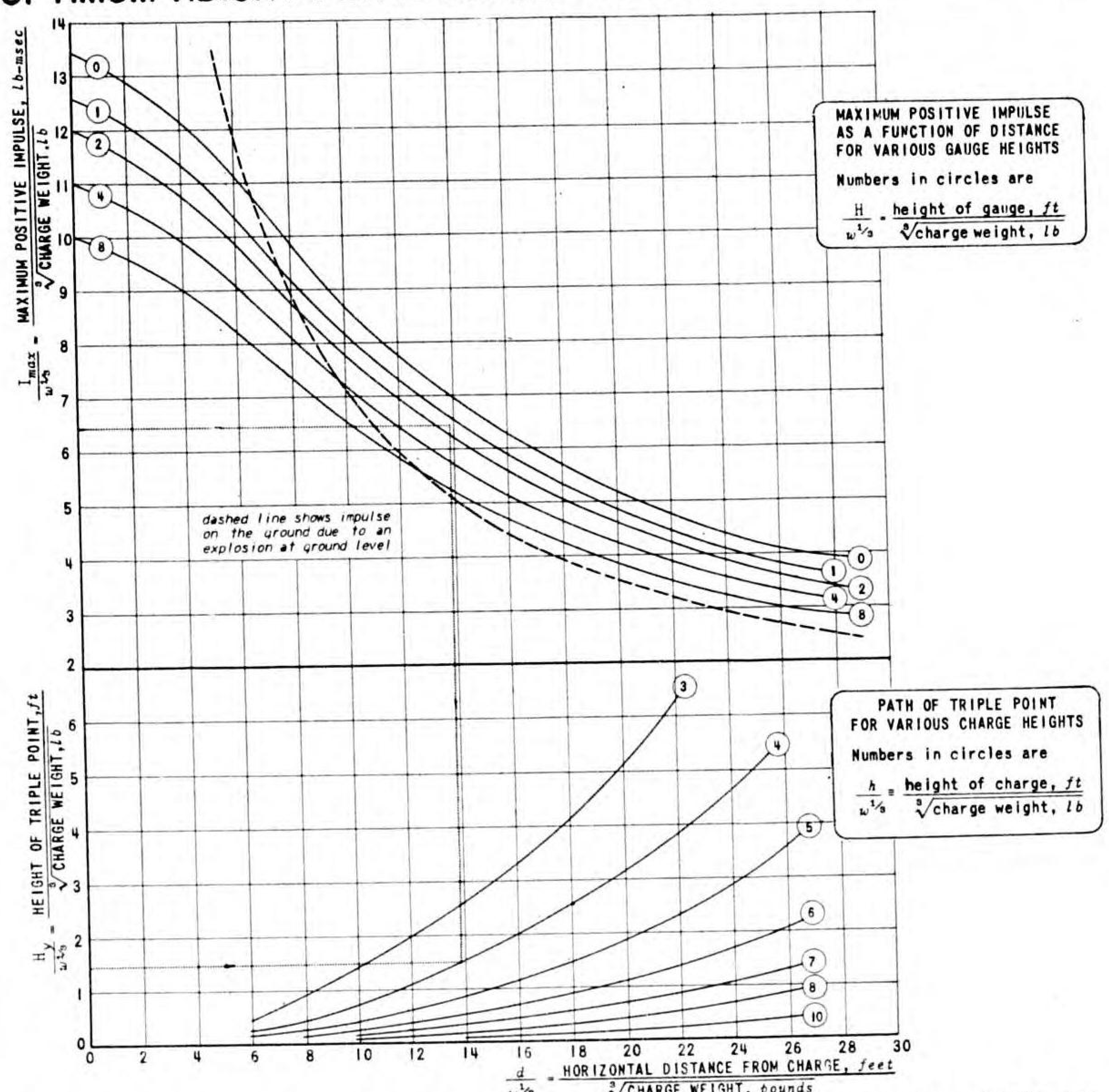
As the Mach wave grows in height it absorbs the incident and reflected waves. Ultimately, at distances very large compared to the height of burst, the whole configuration of shocks becomes approximately a single spherical shock wave intersecting the ground orthogonally.

The pressure and impulse at a point which is a horizontal distance d from the charge & a height H above the ground go through a maximum as the height of burst h of the charge is varied. The height of detonation which maximizes these quantities at a point (d, H) is that which creates a triple point passing approximately through (d, H).

The height of burst which maximizes the pressure and impulse at a point *along the ground* at a horizontal distance d from the charge is the height for which Mach reflection just forms at the point in question. The relation between d and h for beginning of Mach reflection is given in the graph in terms of the scaled variables $d/w^{1/3}$ & $h/w^{1/3}$ where w is the weight of charge.



OPTIMUM HEIGHT FOR MAXIMUM IMPULSE



As the height of detonation of a charge is varied the positive impulse at a fixed horizontal distance d and height above
ground H goes through a maximum whose value is denoted by I_{max}. The values of $I_{max}/w^{1/3}$ as a function of $d/w^{1/3}$ are
plotted in the upper figure for several fixed $H/w^{1/3}$. The height of detonation of the charge which will maximize the im-
pulse at a point (d, H) is the one which will produce a Mach reflection whose triple point passes approximately through the
point (d, H). For convenience the impulse on the ground due to a charge detonated on the ground is also given in this
figure. In the lower figure each curve is a path of the triple point for a fixed value of $h/w^{1/3}$ where h is the height
of detonation of the charge.

The graphs may be used to determine the height of detonation necessary in order to maximize the horizontal distance at
which a given level of impulse is formed at a height H above the ground. For example, suppose that a building 40 feet
high is to be attacked and that a positive impulse of 90 lb-millisec/in^2 is necessary to accomplish the desired damage.
The impulse should have its maximum at half the height of the wall, so the value of H is 20 feet. Assume that a 4000-lb
LC bomb filled Comp. B is to be used; it is found from Sheet 3A2a that this is equivalent to 2760 pounds of bare TNT so
$w^{1/3}$ for use in the graphs above is 14. Then $I/w^{1/3}$ is 6.43 and $H/w^{1/3}$ is 1.43. From the upper figure we find that $d/w^{1/3}$
is 13.9 and using this value we find from the lower figure that $h/w^{1/3}$ is 4. Thus the bomb should be detonated at a height
4 x 14 = 56 feet above the ground, and the maximum distance at which damage can be achieved is 13.9 x 14 = 195 feet. From
the dashed curve in the upper figure we find that if the charge had been detonated on the ground the impulse level of
90 lb-millisec/in^2 would have been reached at 155 feet. Thus in this case the airburst increases the radius of damage
from 155 to 195 feet, and increases the area over which damage can be achieved by about 58%. The example is shown by
dotted lines on the graphs. A change in height of burst of 40% from the optimum height will change the impulse at a
point (d, H) from I_{max} by 10%.

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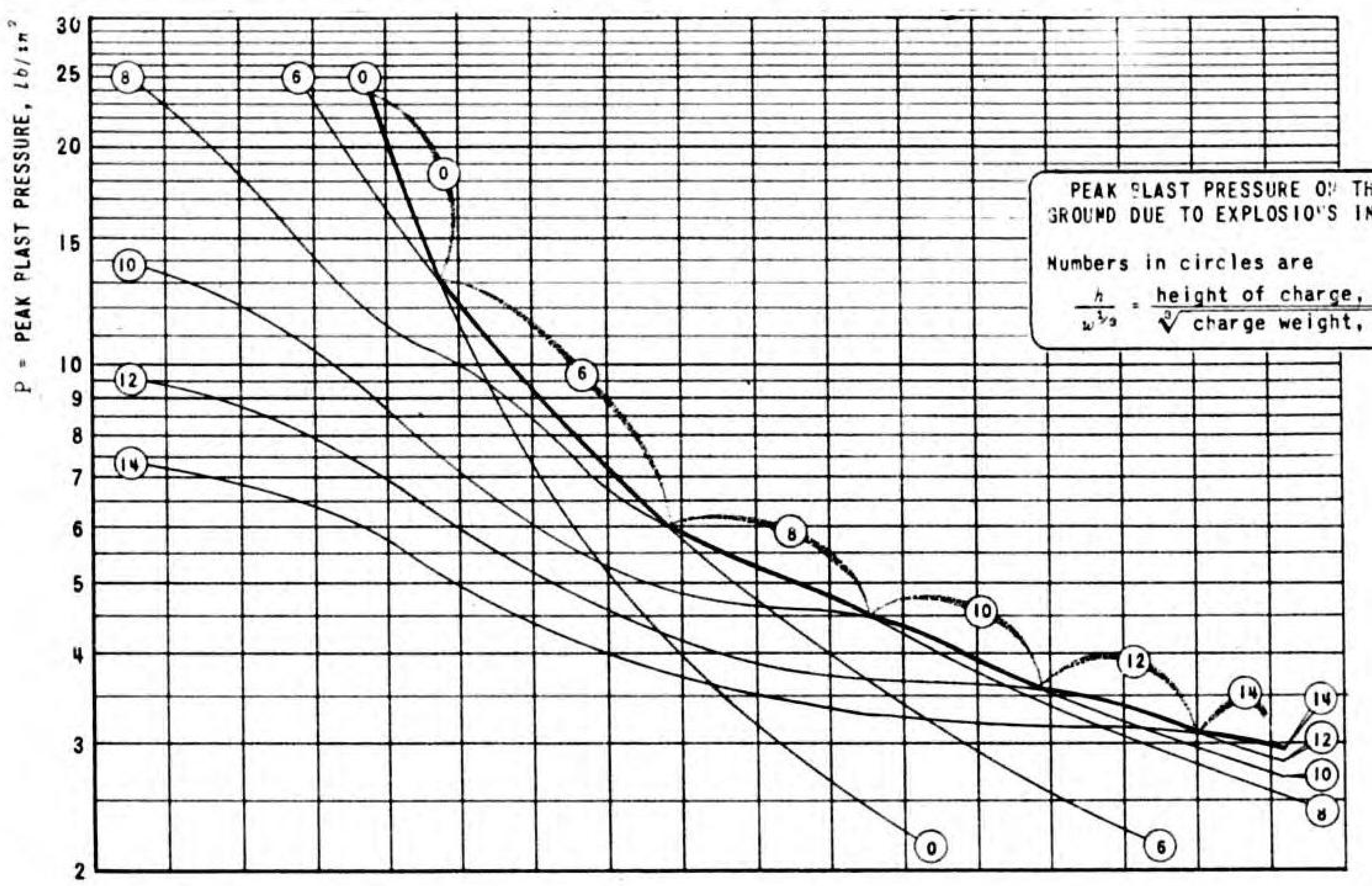
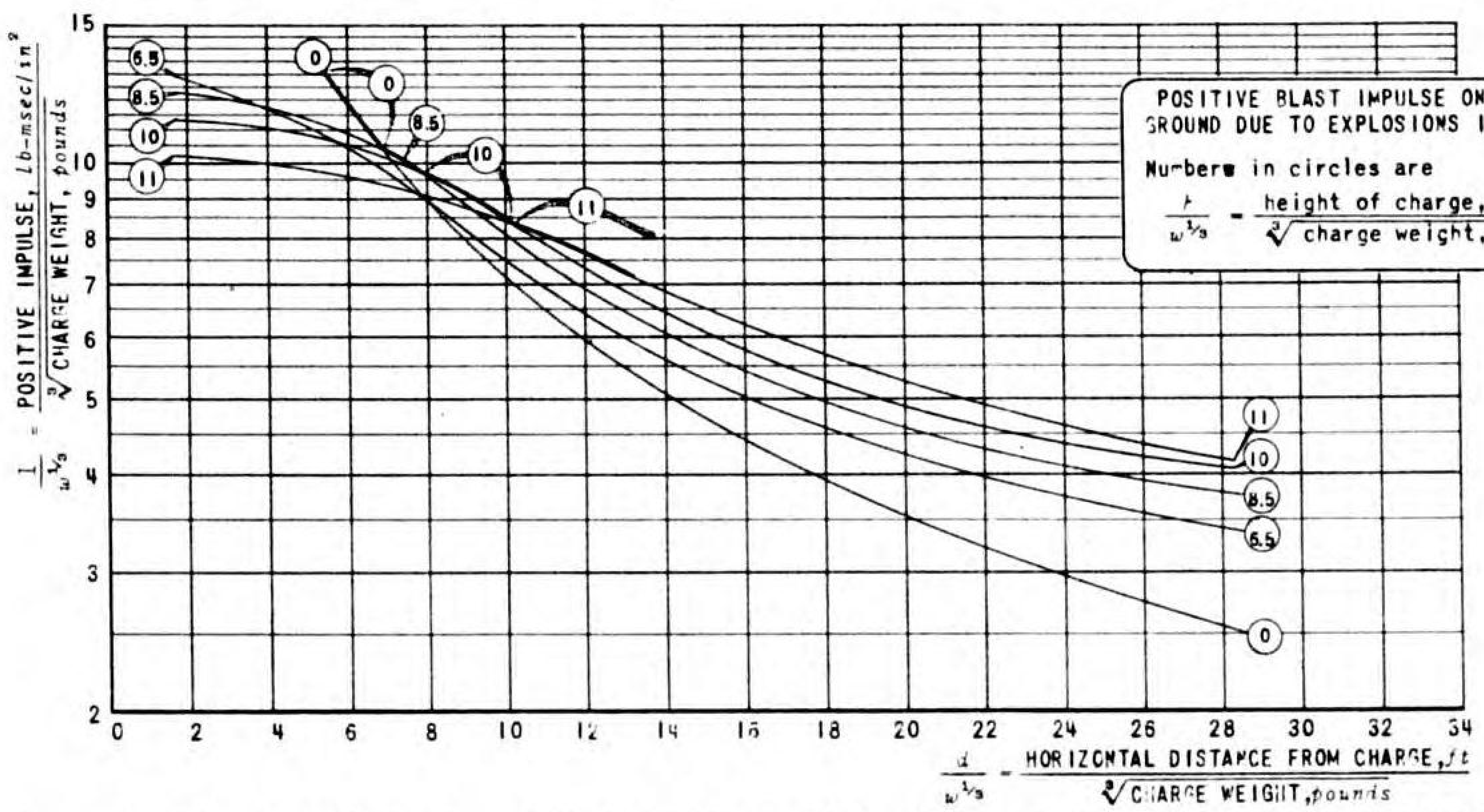
WEAPON DATA

3 A9 HEIGHT EFFECT: PRESSURE & IMPULSE

PRESSURE AND IMPULSE ON THE GROUND DUE TO EXPLOSIONS IN AIR





The curves show the peak blast pressure P and the positive blast impulse I as measured by gauges set flush with level ground at a horizontal distance d from a bare charge of w pounds of TNT detonated at a height h above the ground. The pressure curve labeled "0" is obtained from measurements of pressure from a charge detonated in open air on the assumption that the pressure from w pounds detonated on the ground is equivalent to that from $2w$ pounds detonated at the same distance in open air. The other curves are based on tests using ½-lb bare TNT charges, experiments using mechanically produced shock waves, and deductions from the theory of regular reflection.

To find the height at which a charge should be detonated to yield maximum peak pressure or positive impulse, at a given distance d, read upward from the proper value of $d/w^{1/3}$ to the curve that is highest at that point and take the value of $h/w^{1/3}$ for that curve. To find the height of detonation that will yield a given peak pressure or positive impulse at the greatest distance, read horizontally from the appropriate value of P or $I/w^{1/3}$ to the curve that lies farthest to the right and take the value of $h/w^{1/3}$ for that curve.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Ref: AES-1; AES-2

August 1945

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1083

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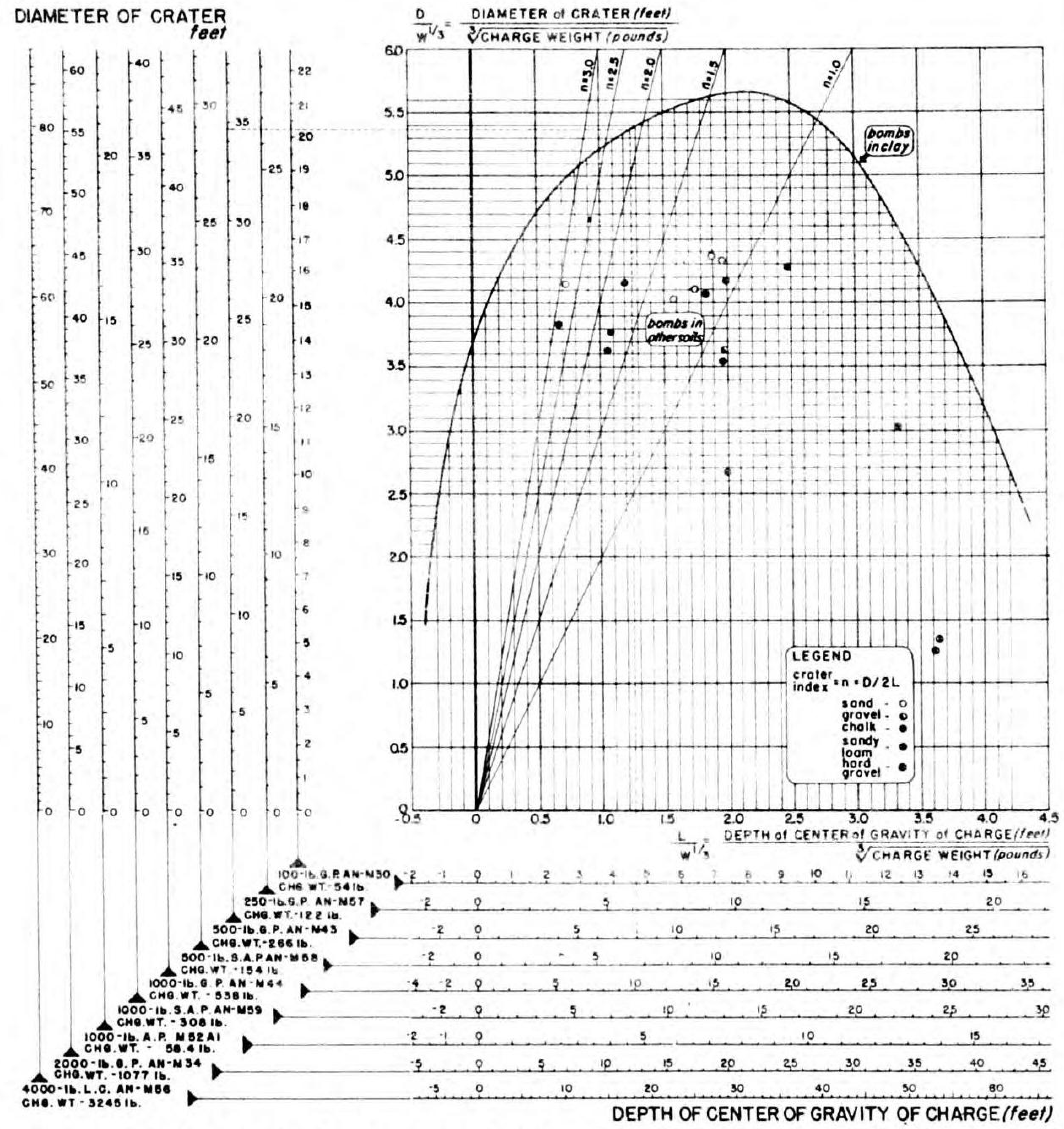
WEAPON DATA

3 B4 EARTH SHOCK: CRATERS

BOMB CRATER DIAMETERS IN CLAY SOIL



THE CURVE GIVES CRATER DIAMETERS TO BE EXPECTED WHEN BOMBS OF NORMAL EXPLOSIVE FILLING (TNT or Amatol) ARE DETONATED IN CLAY SOIL. CRATER DIAMETER IS GIVEN AS A FUNCTION OF DEPTH OF THE CENTER OF GRAVITY OF THE BOMB INCLUDING NEGATIVE VALUES OF PENETRATION CORRESPONDING TO EXPLOSIONS ABOVE GROUND. THE DIAMETERS CAN BE READ DIRECTLY FOR THE COMMONER AMERICAN BOMBS ON THE APPROPRIATE PAIRS OF SCALES.

THE CURVE PREDICTS DIAMETERS IN CLAY WITH AN AVERAGE DEVIATION OF 6%.

A FEW POINTS REPRESENTING CRATERS IN SOILS OTHER THAN CLAY ARE INDICATED.

CRATER DIAMETERS ARE UNDERSTOOD TO BE MEASURED IN STANDARD WAY, i.e. AT ORIGINAL GROUND SURFACE BETWEEN SHEAR SHOULDERS.

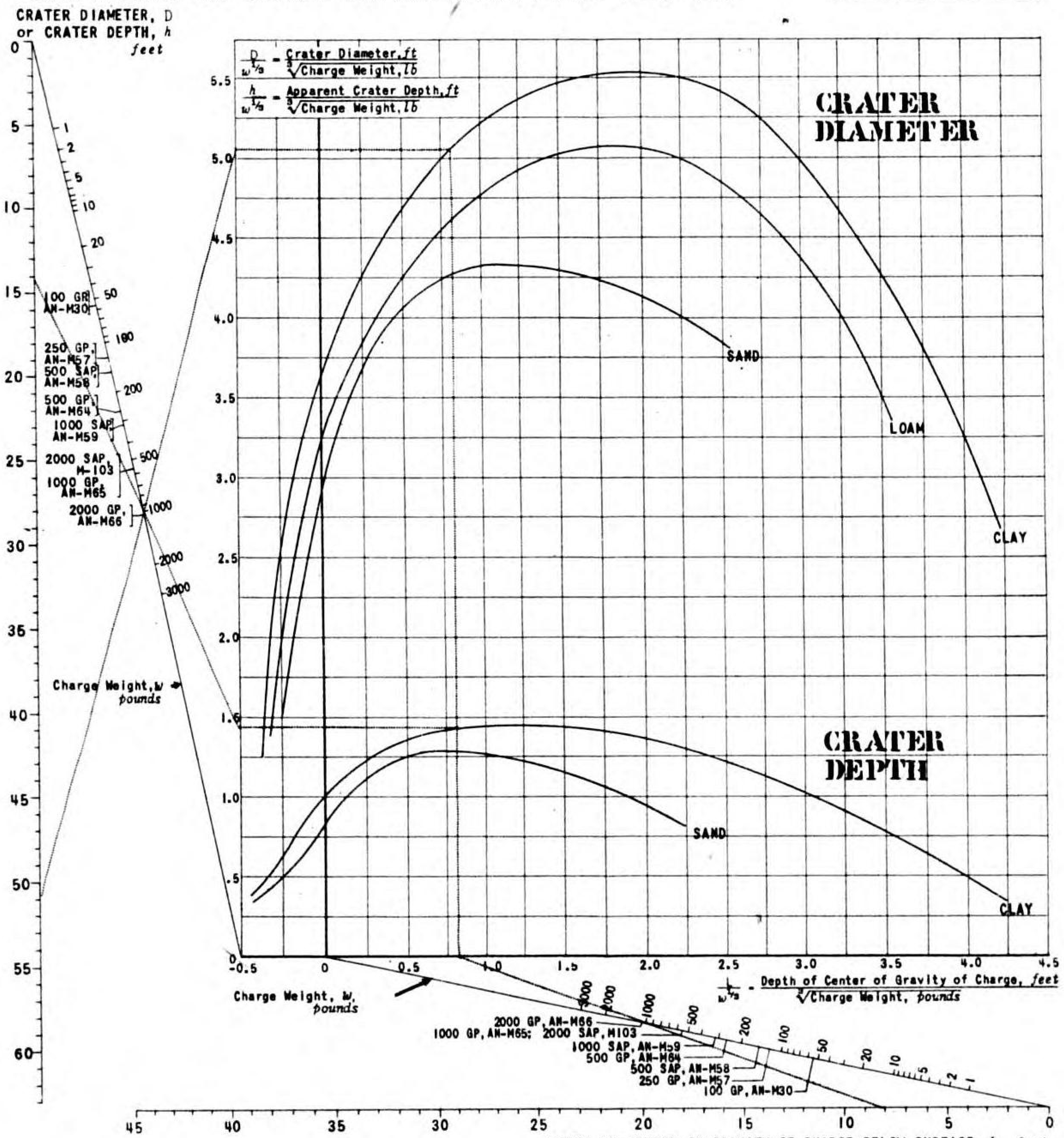
EXAMPLE: Dotted line indicates that a 500-lb. G.P., AN-M43, bomb detonated 8 ft. below ground level will produce a crater nearly 35 ft. in diameter.

DATA: FROM BRITISH AND AMERICAN EXPERIMENTS ON DETONATION OF BOMBS AND BARE CHARGES

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

September 1943

CRATERS IN SOIL: DIAMETER AND DEPTH

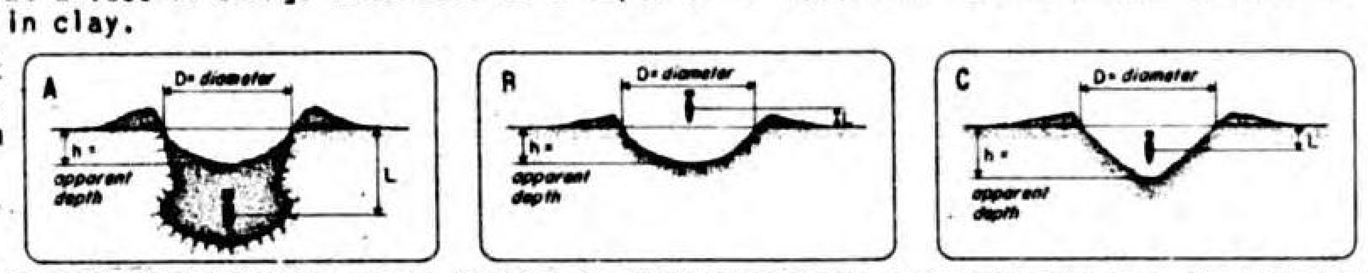


The curves give the mean value of crater diameter and apparent crater depth for charges detonated in clay, loam, or sand as a function of the depth of the center of the charge below the surface of the ground; negative values of depth are included, corresponding to detonation above ground. Deviation between mean and observed values may be as much as 30%.

The curves are for TNT. Craters due to composition B or Amatol 50/50 are not significantly different. Tritonal forms craters approximately 10% larger than given by the curves. HBX and Minol form craters approximately 15% larger.

EXAMPLE: The dotted line indicates that a 1000-lb charge detonated at a depth of 8 feet will form a crater 51 feet in diameter and 14 feet in apparent depth in clay.

TYPICAL CRATER PROFILES showing apparent depth, diameter, and position of charge.
A: Bomb at moderate depth, clay or loam
B: Bomb at or above ground, any soil.
C: Bomb below ground surface, dry sand.



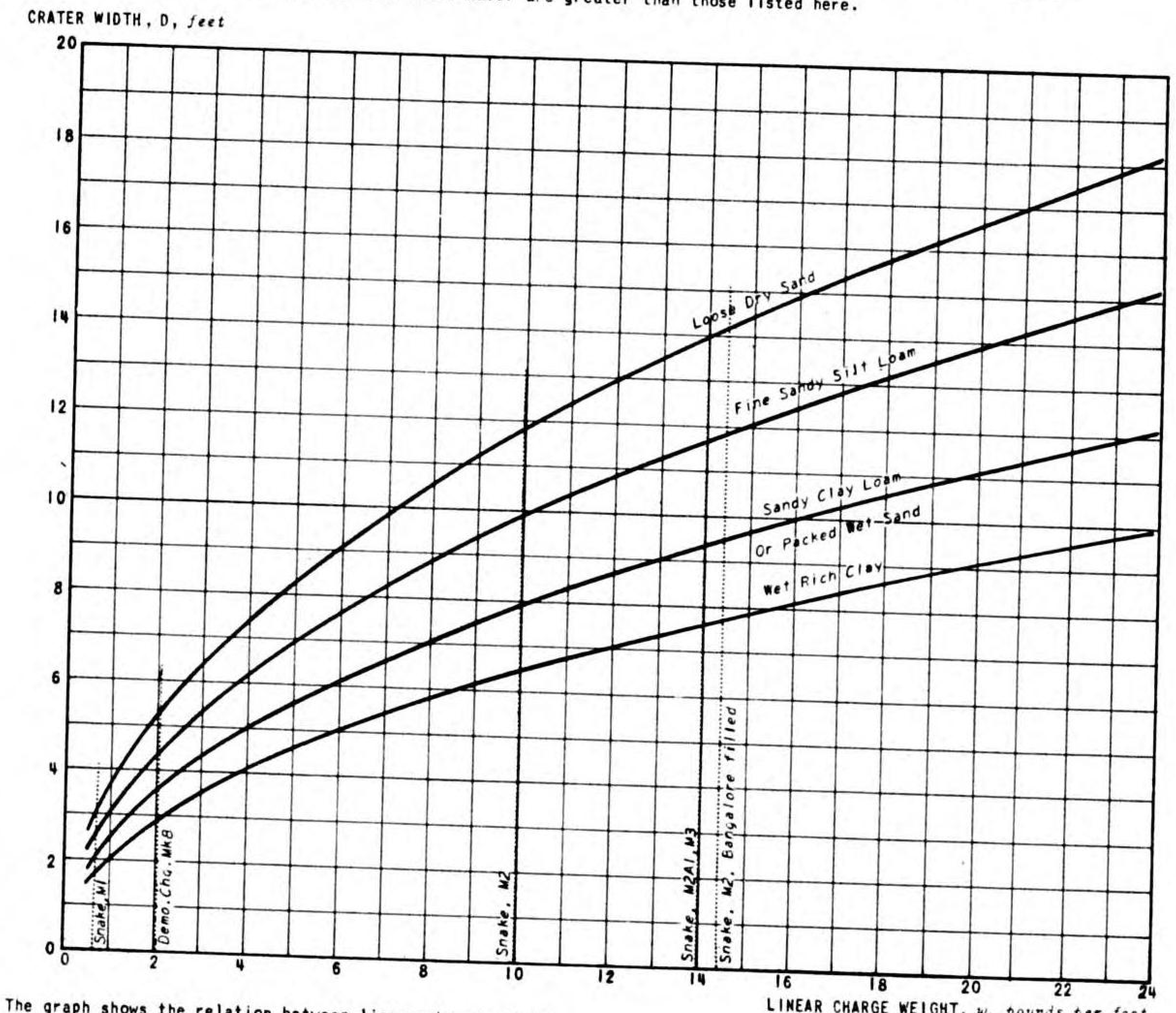
★ Revised:
August 1945

CRATERING BY LINE CHARGES

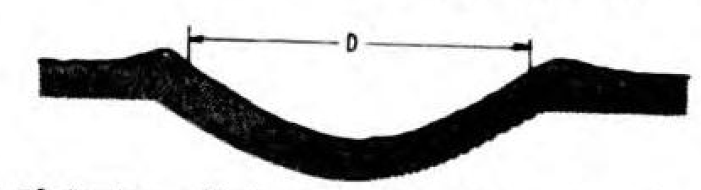
The width of crater D, in feet formed by explosion of a line charg. on various soils is given by the following empirical relations, where w is the linear charge weight in pounds per foot.

Type Soil	Average Crater Width D, *feet*	70% of Crater Widths Fall Between
Loose Dry Sand	$D = 3.7\sqrt{w}$	$3.0\sqrt{w}$ and $4.4\sqrt{w}$
Packed Wet Sand	$D = 2.6\sqrt{w}$	$2.1\sqrt{w}$ and $3.1\sqrt{w}$
Fine Sandy Silt Loam	$D = 3.2\sqrt{w}$	$2.6\sqrt{w}$ and $3.9\sqrt{w}$
Sandy Clay Loam	D = 2.[illegible]$\sqrt{w}$	$2.0\sqrt{w}$ and $3.4\sqrt{w}$
Wet Rich Clay	$D = 2.1\sqrt{w}$	$1.5\sqrt{w}$ and $2.8\sqrt{w}$

Crater widths for line charges exploded *under water* are greater than those listed here.



The graph shows the relation between linear charge weight, w, in lb/ft and the width of crater, D, in feet formed by detonating line charges on various soils. This width is measured between the shear shoulders of the crater as shown in the sketch.



The lines which are drawn are based on the average of a large number of tests. It is expected that a majority (70%) of craters will differ from the average by less than 25%. A minority (30%) of the shots will show extreme variation. Explosives tested include C-2, Amatol, TNT and liquid explosives. Variation in crater width is attributed chiefly to soil conditions; effect of different explosives is masked by this variation.

Example: The M-3 snake (14 lb/ft) produces craters which should average 14 feet across in dry sand; 12 feet in fine sandy silt loam, 9½ feet in sandy clay loam or packed wet sand, or 7½ feet in wet rich clay.

Source: Tests by Engineer Roard, U.S. Arry: and by Joint Army-Navy Experimental Testing Roard, U.S.

Ref: AES-13
Aug ·t 1945

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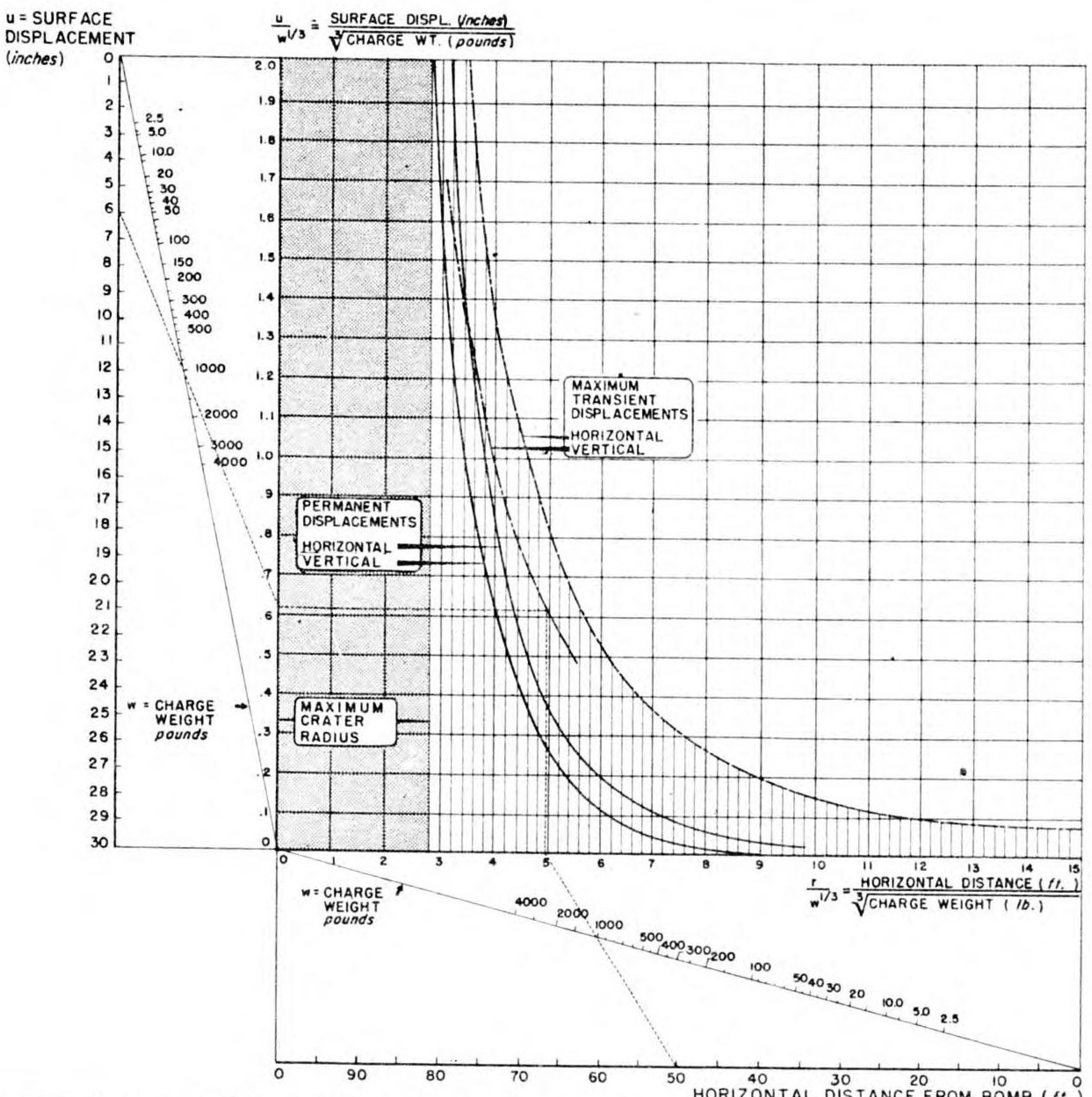
WEAPON DATA

EARTH DISPLACEMENTS DUE TO UNDERGROUND EXPLOSIONS IN CLAY SOIL

3B2 EARTH SHOCK DISPLACEMENTS

Data taken from British experiments on detonation of bombs and American experiments with bare charges.



The curves show horizontal and vertical displacements of the surface of the ground measured at various distances from the exploding charge. The phenomena obey a model law, so that results for different weights of charge may be represented on the same curve.

SOIL EFFECT: Values given are from observations on clay and clay-gravel mixture. Displacements in chalk, not shown on this plot, were found to fall below those in clay.

TYPE OF EXPLOSIVE: The curves are based on experiments using the following types of explosives: T.N.T., 40/60 Amatol, Baratol, Dithekite, Minol, Black Powder and Dynamite, with charge weights ranging from 2.5 to 990 pounds. On the other hand, displacements in clay obtained with Torpex and Hexanite are greater than for equal weights of any of the above explosives.

ABSENCE OF DEPTH EFFECT: The data indicate that for the range of depths tested, the displacements obtained are independent of the depth of burial L provided only that the bomb or charge is completely buried. Depths in these experiments varied from 7 to 22 feet, and the corresponding values of $L/W^{1/3}$ were between 1.1 and 3.6 $ft/lb^{1/3}$.

ACCURACY OF GRAPH: The curves predict displacements over the entire range with an average deviation of 15%.

EXAMPLE: Dotted line indicates that a 1000 lb. charge produces a transient vertical displacement of 6 inches at 50 ft.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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November 1943

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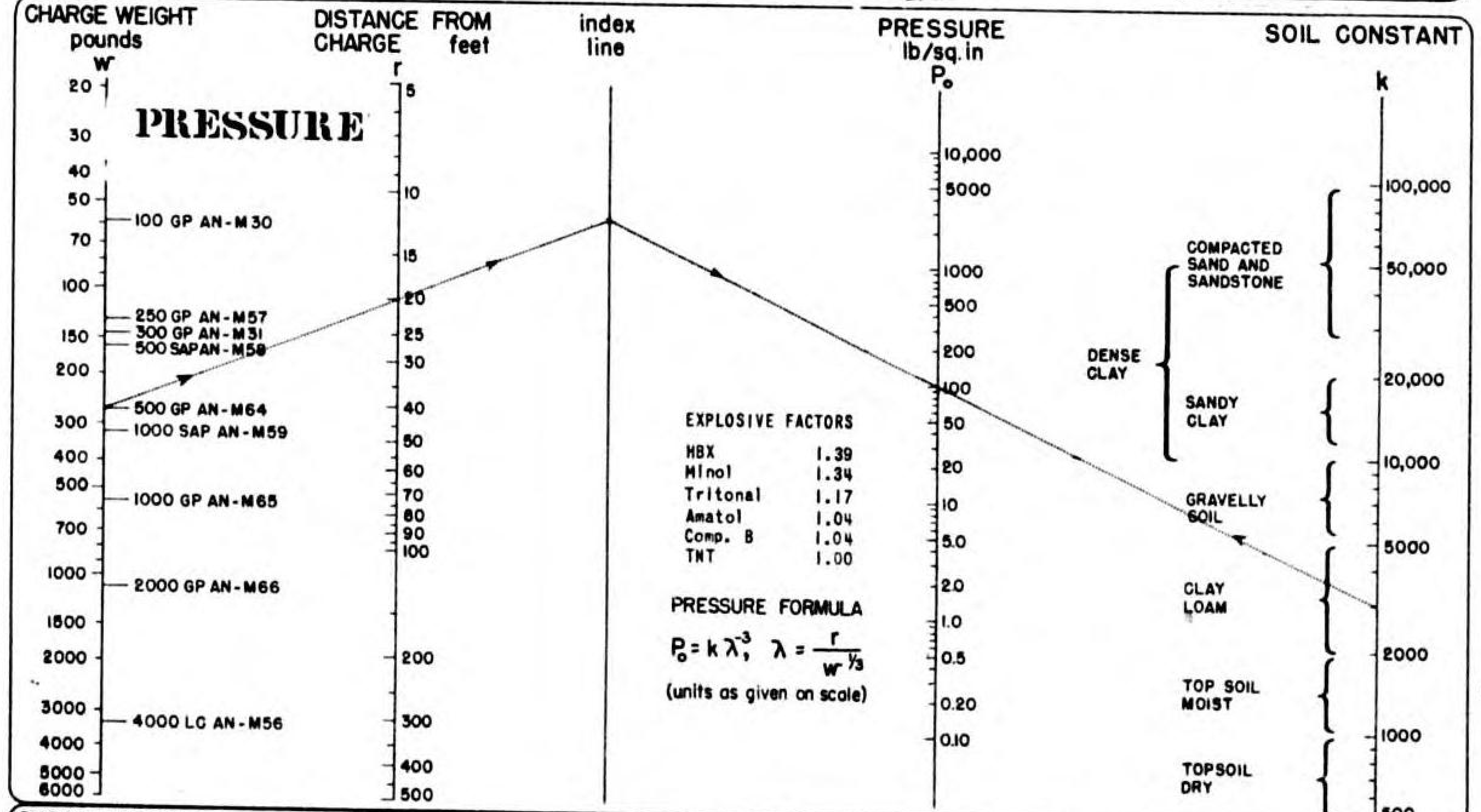
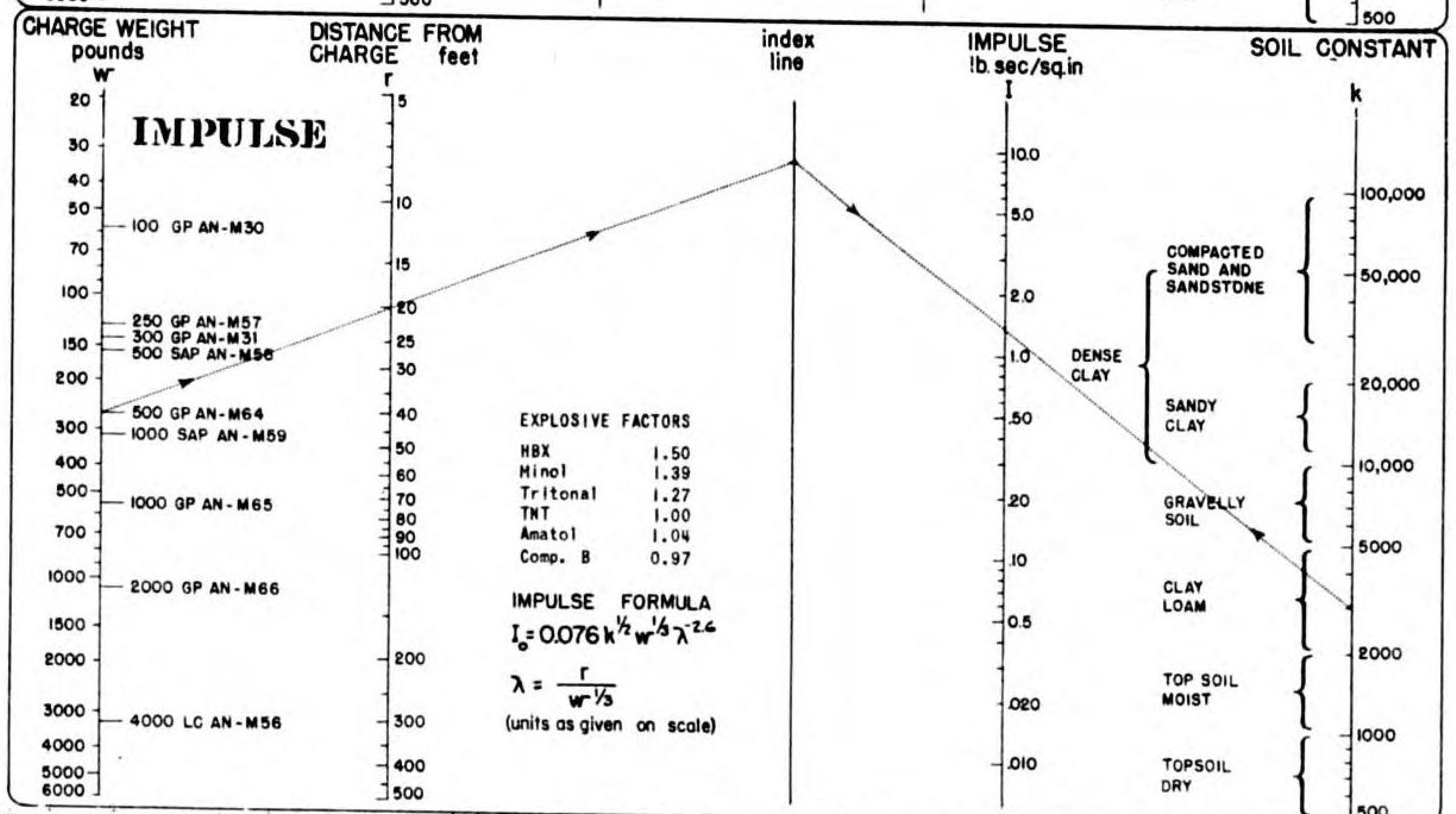
WEAPON DATA

PEAK PRESSURE AND IMPULSE DUE TO EXPLOSION IN EARTH

3B3* EARTH PRESSURE - IMPULSE





The nomograms yield values of peak pressure and positive impulse in free earth due to detonation of based charges of TNT and bombs filled 50/50 Amatol. The equations are based on tests for the U. S. Engineers, and extensive small scale tests. In these tests the charge was buried at the depth giving maximum crater diameter ($2.1\ w^{1/3}$). ft and pressure and impulses were measured at the same depth. Under different geometrical conditions the values of pressure and impulse will differ from those given here. With gauges at a constant depth, variations in the charge depth between about $0.7\ w^{1/3}$ and $5\ w^{1/3}$ ft appear to produce negligible change in pressure and impulse values. On the other hand for fixed charge depth alteration of the gauge depth causes appreciable change in pressure measurements, there being a general increase with depth. Values of k for typical soils are computed from the velocity of seismic waves in the subsurface material. Actually k depends on many factors and ranges designated for various soil types should be considered a rough guide only. For explosives other than TNT, final values of pressure or impulse read from nomogram should be multiplied by the factors tabulated above.

Pressures measured at the surface of a buried massive target are found to be about twice the free earth values given by the nomograms. Impulse values are approximately 2.5 times the free earth values.

EXAMPLE: The dotted lines indicate that at a distance of 20 ft from a 267-lb charge of TNT the maximum free earth pressure in clay loam will be about 100 lb/in^2 and the impulse about 1.4 lb-sec/in^2.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Ref: PTM No. 93

*Revised: September 1945

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3B3*

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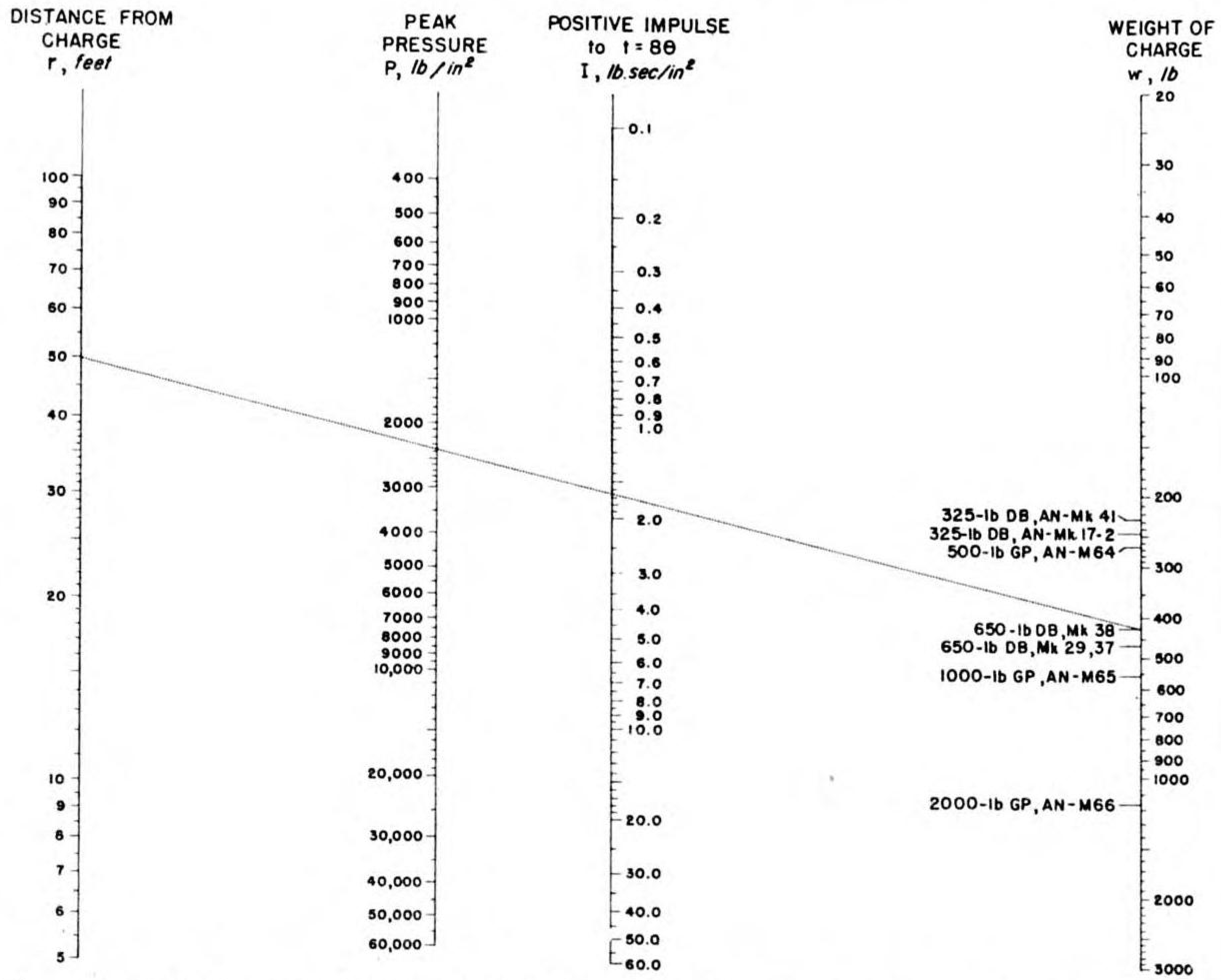
WEAPON DATA

PEAK PRESSURE AND IMPULSE DUE TO UNDERWATER EXPLOSIONS

3 C1 UNDERWATER PRESSURE-IMPULSE

Data supplied by the Underwater Explosives Research Laboratory, Division 8, NDRC.



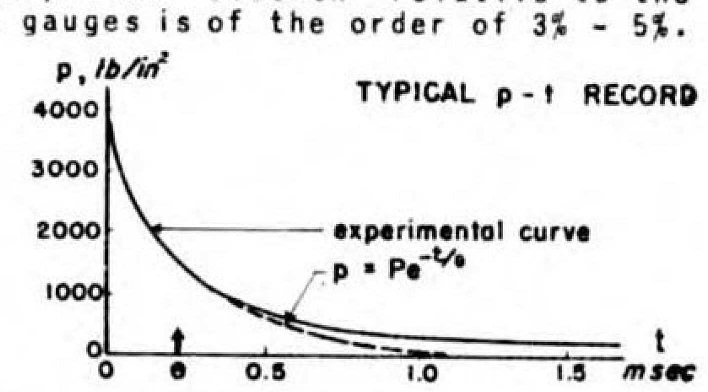
The nomogram yields values of underwater peak pressure and positive impulse due to detonation of charges of cast TNT. Values corresponding to TNT-filled American depth bombs and GP bombs accommodating hydrostatic fuses are indicated on the charge weight scale. Peak pressure measurements on the following explosives range from 15% to 20% higher than for TNT: DBX, Minol, DBY, Special DBX, DBU, Torpex, — the values increasing in the order given.

The scales correspond to the following empirical equations based on a large number of measurements:

$$P_{lb/in^2} = 20{,}400\left(\frac{w_{lb}^{1/3}}{r_{ft}}\right)^{1.14}; \qquad I_{lb.sec/in^2} = 1.50\left(\frac{w_{lb}^{2/3}}{r_{ft}}\right)$$

Gauges were located in the equatorial plane of the charge and were placed "side-on" relative to the oncoming wave. Average deviation of values obtained from different gauges is of the order of 3% - 5%.

The sketch shows a typical pressure-time record. Since the tail portion of such a curve decreases very slowly, it is necessary to measure I to a chosen point in order to obtain a definite value. This limit has been chosen as $t = 8\theta$, where θ is the time constant of a decreasing exponential function which fits the initial part of the curve. Absolute values of impulse may be inexact by as much as 15%.



EXAMPLE: At 50 feet a 650-lb Mk 38 depth bomb (charge weight = 425 lbs.) produces a peak pressure of 2400 lb./in². and a positive impulse of about 1.7 lb. sec./in².

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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April 1944

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WEAPON DATA

MAXIMUM RADIUS OF BUBBLE OF BURNT GASES FROM AN UNDERWATER EXPLOSION

3 C2 UNDERWATER BUBBLE RADIUS

WEIGHT OF CHARGE, *pounds*	DEPTH OF CHARGE, *feet*												
	2	3	5	8	10	15	20	25	30	40	50	75	100
0.1	1.8	1.7	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.1
0.25		2.4	2.3	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.6	1.5
0.5		3.0	2.9	2.9	2.8	2.7	2.6	2.5	2.5	2.3	2.2	2.0	1.9
0.75			3.4	3.3	3.2	3.1	3.0	2.9	2.8	2.7	2.6	2.3	2.2
1.00			3.7	3.6	3.6	3.4	3.3	3.2	3.1	2.9	2.8	2.6	2.4
2.00			4.7	4.5	4.5	4.3	4.2	4.0	3.9	3.7	3.6	3.2	3.0
•3.00				5.2	5.1	4.9	4.8	4.6	4.5	4.2	4.1	3.7	3.4
5.00				6.2	6.1	5.8	5.6	5.5	5.3	5.0	4.9	4.4	4.0
7.5				7.1	7.0	6.7	6.4	6.3	6.1	5.8	5.5	5.1	4.7
10.				7.8	7.7	7.4	7.1	6.9	6.7	6.4	6.1	5.5	5.1
15.					8.8	8.4	8.1	7.9	7.6	7.3	7.0	6.3	5.9
20.					9.6	9.3	9.0	8.7	8.4	8.0	7.7	7.0	6.4
25.						10.	9.7	9.4	9.1	8.6	8.2	7.5	6.9
30.						11.	10.	10.	9.6	9.2	8.8	8.0	7.4
40.						12.	11.	11.	11.	10.	9.6	8.8	8.1
50.						13.	12.	12.	11.	11.	10.	9.5	8.8
60.						13.	13.	13.	12.	12.	11.	10.	9.3
70.						14.	14.	13.	13.	12.	12.	11.	9.8
80.							14.	14.	13.	13.	12.	11.	10.
90.							15.	14.	14.	13.	13.	12.	11.
100.							15.	15.	14.	14.	13.	12.	11.
150.							18.	17.	16.	16.	15.	14.	13.
200.							19.	19.	18.	17.	16.	15.	14.
250.								20.	19.	19.	18.	16.	15.
300.								21.	21.	20.	19.	17.	16.
400.								23.	23.	22.	21.	19.	18.
500.									25.	23.	22.	20.	19.
750.									28.	27.	26.	23.	22.
1000.										29.	28.	26.	24.
1500.										34.	32.	29.	27.
2000.										37.	36.	32.	30.
4000.											45.	41.	39.

CALCULATED BUBBLE RADIUS FOR TNT, *feet*

To estimate radius for other explosives multiply value in table by:
1.07 for tetryl
1.21 for torpex

WEIGHT CONVERSION TABLE

pounds		*grams*
0.1	=	45.4
0.25	=	113.5
0.5	=	227.
0.75	=	340.5
1.00	=	454.

The table gives the maximum radius of the bubble formed by burnt gases from an underwater explosion and is based on the equation given below.

$$R = k\left[\frac{w}{(h + h_0)}\right]^{\frac{1}{3}}$$

where: R = maximum radius, *feet*
k = constant dependent on explosive charge = 12.2 $lb^{-1/3}$ $ft^{4/3}$ for TNT
w = weight of charge, *pounds*
h = depth of charge, *feet*
h_0 = atmospheric head = 33 ft

This equation is derived theoretically in NDRC Report C4-sr20-010. The constant k was determined from the relation between the period of pulsation and the radius which is given in the above report and in the Applied Mathematics Panel Report 37.1R and from measurements of the period at the Underwater Explosives Research Laboratory. The table has been checked at one point by direct measurement of the bubble radius.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, UNDERWATER EXPLOSIVES RES. LAB.

Restricted

January 1945

IMPULSE CRITERION-DAMAGE LEVELS

Damage to buildings of wall bearing construction has been divided into the following categories:

- A Damage: Buildings completely demolished.
- B Damage: Damaged beyond repair and requiring demolition. If one fourth of the wall area is destroyed, the entire building is said to suffer B damage.
- C Damage: Seriously damaged and requiring repair before being used.
- D Damage: Still habitable, but requiring repair.

The mean radius and maximum radius of each level of damage due to blast has been estimated as follows: From one incident the value of the maximum radius of damage of a given level is obtained by measuring the distance between the bomb and the furthest point of the furthest building suffering that degree of damage. Averages over a number of incidents of such radii for German instantaneously fuzed bombs against British wall bearing construction are given for various sizes of bombs in REN 214 revised.

The mean radius of a given level of blast damage from a bomb is determined as the radius of the circle with the bomb as center which includes as many buildings which do not suffer the specified degree of damage as there are damaged buildings excluded. For a number of incidents one averages the areas so obtained. The radius of a circle with the average area is then the average mean radius. Such radii are also listed in REN 214, revised.

The mean and maximum radii of a given level of damage are found to be proportional to $w^{2/3}$ where w is the weight of explosive in the bomb in pounds, for bombs which are not too large (less than 3500 lb. of explosive). The constant of proportionality depends on the level of damage as well as on the explosive used, case weight, etc. The distance from a bomb with w pounds of explosive at which a given level of positive impulse is obtained also is proportional to $w^{2/3}$. This suggests that a correlation exists between impulse and damage. (This correlation is supported by theoretical arguements to be found in R.C. 349). The table below gives the relation between radii of damage and impulse levels, found to exist for British construction.

IMPULSE LEVELS FOR BRITISH CONSTRUCTION Instantaneous Fuzed Bombs	I, *lb-millisec/in²*
Mean radius, A Damage	120
Maximum radius, A Damage	90
Mean radius, B damage	72
Maximum radius, B Damage	54
Mean radius, C Damage	40
Maximum radius, C Damage	30

IMPULSE LEVELS FOR GERMAN CONSTRUCTION (Damage Determined by Photocover) Instantaneous Fuzed Bombs	I, *lb-millisec/in²*
Mean radius, demolition	120
Maximum radius, demolition	90
Mean radius, visible damage	55
Maximum radius, visible damage	40

Also listed in the table are the categories of damage applied to photo-cover of results of Allied bombing of German wall bearing construction. It was found that the categories of damage A, B, and C could not be distinguished on photo-cover and two categories, demolition and visible damage were introduced. Since German construction is heavier than British, it is to be expected that the impulse level corresponding to a given degree of damage such as A, B, or C would be increased; the amount of increase is given to a first approximation by the ratio of wall thicknesses. Thus, the mean radius of B damage against German construction is expected to correspond to an impulse level of 108 lb-millisec/sq.in. The radius of demolition is thus between the radii for A and B damage whereas that for visible damage is slightly larger than the radius for C damage.

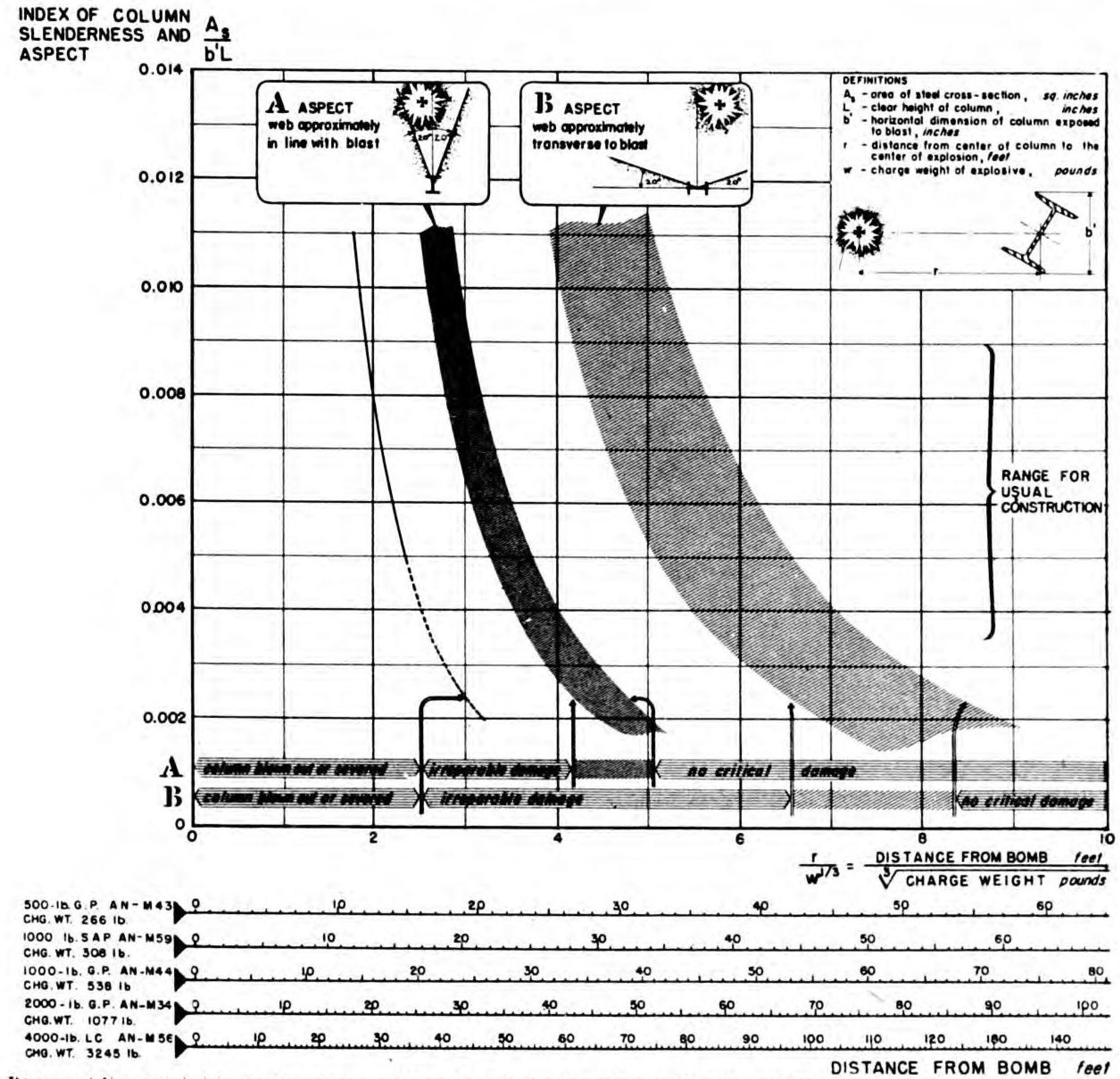
The departure of the area of damage from a circle is reflected in the large difference between the maximum radius of a given level of damage and the mean radius. The reason for this is that because of the built-up-ness of the target there is shielding of the blast. The evidence indicates that on the average this shielding can be taken into account by decreasing the maximum radius of a given category of damage by 25% to obtain the mean radius (since impulse is inversely proportional to distance).

Theoretical considerations and operational data show that the impulse criterion does not hold for very large blast bombs. The weight for which it no longer applies depends on the type of construction. For British and German construction the radius of a given level of damage from bombs having between 3500 and 8000 lbs. of explosive is proportional to $w^{1/2}$. For considerably larger bombs it becomes proportional to $w^{1/3}$. The latter is the same as the dependence of the distance for a given level of peak-pressure on the weight of explosive. This is reasonable since as the weight of explosive increases the duration of the blast at a given point increases and so does the impulse; however, the walls of the building will not fail under blast loading with large impulse unless the practically constant pressure (which occurs in this case) is above the static strength of the walls. (See R.C. 349).

Using the relation given in sheet 3 A2* for impulse due to explosions on the ground, values of the radii for A, B, and C damage due to different bombs have been computed. Results are given in the table below.

Bomb, Instantaneous Fuzing	Mean Radius A Damage, *ft*	Mean Radius B Damage, *ft*	Mean Radius C Damage, *ft*
100-lb GP AN-M30, TNT filled	7	12	21
100-lb GP AN-M30, Tritonal filled	8	14	25
250-lb GP AN-M57, TNT filled	12	19	34
250-lb GP AN-M57, Tritonal filled	14	23	41
500-lb GP AN-M64, TNT filled	20	33	59
500-lb GP AN-M64, Comp. B filled	21	35	64
500-lb GP AN-M64, Tritonal filled	23	38	69
1000-lb GP AN-M65, TNT filled	30	50	90
1000-lb GP AN-M65, Comp. B filled	34	56	101
1000-lb GP AN-M65, Tritonal filled	35	58	105
2000-lb GP AN-M66, TNT filled	50	83	150
2000-lb GP AN-M66, Comp. B filled	54	90	162
2000-lb GP AN-M66, Tritonal filled	59	99	177
4000-lb LC AN-M56, TNT filled	119	200	360
4000-lb LC AN-M56, Comp. B filled	131	220	395
4000-lb LC AN-M56, Tritonal filled	142	236	425

BLAST DAMAGE TO STEEL COLUMNS



The curves define approximately the limiting distances from various bombs at which steel columns will be damaged in different ways: blown out or severed, damaged beyond repair although not blown out, or not damaged critically. The width of the bands is computed on the assumption of reasonable variations in the shape of a cross-section designed to carry a given load. The column index, plotted vertically, is the ratio of the steel cross-section of the column to the area exposed to the blast. This area is the product of the length of the column and its projected width on a line perpendicular to the line joining the column to the bomb. This index is related to the ratio of the radius of gyration of the cross-section to the length of the column: i.e. large values of the index correspond to stubby columns and small values to slender columns.

The columns are assumed to have no partitions or walls attached and to be exposed to blast on all sides. If there are partitions attached to the columns the radius of damage is likely to be greater, since part of the force on the attached elements is transmitted to the columns. Further, in such cases the blast wave cannot so readily make its way around the column to back it up from behind. On the other hand, where the column is supported by a partition or a wall approximately in line with the blast wave, the radius of damage should be considerably smaller.

As shown by the curves, the radius of damage is considerably reduced when the bomb is situated approximately in line with the web of the column (aspect A). For bombs dropped at random in an ordinary building, about 75 - 80% of the cases of damage will be those in which the web is more or less perpendicular to the blast (aspect B), and the remainder will be cases in which the web is more nearly in line with the blast.

The chart does not contemplate the destruction of the column by undermining of the footing. Such an action may cause destruction at a value of $r/w^{1/3}$ of about 3.

For charge weights less than about 200 pounds, the radius of damage appears to be less than that given by the chart.

The bulk of the incidents reported are for single story industrial buildings, with only a few cases of doubtful validity of multi-story framed buildings. All columns are single rolled steel sections.

EXAMPLE: Given a building of average shed-type construction with I-columns 8 in. x 6 in. @ 35 lb/ft. of 12 ft. unsupported length and exposed to blast whose direction is 60° from the web, i.e. aspect B. Then, A_s = 10.3 sq. in., b' = 10 in., L = 144 in., so that $A_s/b'L$ = 0.0073, the column index under these conditions. It may be expected that such a column will be blown out or severed by a 1000-lb GP AN-M44 bomb at distances up to about 17 feet; the same bomb (aspect B) will damage this column beyond repair at distances up to about 36 to 46 feet.

When such detailed information on the construction is not available, it is suggested that the column index be taken as about 0.007, toward the upper part of the range for usual construction.

NOTE: DATA PREPARED FROM BRITISH RE 4 DAMAGE REPORTS AND DATA COMPILATIONS copy no: 1083

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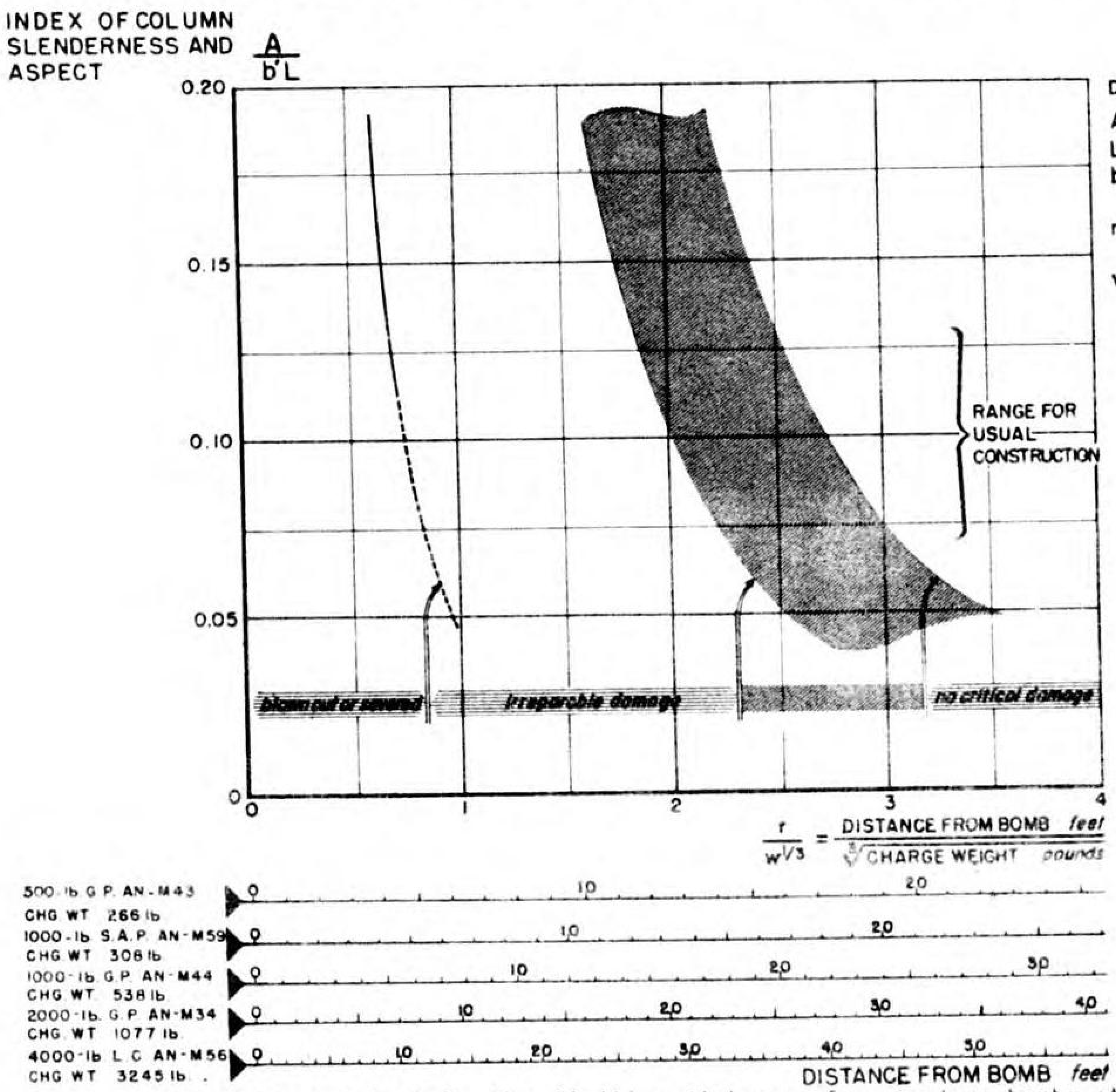
WEAPON DATA

6 A1b*
CONCRETE COLUMNS

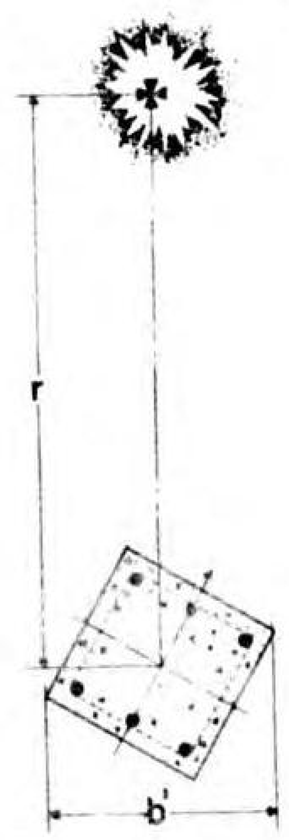
BLAST DAMAGE TO CONCRETE COLUMNS

DATA PREPARED FROM INFORMATION GIVEN IN BRITISH RE 4 DAMAGE REPORTS AND DATA COMPILATIONS



DEFINITIONS

A - area of cross-section, *sq.inches*
L - clear height of column, *inches*
b' - horizontal dimension of column exposed to blast, *inches*
r - distance from center of column to center of explosion, *feet*
w - charge weight of explosive, *pounds*



The curves define approximately the limiting distances from various bombs at which concrete columns will be damaged by blast in different ways - blown out or severed, damaged beyond repair, or not damaged critically. The width of the band is computed on the assumption of reasonable variations in the shape of a cross-section designed to carry a given load. The column index, plotted vertically, is the ratio of the cross-sectional area of the column to the area exposed to the blast. This area is the product of the length of the column and its projected width on a line perpendicular to the line joining the column to the bomb. The index is thus approximately equal to the ratio of the depth of the column to its length, i.e. large values of the index correspond to stubby columns and small values to slender columns.

The columns are assumed to have no partitions or walls attached, and to be exposed to blast on all sides. If there are partitions attached to the columns the radius of damage is likely to be greater, since part of the force on the attached elements is transmitted to the columns. Further, in such cases the blast wave cannot so readily make its way around the column to back it up from behind. On the other hand, where the column is supported by a wall or partition approximately in line with the blast wave, the radius of damage should be considerably smaller.

The chart does not contemplate the destruction of the columns in the lowest story of a building by undermining of the footings. Such an action may cause destruction at a value of $r/_w{}^{1/3}$ of about 3. Neither does the chart consider the action of blast in a relatively confined space, which may cause tensile failure of the column by so-called "uplift" at a greater distance than shown by the chart.

For charge weights less than about 200 pounds, the radius of damage appears to be less than that given by the chart.

EXAMPLE: Given a building of average R/C frame construction having square columns with depth 1/10 the height. Then for blast perpendicular to the face of the column, the column index will be 0.10. It may be expected that such a column will be blown out or severed by a 1000-lb GP AN-M44 bomb at distances up to about 6 feet; the same bomb will damage the column beyond repair at distances up to about 16 to 22 feet.

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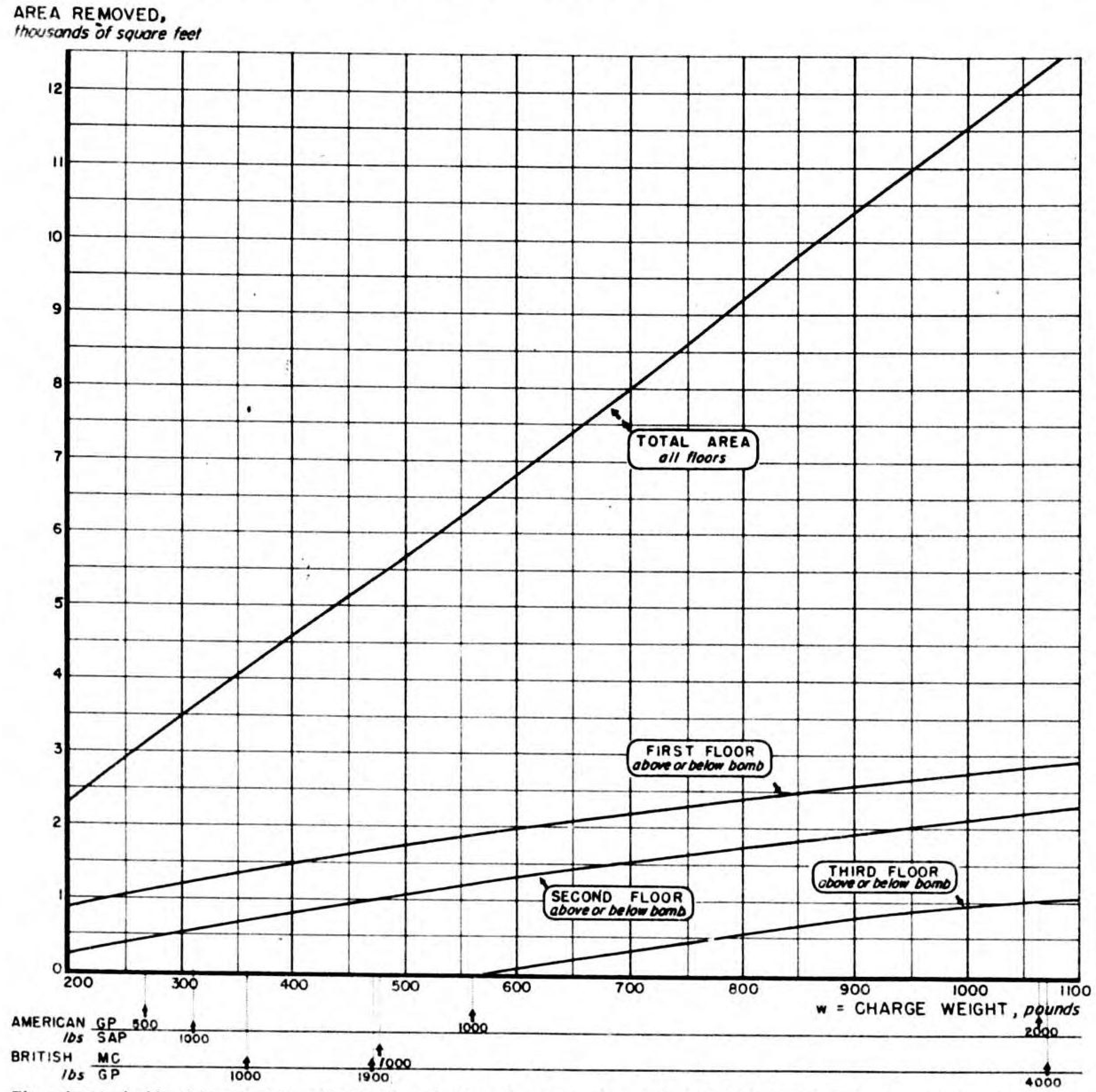
WEAPON DATA

6 A2
CONCRETE FLOOR SLABS

DESTRUCTION OF CONCRETE FLOOR SLABS BY BOMBS



The chart indicates average areas of reinforced concrete floor slabs destroyed by bombs exploding within a building. The curves show, respectively, the average areas of destruction to be expected in the first, second and third floors above or below the bomb and the total area removed on all floors.

It is to be noted that for maximum effectiveness, bombs of about 600 pounds charge weight or less require at least two floors above and below the point of detonation and bombs of charge weight greater than 600 pounds require at least three floors above and below the point of detonation. Bombs of charge weight less than 200 pounds do not appear to produce significant damage.

These curves apply only to ordinary reinforced concrete floor slabs, four to eight inches thick and supported on steel or concrete beams. Filler joist floors or other such types are not included.

In using the chart it should be remembered that the amount of available data on which this presentation is based is small, and some individual values differ from the average represented by the curve by as much as 100%.

SOURCE: Data Compilations and Incident Summaries of the British Ministry of Home Security.

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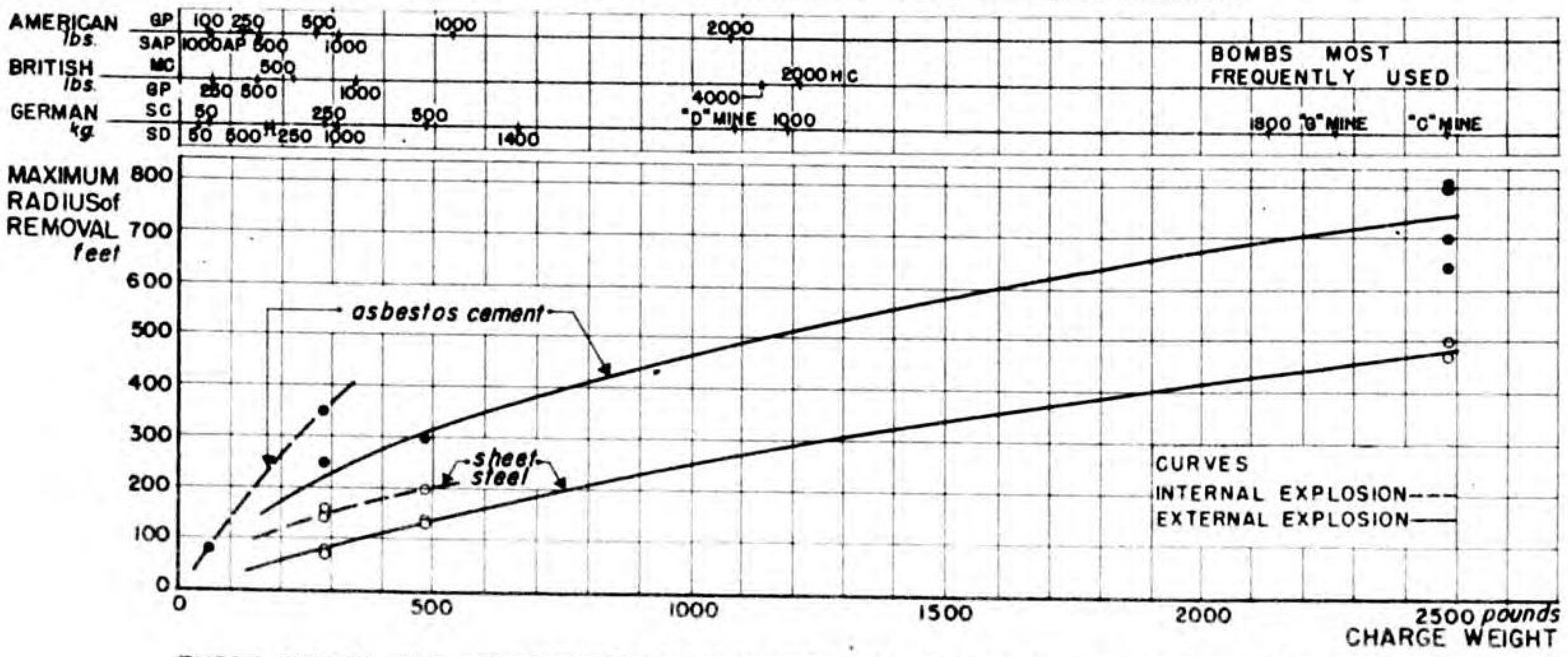
WEAPON DATA

6 A3* ROOFING

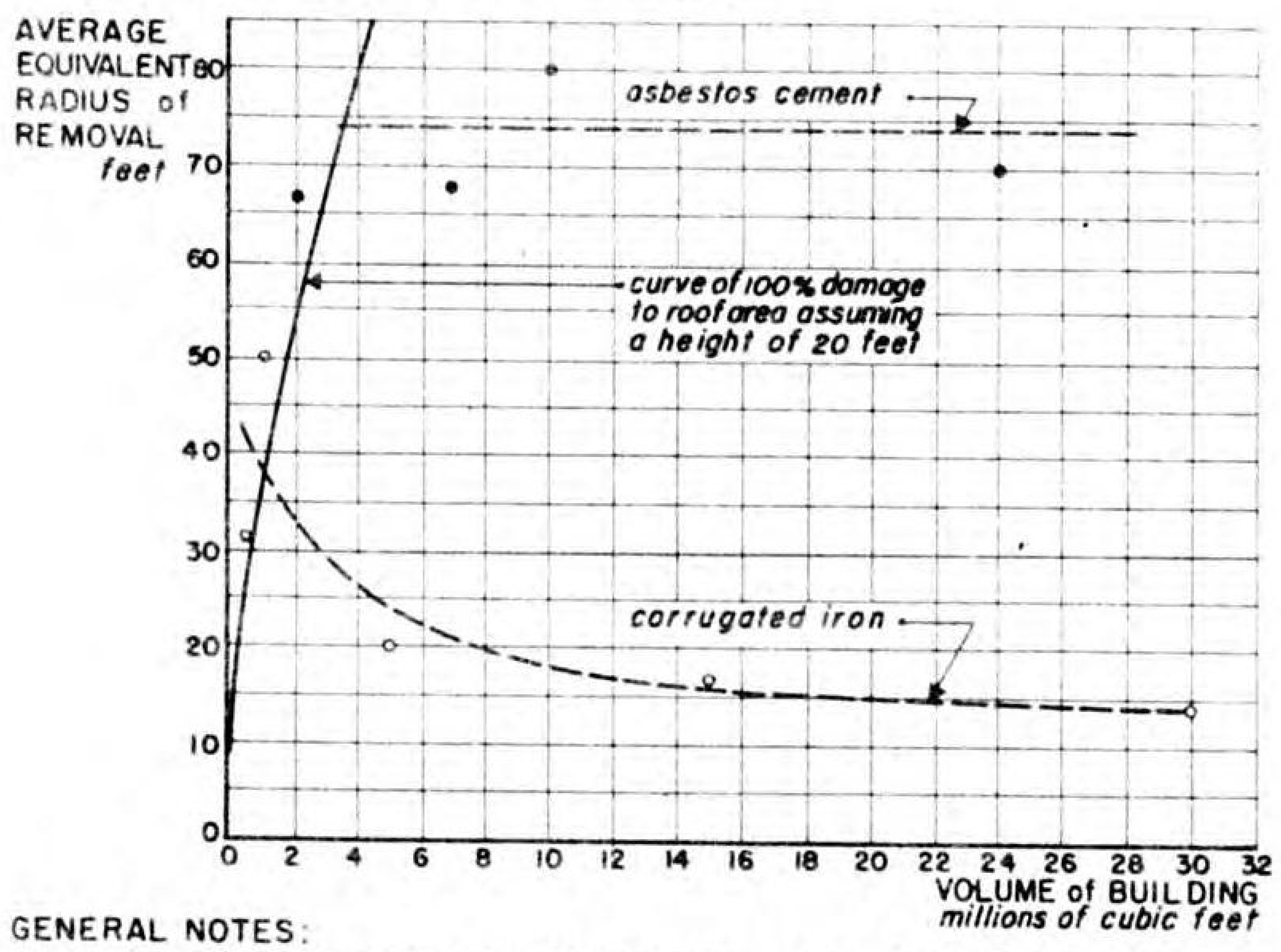
REMOVAL OF LIGHT-WEIGHT SHEET ROOFING BY BLAST

A MAXIMUM RADIUS OF REMOVAL AS A FUNCTION OF THE CHARGE WEIGHT



THESE CURVES GIVE APPROXIMATE MAXIMUM DISTANCES, MEASURED ON PLAN, AT WHICH THE REMOVAL OF SHEET ROOFING MAY BE EXPECTED DUE TO EXPLOSION OF VARIOUS CHARGES INSIDE OR OUTSIDE OF STEEL-FRAME FACTORY TYPE BUILDINGS. GERMAN MINES APPARENTLY PRODUCE GREATER BLAST EFFECTS THAN BOMBS OF EQUAL CHARGE WEIGHT. ACCORDINGLY, CHARGE WEIGHTS FOR "C" AND "D" TYPE PARA-MINES SHOULD BE TAKEN ABOUT 60% GREATER THAN THEIR NOMINAL VALUES, WHILE THAT FOR THE TYPE "G" MINE SHOULD BE INCREASED ABOUT 40% IN ORDER TO ALLOW FOR THE EFFECT OF A RELATIVELY THICKER STEEL CASE.

B REMOVAL OF ROOFING BY ONE 110-lb. (50 kg. SC) G.P. BOMB EXPLODING INSIDE SINGLE STORY SHED-TYPE BUILDINGS OF VARIOUS VOLUMES



THIS CHART GIVES THE AVERAGE EQUIVALENT RADIUS OF REMOVAL OF SHEET ROOFING BY A SINGLE 110-lb. G.P. (50 kg., sc) BOMB EXPLODING INSIDE OF SINGLE STORY SHED BUILDINGS OF VARIOUS VOLUMES..... AVERAGE RADIUS IS THE RADIUS OF A CIRCLE OF AREA EQUAL TO THE AREA OF DAMAGE, ALL MEASUREMENTS BEING ON PLAN ... THE AVERAGE HEIGHT OF BUILDINGS EXAMINED IS 20 ft. TO EAVES. ASBESTOS CEMENT ROOFING IS AFFECTED TO A MUCH GREATER DISTANCE THAN CORRUGATED IRON; HOWEVER, THE LATTER HAS A GREATER TENDENCY TO CONFINE THE EXPLOSION.

GENERAL NOTES:

WHEN HOOK BOLTS ARE PLACED MORE THAN ONE TO EACH 6 TO 8 SQUARE FEET OF CORRUGATED IRON ROOFING, PURLINS WILL BE DAMAGED; WITH FEWER HOOK BOLTS, A RELATIVELY GREATER NUMBER OF SHEETS WILL BE BLOWN OFF........ INSULATION BOARD PLACED UNDER THE PURLINS PROMOTES TRANSFER OF BLAST UPLIFT EFFECT TO THEM, USUALLY CAUSING GREATER STRUCTURAL DAMAGE.... RADII OF DAMAGE FOR BOARDED ROOFS CAN BE TAKEN TO BE APPROXIMATELY 30% LESS THAN THOSE FOR STEEL SHEETS..... FOR SLATES AND TILES ON BATTENS, RADII ARE OF THE SAME ORDER AS THOSE FOR ASBESTOS CEMENT....... CHARTS "A" AND "B" ARE BASED ONLY ON INCIDENTS IN WHICH BOMBS EXPLODED AT OR ABOVE GROUND LEVEL...... DAMAGE WOULD BE EXPECTED TO BE LESS FOR EXPLOSIONS BELOW GROUND.

DATA COMPILED FROM R.E. NOTE 220 AND R.E. 4 - DATA COMPILATION NO 8, BRITISH MINISTRY OF HOME SECURITY.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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WEAPON DATA

6 A4* GLASS DAMAGE

BLAST DAMAGE TO GLASS

The table gives the distance for 50% probability of glass breakage by explosion of high explosive bombs, for several common sizes and strengths of glass window panes. Values are given for panes in the *side-on* position relative to the blast, and may be used either for simply supported ones or for those restrained at the edges. If the glass is *face-on* to the blast and there is no shielding, the distance may be doubled or greater. If the glass is partially shielded from the blast, the distance will be reduced. For loose fitting panes this distance may be one-half that given in the table.

DISTANCE FOR 50% PROBABILITY OF GLASS BREAKAGE BY AIR BLAST FROM BOMBS

Glass		Bomb Size *lb* and Type					
Size *in*	Modulus of Rupture *lb/in²*	100 GP	250 GP	500 GP	1000 GP	2000 GP	4000 LC
		Distance for 50% Breakage of Glass, *feet*					
11x14x0.12	3000	290	420	540	720	910	1300
	4000	210	300	400	530	670	1000
	5000	140	210	290	390	500	760
11x14x0.25	3000	70	100	130	170	220	320
	4000	50	80	100	130	160	240
	5000	40	60	70	100	130	180
15x15x0.12	3000	360	520	680	920	1200	1700
	4000	250	370	490	670	850	1300
	5000	160	240	340	470	610	950
12x18x0.12	3000	400	580	760	1020	1300	1900
	4000	280	420	550	740	940	1400
	5000	190	290	390	540	690	1060
12x18x0.25	3000	100	150	190	250	310	450
	4000	80	110	140	180	230	340
	5000	50	80	100	140	180	260
28x32x0.12	3000	860	1400	2000	2800	3800	6100
	4000	540	910	1300	1900	2600	4300
	5000	250	450	690	1080	1600	2800
28x32x0.25	3000	290	430	590	810	1050	1600
	4000	190	300	410	560	750	1160
	5000	110	180	260	380	510	820
48x48x0.12	3000	910	1600	2500	4100	6000	10500
	4000	470	1020	1600	2600	3800	7000
	5000	140	350	670	1100	1700	3500
48x48x0.25	3000	400	680	990	1500	1900	3200
	4000	250	430	640	980	1300	2200
	5000	100	200	310	510	740	1400
48x84x0.25	3000	570	1020	1500	2400	3300	5600
	4000	340	610	940	1500	2100	3800
	5000	140	270	430	760	1100	2100

Special atmospheric conditions may greatly increase the distances given in the table.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

WEAPON DATA

6 A5* EARTH SHOCK UNDERGROUND R/C WALLS

EFFECT OF EARTH SHOCK ON UNDERGROUND REINFORCED CONCRETE WALLS

MAXIMUM DISTANCE for indicated degree of damage, r in *ft*

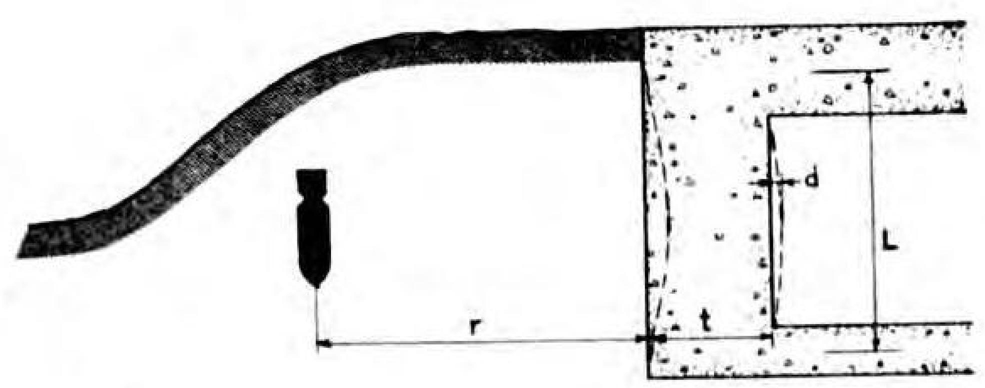
WALL THICKNESS, *ft*	100-lb GP AN-M30			250-lb GP AN-M57 500-lb SAP AN-M58			500-lb GP AN-M64 1000-lb SAP AN-M59			1000-lb GP AN-M65			2000-lb GP AN-M66			12000-lb GP T10			22000-lb GP T14		
	MODERATE	HEAVY	BREACH	MODERATE	HEAVY	BREACH	MODERATE	HEAVY	BREACH	MODERATE	HEAVY	BREACH	MODERATE	HEAVY	BREACH	MODERATE	HEAVY	BREACH	MODERATE	HEAVY	BREACH
1	11.6	7.8	5.6																		
2	8.2	5.8	4.2	12.4	8.7	5.3	18.0	12.4	9.0		17.0	12.3									
3	6.5	4.6	2.9	10.1	7.1	5.0	14.7	10.5	7.5	21.0	14.6	10.6	29.8	20.2	14.7						
4	5.3	3.5		8.5	6.0	3.7	12.7	9.0	6.3	18.2	12.9	9.2	25.9	18.1	13.1		36.0	26.0			
5	4.3	*1.8*		7.2	4.9		11.1	7.8	4.9	16.2	11.5	8.1	23.0	16.4	11.8	49.0	33.5	24.0		36.0	26.0
6	*2.5*			6.3	*3.8*		9.8	6.6	2.5	14.6	10.3	6.8	21.0	14.9	10.5	46.5	32.0	23.0	50.0	33.5	24.5
7				*5.1*			8.6	5.7		13.2	9.1	5.2	19.3	13.7	9.4	41.5	29.0	21.5	46.0	32.0	23.0
8				*2.9*			7.6	*4.2*		11.9	8.1		17.8	12.5	7.9	39.0	27.5	20.0	43.5	30.5	21.5
9							*6.6*			10.9	7.1		16.3	11.3	6.1	36.5	26.0	18.5	40.5	28.5	20.5
10							*4.7*			9.9	*5.6*		15.2	10.4		34.5	24.5	17.5	38.5	27.5	19.5

The bombing efficacy is $\pi r^2/w$ where πr^2 is the area in square ft within which any walls present will be damaged, and w is the weight of the explosive charge in the bomb, in pounds. For area bombing of underground walls, the efficacy reaches a maximum for $t/w^{1/3}$ between 0.4 and 0.5, where t is the thickness of the wall in feet. This determines the optimum size of bomb for area bombing of underground walls of any known thickness.

Similarly, for area bombing of very long narrow underground targets with reinforced concrete walls, the maximum expectation of damage per pound of explosive will be attained for $t/w^{1/3}$ between 0.8 and 1.0 for breaching or heavy damage.

DAMAGE CRITERIA ASSUMED:

DESCRIPTION OF DAMAGE	TYPE OF DAMAGE		d/L, in/ft
	2-edge support	4-edge Support	
SLIGHT	Fine Cracks	Fine Cracks	0.02
MODERATE	Medium Cracks	Light Scabbing	0.1
HEAVY	Heavy Cracks and Scabbing	Severe Scabbing	0.2
BREACHING	Breached	Breached	0.5

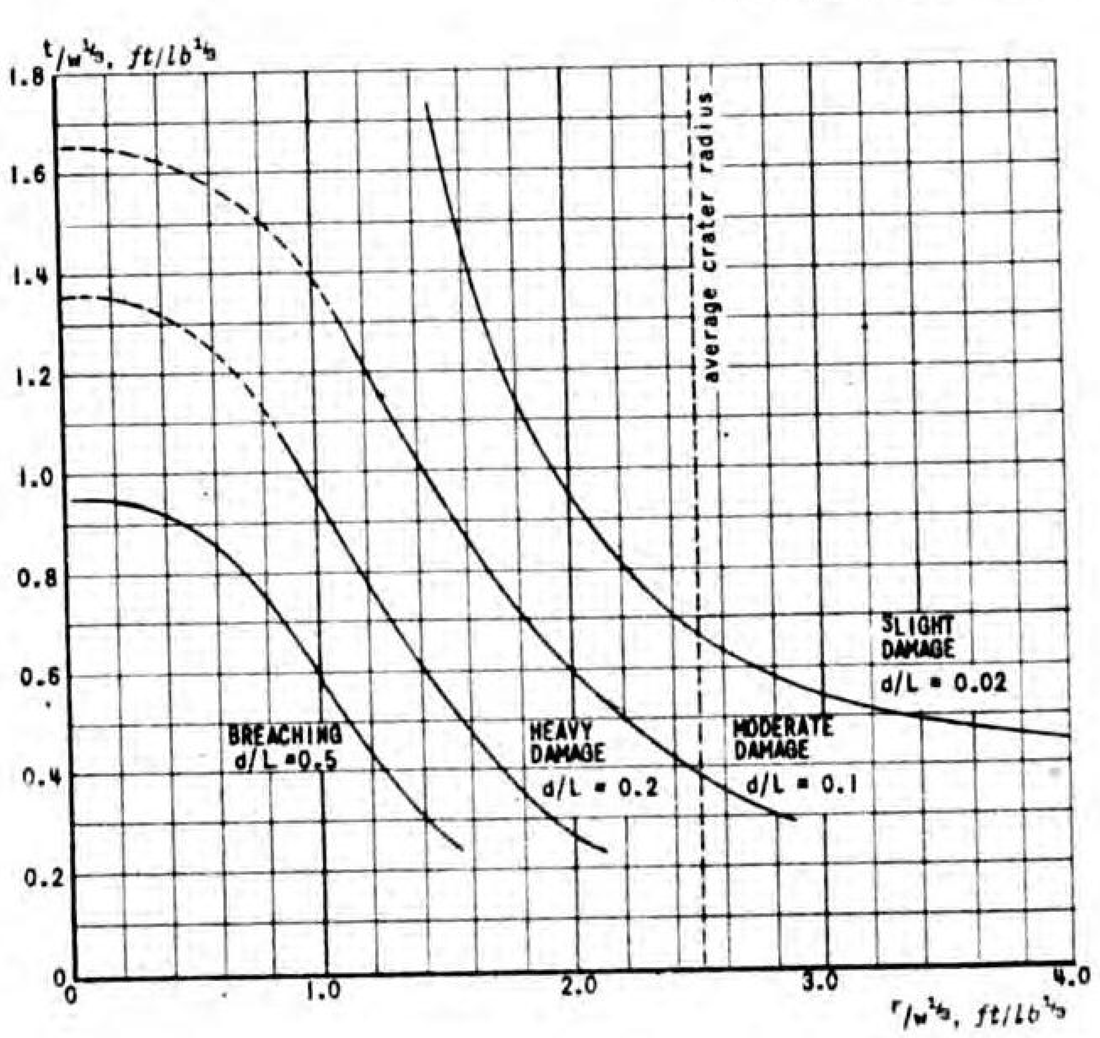


The table gives values of the maximum distance at which various degrees of damage will result from detonation of bombs in earth. The figures given in the table apply to lightly reinforced rectangular concrete wall panels supported along either two opposite edges or along all four edges. The bomb is assumed to be approximately opposite the center of the face of the wall; any marked departure from this position will generally result in less damage. Under the same conditions the 2-edge and 4-edge supported walls will be damaged differently as described by the *Damage Criteria* above, but the ratio of central deflection to span is a good measure of damage for both types.

This information is based on tests of walls whose face dimensions are in the ratio of about 3:5, and whose span to thickness ratio is between 5:1 and 15:1. The test walls were reinforced with mild steel bars, about one percent by volume. Damage and central deflection were measured for bombs detonated at various distances on the earth side of the wall as shown in the sketch. Charge weights used in these tests ranged from 1/8 lb to 1000 lb.

The graph gives the ratio of central deflection to span for various wall thicknesses and charge distances in terms of the scale variables $t/w^{1/3}$ and $r/w^{1/3}$.

Tabulated values based on only meager data are given in *italics*. Similarly, the corresponding parts of the curves on the graph are dotted.



SOURCES:
Tests by Ministry of Home Security and Road Research Laboratory (British) and by Committee on Fortification Design (U.S.A.)

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Ref: EWT-5g (OSRD-5405g)
★Revised: August 1945

WEAPON DATA

6 A6* DAMAGE TO R/C WALLS IN AIR

DAMAGE TO REINFORCED CONCRETE WALL PANELS BY DETONATIONS IN AIR

MAXIMUM DISTANCE for indicated degree of damage, r in *ft*

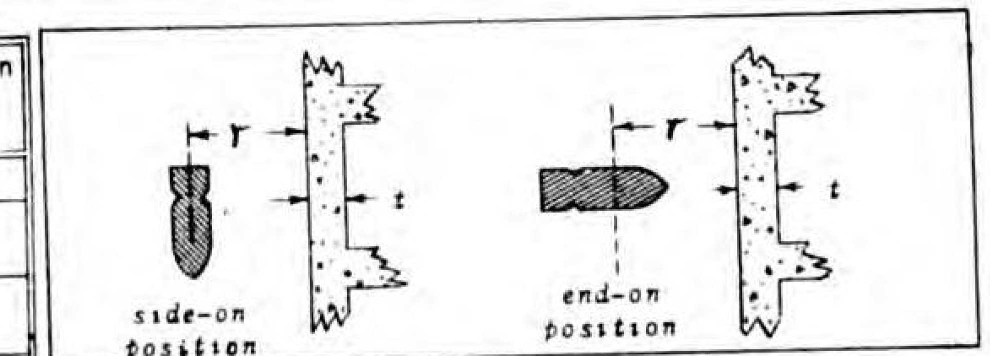
WALL THICKNESS, *ft*	100-lb GP AN-M30			250-lb GP AN-M57 500-lb SAP AN-M58			500-lb GP AN-M64 1000-lb SAP AN-M59			1000-lb GP AN-M65			2000-lb GP AN-M66			12000-lb GP T10			22000-lb GP T14		
	MODERATE	HEAVY	BREACHING	MODERATE	HEAVY	BREACHING	MODERATE	HEAVY	BREACHING	MODERATE	HEAVY	BREACHING	MODERATE	HEAVY	BREACHING	MODERATE	HEAVY	BREACHING	MODERATE	HEAVY	BREACHING
1	3.1	2.2	1.2	5.4	4.4	2.6	9.4	7.9	3.9			9.0	11.8	9.6	5.7			18.9			
2	1.2	0.5		2.4	1.3	0.5	4.2	2.8	1.4	7.2	5.4	3.0	7.4	5.0	2.6	23.7	20.0	12.4	35.0		18.6
3	0.5			1.3	0.3		2.5	1.2	0.1	4.4	2.6	1.2	5.2	2.9	1.1	15.8	12.0	16.7	24.2	19.6	11.8
4				0.7			1.6	0.3		3.0	1.3		3.8	1.7		12.2	8.3	4.3	19.6	14.9	8.3
5							1.0			2.1	0.4		2.8	0.7		10.3	6.5	3.1	15.7	11.0	5.7
6										1.4			2.1	0.1		7.[illegible]	4.1	1.2	12.8	8.1	3.8
7													1.5			6.[illegible]	3.1	0.3	10.7	6.2	2.4
8																5.[illegible]	2.1		9.4	5.0	1.5
9																4.[illegible]	1.2		8.1	3.6	0.2
10																					

The bombing efficacy is $\frac{\pi r^2}{w}$ where πr^2 is the area in square feet within which any walls present will be damaged, and w is the weight of explosive charge in the bomb, in pounds. For area bombing of reinforced concrete walls the efficacy increases with the charge weight, so the maximum damage per pound of explosive will be attained by use of the bomb with the largest possible charge.

Similar reasoning shows that for area bombing of very long narrow targets having reinforced concrete walls, the bomb with the largest possible charge gives the greatest expectation of damage per pound of explosive.

DAMAGE CRITERIA ADOPTED:

DESCRIPTION OF DAMAGE	TYPE OF DAMAGE	Aver. Deflec'n / Span in/ft.
SLIGHT	Slight Cracking and Bending	0.1
MODERATE	Light Punching and Cracking with Possibly Some Spalling	0.5
HEAVY	Heavy Punching, Shattering, or Possible Perforation	1.2
BREACHING	Perforation with Extensive Scabing. Bars May be Bent or Bulged.	---



For contact and very near contact shots, nose-on position of a bomb will cause less damage than side-on. Figures given correspond to side-on position, the bomb detonating not far from a point opposite center of wall. Positions appreciably offside usually result in lessened damage.

The table gives max. distance at which an air-backed reinforced concrete wall or wall panel that will experience various degrees of damage due to explosion of TNT-filled bombs in air nearby or in side-on contact with the wall.

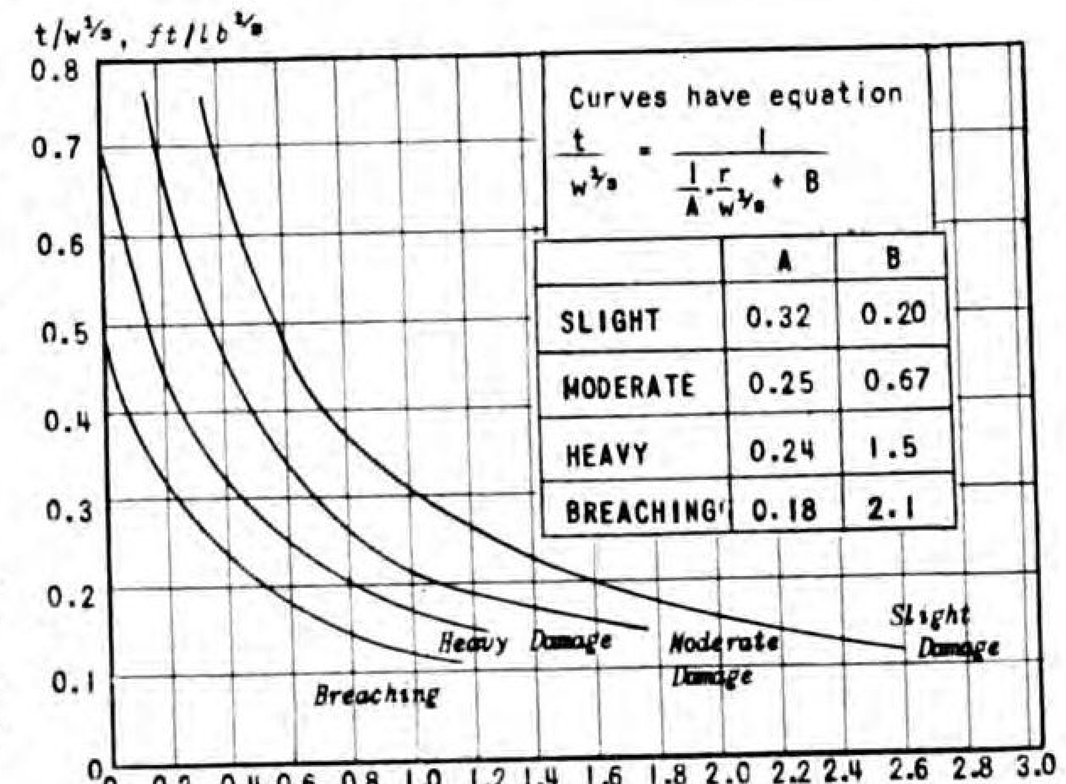
These data derive from tests, both model and full scale, on rectangular panels with face dimensions from 3 to 25 times the thickness. Charges used in tests ranged from about 1¼ oz. to 1700 lb. Test panels were supported along all four edges, and results showed no appreciable difference between freely supported and fixed edges.

Tests involved various degrees of reinforcing and different explosives, but all data were reduced to a basis of ½% steel by volume and bombs filled TNT. Degree of damage and ratio of central deflection to span correlate fairly well for slight, moderate and heavy damage.

Tabulated data refer to about ½% reinforcing steel by volume. For ½% steel, multiply thickness values by 0.9 for breaching and by 0.7 for other degrees of damage.

Fragments from nearby bomb detonations usually cause surface scars and a few perforations; this type of damage is not included in the present analysis.

The graph gives damage curves in terms of scale variables $r/w^{1/3}$ and $t/w^{1/3}$, where t = wall thickness (ft), r = distance from wall to bomb (ft) and w = weight of charge (lb).



SOURCE: Tests by Ministry of Home Security (British), Ordnance Department (U.S.A.), and Corps of Engineers, (U.S.A.).

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

PIM No.104 & EWT-3
★ Revised: August 1945

WEAPON DATA

DAMAGE TO SINGLE-STORY INDUSTRIAL BUILDINGS BY HE BOMBS

6 B1 HE BOMBS: INDUSTRIAL BUILDINGS

A. STRUCTURAL DAMAGE DUE TO HIGH EXPLOSIVE BOMBS

The table gives the Mean Area of Effectiveness (MAE) and the near miss distance for common General Purpose bombs (fuzed 0.1 seconds delay nose, 0.01 seconds delay tail) on European Type industrial buildings, and for the 4000-lb LC bomb (fuzed instantaneous). Bombs striking within the near miss distance from the building may be expected to cause damage comparable to that of a direct hit in about one out of ten cases. Bombs striking further from the building than the near miss distance cause no appreciable structural damage. The effects of the near miss hits are included in the values of MAE tabulated below.

STRUCTURAL CLASS 1, 3 and 5	MAE, *sq feet per bomb*, and NEAR MISS DISTANCE, r *in feet*							
	500-lb GP		1000-lb GP		2000-lb GP		4000-lb LC	
	MAE	NEAR MISS DISTANCE	MAE	NEAR MISS DISTANCE	MAE	NEAR MISS DISTANCE	MAE	NEAR MISS DISTANCE
(1) Single story, areas > 10,000 sq.ft. Principal spans of roof trusses < 75 ft. Height to eaves generally < 25 ft. Roof structure: simple beams and columns, arches or rigid frames, trusses, sawtooth trusses, etc. No traveling cranes.	3050 ± 250	15 ft	6400	20 ft	12,800	35 ft	32,000	80 ft
(3) Single story, areas > 10,000 sq ft. Principal spans of roof trusses > 75 ft. Height to eaves generally > 25 ft. Roof structure: lattice trusses, long span arches, etc. No traveling cranes.	5270 ± 950	15 ft	11,000	20 ft	22,000	35 ft	55,000	80 ft
(5) All single story buildings of < 10,000 sq.ft. plane area	3100 ± 250	15 ft	6500	20 ft	13,000	35 ft	33,000	80 ft

Results for the 500-lb GP bomb were obtained from an analysis of 38 USAAF attacks on European Industrial targets. The values of the MAE's were determined from the damaged data, and from the number of hits as determined by photointerpretation. The MAE's were determined from the relation $g = A[1-(1-M/A)^h]$ where g is the total area of damage, in square feet, A is the total area of the building in square feet, h is the total number of hits, and M is the MAE per bomb. Bombs used in the raids analyzed were fuzed 0.1 nose and 0.01 tail, or 0.1 nose and 0.025 tail, the majority of the bombs having the shorter fuzing. See EWT-2f for averaging process for a number of damaged buildings.

Values given for the 1000-lb and 2000-lb bombs were estimated from the values determined for the 500-lb GP bomb on the assumption that the MAE is proportional to the weight of charge in the bomb. Experience has shown that this assumption is approximately correct.

B. STRUCTURAL AND FIRE DAMAGE DUE TO HIGH EXPLOSIVE BOMBS

Analysis of a number of incidents has shown that the probability of a serious fire being started by a 500-lb GP bomb is 0.17. Thus the overall mean area of effectiveness for structural and fire damage in industrial buildings with 500-lb GP bombs is 0.83(MAE) + 0.17(E) where MAE is the mean area of effectiveness for structural damage and E is the average expected damage due to one fire. For combustible buildings, E is the total area of one fire division; for non-combustible buildings, E is approximately 35,000 sq.ft. for large fire divisions and a correspondingly smaller area for fire divisions smaller than 100,000 sq.ft. (see graph on sheet 6 B2). The table gives the gross MAE for both structural damage and fire damage for European industrial type buildings attacked by 500-lb GP bombs fuzed 0.1, nose, and 0.01, tail.

STRUCTURAL CLASS *see above*	COMBUSTIBLE or NON-COMBUSTIBLE	GROSS MAE, *sq ft per bomb* for Structural and Fire Damage by 500-lb GP Bombs on Fire Divisions of Different Areas, *sq ft*					
		7,000	15,000	30,000	60,000	100,000	200,000
1	C	3720	5080	7630	12,730	19,500	36,500
	N	3650	4570	6130	7390	8100	8370
3	C	5560	6920	9470	14,570	21,400	38,400
	N	5490	6410	7970	9230	9940	10,210
5	C	3760	5120	7670	12,770	19,600	36,600
	N	3690	4610	6170	7430	8140	8410

DEFINITIONS:

FIRE DIVISION: An area of a building separated from other areas by fire walls or by air gaps, within which a fire is expected to be retained.

COMBUSTIBLE: A building with roof which is constructed of wood sheathing or planking irrespective of whether or not it is supported by wood or non-combustible framing. Tile roofs on wood sheathing are also included in this classification.

NON-COMBUSTIBLE: A building with roof which is constructed of non-combustible material such as gypsum slab, concrete slab, corrugated iron, etc., and supported on exposed steel framing.

Once a fire is sufficiently well established to produce "serious" damage the extent of its spread does not depend on whether the fire is initiated by an incendiary Bomb or by a High Explosive Bomb.

A fire well established in a *combustible* roof single story fire division will usually burn out the division completely.

The structural classes given in the table are not characteristic of European construction only. Construction practice in various countries shows enough similarity to warrant using the values given for structural damage universally. Differences in roofing material may change the gross MAE materially.

WEAPON DATA

DAMAGE TO SINGLE-STORY INDUSTRIAL BUILDINGS BY INCENDIARY BOMBS

6 B2 INCENDIARIES: INDUSTRIAL BUILDINGS

Damage to industrial buildings by Incendiary Bombs is due to fires started by the bombs. The probability of an Incendiary Bomb starting a fire in a building depends strongly upon

- ROOF – Whether combustible or non-combustible.
- HEIGHT – Height to eaves of a single story building. (Height of upper story only for multi-story buildings)
- OCCUPANCY – Percentage of floor area covered by combustible material, as estimated by Intelligence.

Once a fire is sufficiently well established to cause "serious" damage the extent of its spread does not depend on the origin of the fire. A fire well established in a *combustible roof* fire division will usually burn out the entire fire division. A fire well established in a *non-combustible roof* fire division usually burns out only a part of the fire division.

The Mean Area of Effectiveness, MAE, of incendiary bombs for one fire division of an industrial building with a combustible roof is equal to the area of the fire division times the probability of a fire being started by an incendiary bomb; for an industrial building with a non-combustible roof, the MAE is equal to the area which will be burned out* times the probability of a fire being started by an incendiary bomb. Thus the MAE depends on the *roof*, the *height*, the *occupancy* and the *area* of the fire division. The table gives the MAE in square feet per bomb for various combinations of these factors

*(See graph below)

MEAN AREA OF EFFECTIVENESS, (MAE) *square feet per bomb*, FOR INCENDIARY BOMBS AGAINST INDUSTRIAL BUILDINGS

BUILDING CLASSIFICATION		100-lb, IB, AN-M47 Area of One Fire Division, *sq ft*						4-lb, IB, AN-M50 Area of One Fire Division, *sq ft*						
Height *feet*	Occupancy *percent*	7000	15000	30000	60000	100000	200000	7000	15000	30000	60000	100000	200000	
7-9 or 10-19	5	2300	5000	9900	19800	33000	66000	0	0	0	0	0	0	COMBUSTIBLE
	15	4600	9900	19800	39600	66000	132000	140	300	600	1200	2000	4000	
	25	5500	11700	23400	46800	78000	156000	350	750	1500	3000	5000	10000	
	35	6200	13400	26700	53400	89000	178000	700	1500	3000	6000	10000	20000	
	45	7000	15000	30000	60000	100000	200000	1050	1250	4500	9000	15000	30000	
20-29	5	1200	2500	5100	10200	17000	34000	0	0	0	0	0	0	
	15	2400	5000	9900	19000	33000	66000	70	150	300	600	1000	2000	
	25	2700	5800	11700	23400	39000	78000	210	450	900	1800	3000	6000	
	35	3100	6600	13200	26400	44000	88000	350	750	1500	3000	5000	10000	
	45	3500	7500	15000	30000	50000	100000	490	1050	2100	4200	7000	14000	
30-39	5	490	1050	2100	4200	7000	14000	0	0	0	0	0	0	
	15	840	1800	3600	7200	12000	24000	0	0	0	0	0	0	
	25	1120	2400	4800	9600	16000	32000	140	300	600	1200	2000	4000	
	35	1260	2700	5400	10800	18000	36000	210	450	900	1800	3000	6000	
	45	1400	3000	6000	12000	20000	40000	280	600	1200	2400	4000	8000	
40-49	5	210	450	900	1800	3000	6000	-	-	-	-	-	-	
	15	490	1050	2100	4200	7000	14000	-	-	-	-	-	-	
	25	560	1200	2400	4800	8000	16000	-	-	-	-	-	-	
	35	630	1350	2700	5400	9000	18000	-	-	-	-	-	-	
	45	700	1500	3000	6000	10000	20000	-	-	-	-	-	-	
50-59	0-45	0	0	0	0	0	0	-	-	-	-	-	-	
all heights	5	0	0	0	0	0	0	NON-COMBUSTIBLE						
	15	0	0	0	0	0	0							
	25	380	730	1200	1700	2000	2100							
	35	820	1600	2600	3700	4300	4500							

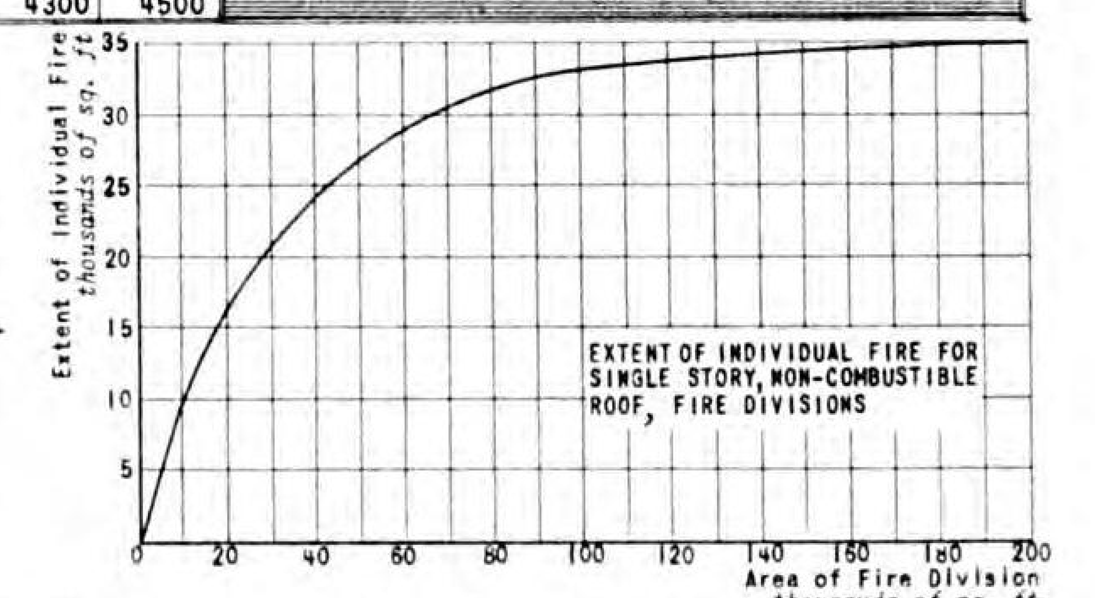
DEFINITIONS:

FIRE DIVISION: An area of a building separated from other areas by fire walls or by air gaps, within which a fire is expected to be retained.

COMBUSTIBLE: A building with roof which is constructed of wood sheathing or planking irrespective of whether or not it is supported by wood or non-combustible framing. Tile roofs on wood sheathing are also included in this classification.

NON-COMBUSTIBLE: A building with roof which is constructed of non-combustible material such as gypsum slab, concrete slab, corrugated iron, etc., and supported on exposed steel framing.

Values given for the M-47 are considered more reliable than those for the M-50.



The information given here was based on analysis of USAAF attacks on European Industrial targets. These values can be applied to structures of other types only if the effects of differences in construction, combustibility of the roof, and type and extent of the occupancy are taken into account. (See EWT-5)

BOMBING OF STEEL MILLS

In a steel plant large enough for coke ovens and steel furnaces to be used as separate targets, the best bombs are the 500-lb GP fuzed 0.025 sec delay for the coke ovens and the 2000-lb GP fuzed 0.025 or 0.1 sec delay for the steel furnaces. If one overall attack is to be made, the best bomb is the 1000-lb GP fuzed 0.025 sec delay, with the 2000-lb GP fuzed 0.025 sec delay a good second choice.

The principal components of a steel mill in order of their vulnerability to bombing attack, the recommended bomb and fuze delay, and the results to be expected from bombing attack are as follows:

COMPONENT	RECOMMENDED BOMB & FUZE	RESULTS
Coke Ovens	500-lb GP or 1000-lb GP. 0.025 sec delay	One direct hit will disable one section for 3 to 8 months. This will reduce the quantity of coke and gas available to the blast furnaces. Auxilliary equipment such as the aspirating plant, coke loading and ramming equipment, etc. is also highly vulnerable.
Open Hearth Furnaces	2000-lb GP or 1000-lb GP. 0.025 or 0.1 sec delay	At least 25% of the furnaces must be damaged to affect production seriously. Damaged ovens require several months for repairs. Gantry cranes and other equipment are additional targets.
Blooming Mills	2000-lb GP or 1000-lb GP. 0.025 or 0.1 sec delay	These are frequently a bottleneck of the plant. Small,target, but essential to operation and difficult to repair. Smaller bombs could damage controls.
Blast Furnaces and related equipment	2000-lb GP 0.025 or 0.1 sec delay	Direct hits required. Small target. Stoves, hoists, and charging equipment are also vulnerable to smaller bombs. Long repair or rebuilding time if a direct hit is made on furnace
Conveying Equipment and Services	500-lb GP or larger	Good secondary objectives within the target area. Bridge cranes at ore docks, coke pushers, gantry cranes throughout plant, etc. are all essential and vulnerable to direct hits. Services are essential and vulnerable to direct hits or near misses.
Air Compressors	2000-lb GP or larger. 0.1 or 0.025 sec delay	Important, but of very heavy construction. Small target difficult to hit and damage.

BOMBING OF DAMS

Planning attacks on dams of all types requires careful engineering investigation of the design. In general, the largest practicable bomb should be used. Many dams will not be vulnerable to any bomb smaller than the 12,000-lb or 22,000-lb GP, or some special weapon.

Attack on a dam should be made when the water level behind the dam is at its highest stage.

Earth dams are best attacked with GP bombs: by deeply cratering the crest if the dam contains no steel or concrete core; by deep penetration and resulting shattering of such a core if present; or by deeply cratering the upstream slope of the seal blanket. The choice of the method depends on the design. Long delay fuzing should be used in most cases.

Masonry and concrete dams should be attacked by the underwater explosion of a large charge in contact with the dam on the upstream side; the details to be carefully worked out for all larger dams. Fuzing should be of short delay, sufficient to develop the full tamping effect of the water.

Gates can be attacked by the adjacent underwater explosion on the upstream side of fairly large bombs with short delay fuzing (0.025 sec) sufficient to develop the full tamping effect of the water.

Operating machinery and control houses are best attacked by the direct hit of intermediate sized bombs fuzed with slight delay (0.025 sec or 0.01 sec) for penetration into the building. There is no appreciable near-miss damage and even total destruction is not too serious.

WEAPON DATA

6 C2b
PENSTOCKS

BOMBING OF PENSTOCKS

The best mode of attack on penstocks is by means of bombs that will penetrate the pipe and explode in the interior. The use of bombs intended to produce large movements of the pipe through earth shock, air blast, or by cratering, is not likely to be effective.

It is recommended that GP bombs, fuzed 0.01 sec nose and tail, be used. Table I shows sizes of bombs required to rupture penstocks when the bomb explodes at the center of the penstock. Generally, an up-slope approach within 30° of the pipe axis, at medium to high altitude gives the largest equivalent horizontal vulnerable area. But the probability of hitting the pipe and of the explosion occurring in the lethal annulus of the pipe must be considered.

Table I

SIZES OF BOMBS REQUIRED TO RUPTURE PENSTOCKS WHEN EXPLODED AT THE CENTER

Diameter of Pipe *ft*	Thickness of PipeWall *in*	Size of Rupturing Charge of TNT *lb*	Size of GP Bomb *lb*
22	1.50	525	1000
16	1.25	240	500
13	1.00	127	250
10	0.75	56	100

If the bomb explodes near the side wall, a smaller bomb than listed above may be sufficient to split the pipe.

A detailed study of the vulnerability of penstocks is given in the first reference. On the basis of model tests made to determine the weight of charge required to rupture a penstock by internal explosion, and of ricochet tests conducted against curved air-backed plates and against water-filled cylinders, recommendations are made as to the weapon to be used in attack. A table of equivalent horizontal vulnerable area factors is given for various slopes of penstocks, angles of fall of bomb, and angles of attack, as an aid to selecting the best combination of bombing conditions and the lowest required bomb density. A procedure for analyzing a penstock installation to determine the type of bombing attack required is given. By means of this analysis, the type, size, and fuzing of bombs and the bombing density can be determined for any desired probability of destruction of the penstock. Diagrams and curves are given to assist in the computation.

WEAPON DATA

6 D1
GUN POSITIONS

BOMBING OF GUN POSITIONS

OPEN GUN EMPLACEMENTS

The table gives the Mean Area of Effectiveness for unserviceability and the Mean Area of Effectiveness for temporary unserviceability in square feet per bomb for light, medium, and heavy guns. Values are for guns that do not have protective shielding of the vulnerable parts.

In the table, guns are classified as *light* (20mm and 37mm), *medium* (75mm to 120mm) and *heavy* (150mm and larger). *Unserviceability* means damage requiring shop repair or more than 24 hours field repair. *Temporary unserviceability* means unserviceable but repairable in less than 24 hours. MAE is defined in data sheet 6 D3.

MEAN AREA OF EFFECTIVENESS PER BOMB FOR VARIOUS BOMBS vs UNSHIELDED GUNS

	BOMB			Light Guns		Medium and Heavy Guns	
		Crater Radius *feet*	Fuzing *sec*	MAE for Unserviceability *sq.ft.*	MAE for Temporary Unserviceability *sq.ft.*	MAE for Unserviceability *sq.ft.*	MAE for Temporary Unserviceability *sq.ft.*
EARTH SHOCK open or revetted	100-lb GP,AN-M30	9.25	1/100	1000	4300	270	1600
	250-lb GP,AN-M57	12.0	or	1800	7200	450	2700
	500-lb GP,AN-M64	15.5	1/40	3000	12000	750	4500
	1000-lb GP,AN-M65	19.75	"	4900	19600	1200	7300
FRAGMENTATION guns in open	20-lb F,AN-M41		Inst.	Lack of data does not warrant prediction of MAE for light guns.		300	600
	20-lb Para.Frag		"			300	600
	90-lb F,AN-M82		"			2400	4800
	100-lb GP,AN-M30		"			3700	7400
	260-lb F,AN-M81		"			7000	14000
	500-lb GP,AN-M64					10400	20800

MEAN AREA OF EFFECTIVENESS for UNSERVICEABILITY

	BOMB	Fuzing	Light Guns Diameter of Emplacement					Medium Guns Diameter of Emplacement				
			20'	30'	40'	50'	60'	20'	30'	40'	50'	60'
FRAGMENTATION guns in revetments	20-lb F,AN-M41	Inst.	300	-	-	-	-	300	-	-	-	-
	20-lb Para.Frag	"	300	-	-	-	-	300	-	-	-	-
	90-lb F,AN-M82	"	600	1100	1800	2600	3600	600	950	1500	2000	2300
	100-lb GP,AN-M30	"	600	1100	1800	2600	3600	600	1100	1800	2400	3200
	260-lb F,AN-M81	"	600	1100	1800	2600	3600	600	1100	1800	2600	3200
	500-lb GP,AN-M64	"	600	1100	1800	2600	3600	500	1100	1800	2600	3200
	"	VT	10400	10400	10400	10400	10400	10400	10400	10400	10400	10400
	"	"	20800 sq.ft. MAE for Temporary Unserviceability for all revetted guns.									

COVERED CONCRETE GUN EMPLACEMENTS

Covered concrete gun emplacements can be destroyed by a bomb perforating the roof and detonating inside of the structure, or seriously damaged by a bomb exploding underground close to the side walls. Bombs should be fuzed 0.025 seconds delay for either type of damage. Data sheet 2C1a may be used to select bombs capable of perforating the roof, and the radii for *breaching* given in Data Sheet 6A5* may be used as near miss distances for damage underground explosion close to the wall. The vulnerable area for *perforation* is the inside plan area of the gun emplacement, and the vulnerable area for *damage by near misses* is the area of a band around the outside of the emplacement, having a width equal to the near miss distance defined above. The most efficient bomb is that bomb having the largest vulnerable area per ton, and is usually the smallest bomb capable of perforating the roof of the gun emplacement.

PASSAGE OF WIRE AND OBSTACLES

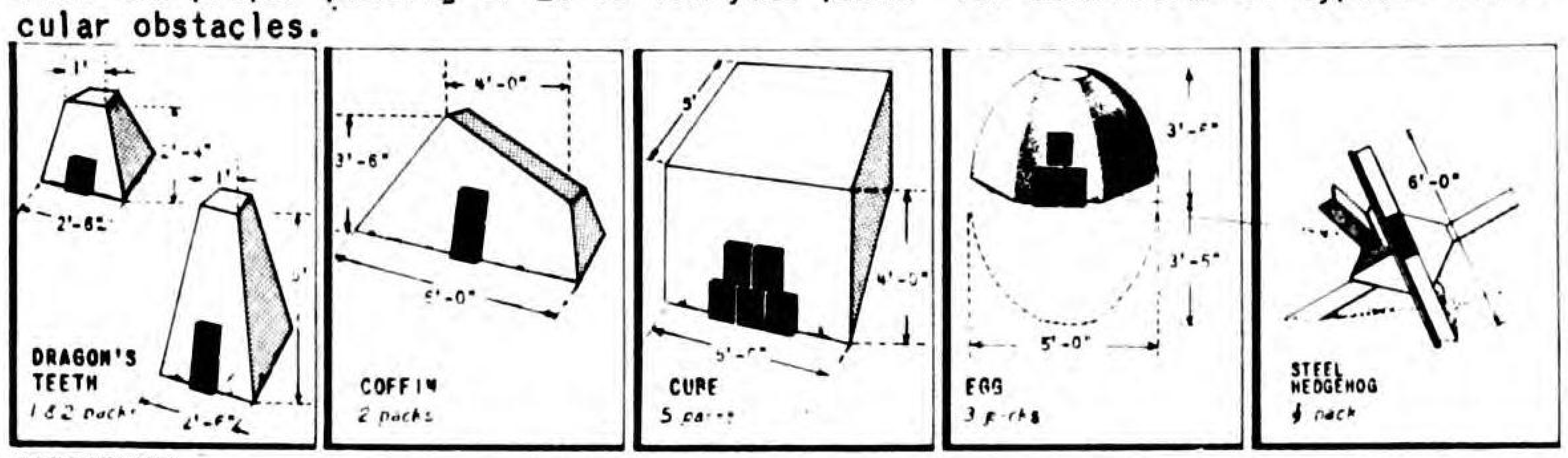
BARBED WIRE

Barbed wire may be cleared by aerial bombardment, rocket attack, or ground demolition. The table gives the average radius of clearance of ordinary barbed wire obstacles by various explosive weapons. Within the radius of clearance, trip wires of anti-personnel mines will also be cut.

WEAPON	RADIUS OF CLEARANCE, *feet*
100-lb GP Bomb, fuzed nose inst.	15 - 17
350-lb Depth Bomb, fuzed nose inst.	25 - 30
7.2-in Demo Rocket, fuzed inst.	10 - 12
Bangalore Torpedo, on ground	gap 15 - 20 feet wide

OBSTACLES

Bombing has definitely proven ineffective against obstacles of concrete, stone, wood, or steel. Hand placed demolition charges are usually necessary for destruction of smaller vehicular obstacles, although direct hits with the 7.2-in Demolition Rocket are effective against some types of small obstacles. Obstacles may be demolished by hand placed charges made up of 20-lb Tetrytol packs, using approximately one pound of explosive for each cubic foot of obstacle. The sketches show the proper placing of 20-lb Tetrytol packs for demolition of typical vehicular obstacles.



REFERENCES

A very comprehensive study of this subject is contained in the following reports:

The Engineer Board. Interium Reports on the Passage of Beach and Underwater Obstacles.

Joint Army-Navy Experimental and Testing Board. Progress Reports.

Additional reports concerned with particular phases of the problem are:

War Dept., Technical Bulletin. TB Eng 8, February '44. Methods of Passing Beach and Underwater Obstacles.

War Dept., Engineer Field Manual, FM5-30 Obstacle Technique.

Ordnance Section. 12th Air Force, Bomb Damage Survey of Pre-Invasion Targets in Southern France, **September 30, 1944**

Operational Research Section, 9th Bomber Command, Estimate of Bombing Attacks on the Siegfried Line, **September 13, 1944**

Observers' Report-Army Ground Forces, May 1945, Removal of Beach and Underwater Obstacles; Iwo Jima and Philippine Campaign.

War Dept., Operations Division, June 1945, Reduction of Beach Defenses and Obstacle Clearance in Normandy.

Army Operational Research Group, Report No. 179 (British), Lethal and Material Effects of Gunfire and Bombing Land Targets.

FRAGMENTATION DAMAGE: AIRCRAFT, VEHICLES, PERSONNEL

For discrete targets such as men, guns, tanks, trucks, planes, etc, the mean area of effectiveness (MAE) of a bomb against a target is defined as follows: Using Cartesian coordinates (x, y) in a horizontal plane with the target at $(0,0)$, the probability of target damage of a specified degree or more is a function $p(x,y)$ of the coordinates of the bomb. The MAE is then defined to be $\iint p(x,y)\,dx\,dy$, the integral being taken over all parts of the x,y-plane for which $p(x,y)>0$. Geometrically this may be interpreted as the volume under the surface $z = p(x,y)$ and above the x,y-plane. The physical dimensions, however, are those of area.

The above function $p(x,y)$, and hence the MAE, depend on (1) type of bomb and fuzing, (2) operational conditions under which bomb is dropped, (3) type of target, (4) degree of damage specified, and (5) ground conditions near target, such as unevenness of ground, presence of shielding objects, etc.

A physical picture of the meaning of an MAE may be obtained as follows: Suppose targets are distributed randomly and uniformly, that is, the expected number of targets in a region is proportional to the area of the region. Then the MAE is the area of a circle centered at the bomb and of a size such that the expected number of targets receiving the specified degree of damage outside the circle equals the expected number not receiving the specified degree of damage inside the circle.

The MAE is used as follows: Suppose that an area contains a number of discrete targets with the same MAE = M; the targets need not be uniformly distributed. If a density of D bombs per unit area is delivered to the target, then the expected fraction F of targets damaged is given by $F = 1 - e^{-MD}$. For light densities D such that MD is small compared with 1, F = MD approximately. The exponential formula is derived under the assumption that the bombs are distributed randomly and uniformly over an area large enough to include all possible positions of a bomb capable of damaging any of the targets under consideration.

MAE FOR SUBSTANTIAL DAMAGE BY FRAGMENTS, *sq. ft per bomb*

TARGET	Ground Burst., Inst. Fusing			Air Burst US 500-lb GP	
	British 500-lb MC	British 250-lb MC	Cluster of 18 US Frag AN-M41	Height of burst 10 feet	Height of burst 36 feet
Aircraft	79,000	45,000	110,000		
Mechanical transport	44,000	21,000	100,000	38,000	16,000
Men in deep trenches				5,200	4,800
Men in shallow trenches				5,600	8,000
Men prone, unshielded	24,000	22,000	90,000	25,000	24,000

Substantial damage is defined as follows: For aircraft - complete destruction or damage requiring more than 10 man-days for repair. For mechanical transport-damage involving write-off or requiring repair at a second echelon or base workshop. For personnel - incapacitation.

Source: Bombing trials by the British at Ashley Walk.

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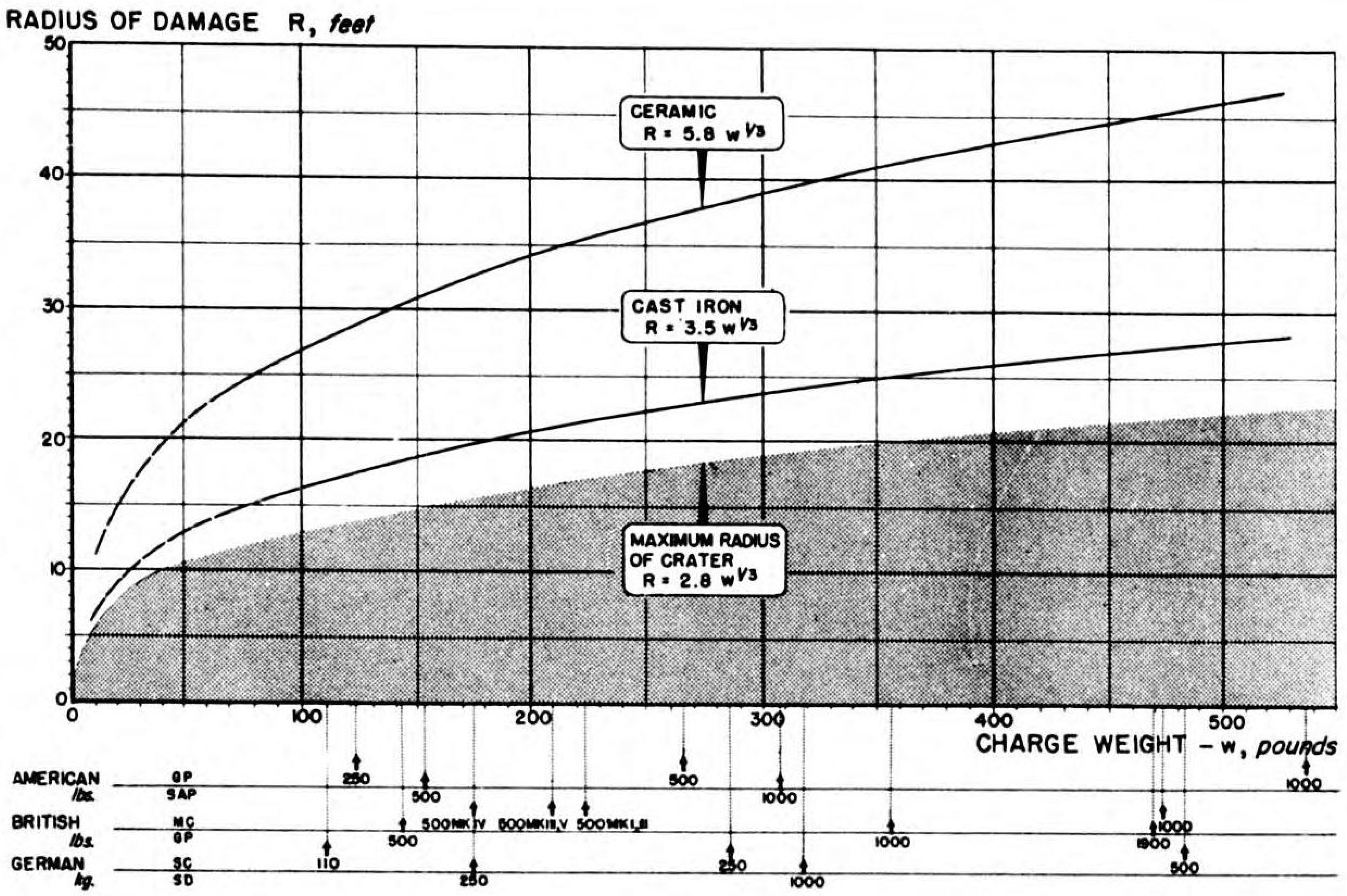
WEAPON DATA

6 E 1
UTILITIES:
UNDERGROUND PIPING

DAMAGE TO UNDERGROUND PIPING



The curves show average radius of damage by medium-sized bombs to pipes made of (a) cast iron and (b) earthenware, brick or tile buried in clay soil. The radius of damage R thus represents roughly the half width of a band within which the pipe will be vulnerable.

SOURCE OF DAMAGE: Damage appears to be caused largely by earth movement rather than by forces transmitted longitudinally through the pipe or through its contents. Services laid in ducts are protected by the "trench effect"; the ducts may be damaged but ground shock will be absorbed, permitting the services to remain intact.

LENGTH OF CAST IRON PIPE DAMAGED: The length of pipe requiring replacement is of the order of one and one-half to two times the radius of damage.

NATURE OF DAMAGE TO CERAMIC PIPE: Earthenware, brick and tile services can be placed in a single category because failure almost always occurs at the joints, which are of comparable strength in all three.

EFFECT OF DEPTH: Data used in compiling results is for services buried at depths of from $2\frac{1}{2}$ to 5 feet, over which range no depth effect is found. Further, the radius of damage depends very little on the depth of the explosion, within the normal limits of bomb penetration.

SIZE OF PIPE: There is no apparent dependence of radius of damage on pipe size within the range commonly used.

MAINTENANCE OF PRESSURE IN WATER SERVICES: In the event that damage to the pipe or its fittings does not result in a complete break, the pressure may hold at a substantial fraction of its normal value for some time. The drop in pressure immediately following the explosion is generally found to increase with $W^{1/3}/r$, where r is the distance from the charge.

OTHER SOILS: Compared with clay, the radius of damage is to be taken slightly smaller in chalk, sand and gravel and slightly more in made ground. If the soil is saturated with water, damage will usually extend to greater distances.*

Source of data: Reports of the British Ministry of Home Security and experiments conducted for the Corps of Engineers, U. S. Army, at Aberdeen Proving Grounds.

* see sheet 3 B1

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WEAPON DATA

6 F 1
BOMBING
AIRFIELD RUNWAYS

BOMBING OF AIRFIELD RUNWAYS

The best method for damaging runways and landing grounds is by cratering with general purpose bombs. A given weight of small bombs will disrupt a larger area than the same weight of larger bombs, the volume of soil removed being approximately the same in either case. For immediate immobilization the number of hits is more important than the size of the craters, but for equal number of hits large bombs are preferred.

WEAPON SELECTION: Plane loading characteristics influence the choice of bomb as follows: **Multiply the crater area listed in the table by the number of the corresponding bombs that the plane can carry, and choose that bomb giving the largest total area.** The height of release and recommended fuzing are to be read from the table. The number of hits required is given in paragraph 2 below.

RECOMMENDED FUZING AND CRATERS EXPECTED FOR GP BOMBS DROPPED ON UNPAVED AIRFIELDS FROM ALTITUDES ABOVE 3000 FEET

(For paved areas, the minimum altitude must be 4500 ft to avoid ricochet; the crater dimensions will be about 10% smaller)

General Purpose Bomb	Fuze delay, *sec.*		Crater Diameter *feet*	Crater Depth *feet*	Add. Volume to Refill crater, *cu. yd.*	Area Cratered ÷ Weight of Bomb	
	Unpaved Runways	Paved Runways				*sq.ft/bomb*	*acres/ton*
100-lb, AN-M30	0.01 or longer	0.025 or longer	16-18	4-5	15-23	230	0.092
250-lb, AN-M57	0.01 or longer	0.025 or longer	21-24	5-7	35-55	400	0.070
500-lb, AN-M43, M64	0.025 or longer	0.025 or longer	27-31	6-9	70-110	640	0.056
1000-lb, AN-M44, M65	0.025 or longer	0.025 or longer	35-40	8-11	140-230	1050	0.049
2000-lb, AN-M34, M66	0.025 or longer	0.025 or longer	44-50	10-14	290-460	1680	0.037

1. Cratering

For general purpose bombs dropped from any altitude above 3000 feet and fuzed 0.01 seconds or longer delay, the craters in most airfields do not differ appreciably from the optimum. The additional soil required to refill a crater to compaction varies in individual cases, but on the average 350 cubic yards of soil per ton of GP bombs or about 1000 pounds of soil per pound of explosive are required to refill craters.

If the drainage of an airfield is known to be poor and the water table high, large bombs with long delay fuzes result in deep craters partially filled with water which are difficult to repair.

2. Number of Hits

A statistical study of widely varying data on runways 200 to 300 feet in width shows that **8 hits per thousand feet of runway length render the runway temporarily inoperative** and 5 craters per thousand feet usually leave the strip serviceable. Operational data from the SWPA are in agreement with this study and show that the number of hits rather than the size of bomb is the controlling factor.

3. Repair Time

Airfields made inoperative by bombing attack can be made serviceable in a short time by repairing the cratering damage. Japanese engineering records show that when heavy equipment is used an average of 125 man-hours was required to repair craters resulting from 100-lb GP bombs.

The use of mechanical obstacles, small fragmentation bombs with anti-disturbance fuzes, and general purpose bombs with very long delay fuzes is recommended for increasing repair times, but should be considered as additional to the minimum requirement of 8 craters per thousand feet of runway length.

Confidential

WEAPON DATA

6 F2
RAILROADS

AIR ATTACK ON RAILROADS

The components of a rail system vulnerable to bombing attack are rail lines, rolling stock, locomotives, and marshalling yards. Small GP bombs (100-lb, 250-lb or 500-lb), fuzed 0.01-sec delay, are the most efficient for attacking rail lines. The 500-lb GP bomb, fuzed instantaneous or 0.01-sec delay, is the best weapon for attacking rolling stock and causes heavy damage if it strikes within about 20 ft of a box car or locomotive. The 1000-lb GP bomb fuzed 0.01 sec delay is slightly less efficient against box cars and slightly more efficient against locomotives. The MAE for damage to rolling stock is 0.29 ton/acre for 1000-lb GP bombs.

Strafing and rocket attack of locomotives will result in damage requiring 1 to 35 days and 1 to 60 days, respectively, for repair. Hits with rockets, however, are extremely difficult to attain, and of the two methods strafing is probably to be preferred. These methods are of little use against other forms of rolling stock or against other railroad installations.

The optimum over-all damage to marshalling yards is caused by the 500-lb GP bomb, fuzed 0.01 sec. A density of 1.5 to 2.0 ton/acre on the target is sufficient to completely disrupt a yard.

Table I EXPECTED RESULTS OF DIRECT BOMB HITS ON TRACKS ON THE FLAT

Bomb		Fuze Delay (sec)	Radius for Damage (ft)	Vulnerable Area per foot of Single Track (acre/ton)	Average Time for repair (hr)
Size (lb)	Type				
100	GP	0.01	7-9	0.0080	4
250	GP	.01	9-12	.0042	6
500	GP	.01	12-16	.0029	8
1000	GP	.01	18-23	.0020	13

Table II APPROXIMATE RADII OF DAMAGE DETERMINED FROM FOUR CATEGORIES OF DAMAGE TO LOCOMOTIVES

Bomb		Radius of Damage for Given Degree of Damage (ft)			
Size (lb)	Type	Destroyed	1000 to 3000 man-hours for Repair	250 to 1000 man hours for Repair	Up to 250 man hours for Repair
500	GP	20	23	26	29
1000	GP	40	44	48	52

Confidential

WEAPON DATA

6 F3
BOMBING
ATTACK ON BRIDGES

BOMBING OF BRIDGES

The table gives bomb and fuze selections for bridges with spans of 100 to 300 feet. For light bridges with short spans the next smaller size bomb may be used. For heavy long span bridges larger bombs are often necessary.

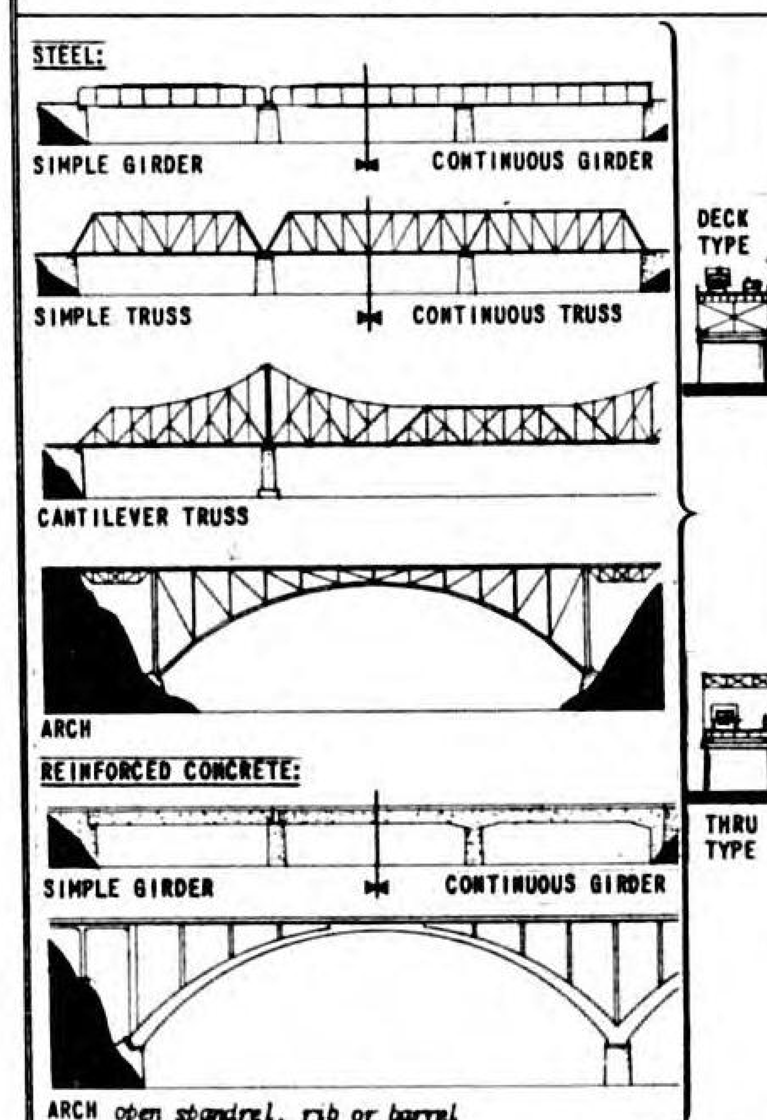
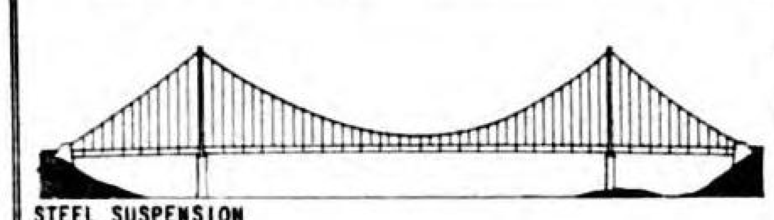
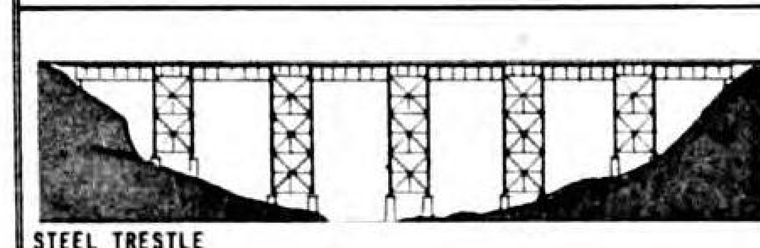
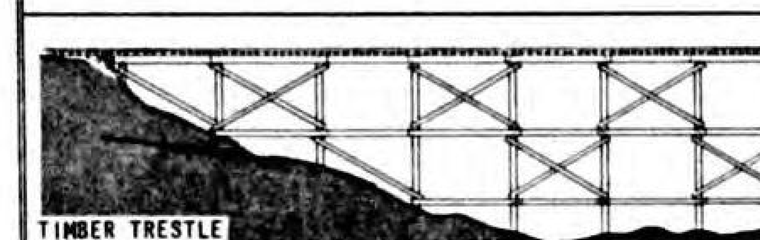
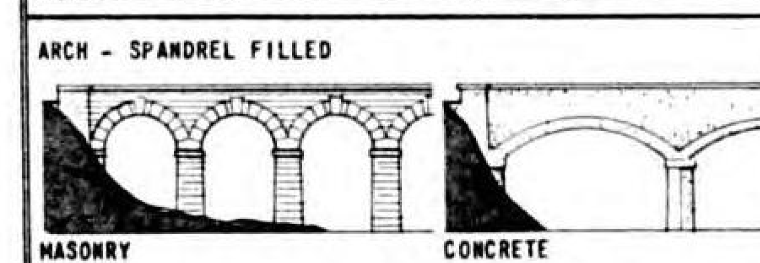
BRIDGE	BOMB RELEASE	COMPONENT TO ATTACK	BOMB	FUZING
 Deck type	min. altitude low dive or glide	**piers or abutments** *piers preferred if vulnerable*	Largest bomb F/B can carry to target. See Tables A&B for smallest effective bomb.	8-15 sec. or longer
	high altitude; med. altitude; high dive or glide	**superstructure and piers** in less than 10 feet of water *preferred target except for multiple short-span bridges*	1000 GP *single track 8-18 ft width* 2000 GP *double track 18ft. or wider*	0.01; Nose 0.01; Tail
		piers *preferred for multiple short-span bridges*	See TABLE A	8-15 sec. or longer
Thru type	min. altitude low dive or glide	**piers or abutments** *piers preferred if vulnerable.*	Largest bomb F/B can carry to target. See Tables A&B for smallest effective bomb.	8-15 sec. or longer
	high altitude; med. altitude; high dive or glide	**superstructure** *preferred target except for multiple short-span bridges*	1000 GP *single track; 8-18ft width* 2000 GP *double track; 18 ft. or wider*	Inst; Nose, Non-delay; Tail *for trusses or girders < 10 ft deep*.......... 0.01; Nose, Non-delay; Tail *for trusses or girders > 10 ft deep*.
		piers *preferred for multiple short-span bridges*	See TABLE A	8-15 sec. or longer
	min. altitude low dive or glide	**piers or abutments** *often too massive*	Largest bomb F/B can carry to target. See Tables A&B for smallest effective bomb.	8-15 sec. or longer
	high altitude; med. altitude; high dive or glide	**superstructure**	1000 GP *if less than 16 feet wide* 2000 GP *if more than 16 feet wide*	Inst; Nose, Non-delay; Tail
	min. altitude; low dive or glide	**tower footings**	Largest bomb F/B can carry to target. See Tables A&B for smallest effective bomb.	8-15 sec. or longer
	high altitude; med. altitude; high dive or glide	**superstructure, tower, and footings**	1000 GP *single track 8-18ft. width* 2000 GP *double track 18ft. or wider*	0.01; Nose 0.01; Tail
	min. altitude; low dive or glide	**trestle piles**	Largest bomb F/B can carry to target. See Tables A&B for smallest effective bomb.	8-15 sec. or longer
	high altitude; med. alt.; high dive or glide	**trestle, superstructure, and piles**	500 GP *single track* 1000 GP *double track*	0.01; Nose 0.01; Tail
	min. altitude; low dive or glide	**piers**	Largest bomb F/B can carry to target. See Tables A&B for smallest effective bomb.	8-15 sec. or longer
	high altitude; med. altitude; high dive or glide	**superstructure**	1000 GP *single track 8-18ft width* 2000 GP *double track 18ft or wider*	.01 or .025; Nose .01 or .025; Tail

TABLE A. BOMB SELECTION FOR BRIDGE PIERS

Pier sizes, *ft x ft* ➡	5 x 15	8 x 30	12 x 30	15 x 50
Bomb selection ➡	500 GP	1000 GP	2000 GP	2000 GP ineffective

TABLE B. BOMB SELECTION FOR BRIDGE ABUTMENTS

Average thickness of abutment, *ft* ➡	3 to 8	8 to 10	10 to 12	greater than 12
Bomb selection ➡	500 GP	1000 GP	2000 GP	2000 GP ineffective

6 F4
TUNNELS

BOMBING OF TUNNELS

1. A tunnel is a good bombing target only if:
   a. The portion attacked is located in broken, weak rock or poor unconsolidated overburden, structurally weak.
   b. It is lined with a structural material reasonably vulnerable to bombing, such as timbering, standard tunnel-liner segments, reinforced or mass concrete of not too great thickness.
2. Tunnels are best attacked by detonation of a bomb in the soil near the tunnel lining after it has penetrated from the surface of the ground through the overburden (where this is possible). This type of attack requires a bomb and altitude of release combination such that the bomb will penetrate to within the lethal distance from the tunnel lining.

LETHAL DISTANCE OF BOMBS AGAINST TUNNEL LININGS

BOMB size, type	LETHAL DISTANCE, *ft* — Slab or Shallow Arch with Some Reinforcing or Massive Concrete Lining — Thickness, *feet*						Pressed Steel or Cast Iron Segments
	$\frac{1}{2}$	$\frac{3}{4}$	1	2	3	4	
100-lb, GP	*10*	9	8	6	5	3	20
250-lb, GP	*15*	13	12	9	8	6	25
500-lb, GP	*21*	*17*	16	12	10	9	30
500-lb, SAP	*16*	14	13	10	8	7	25
1000-lb, GP	*31*	*24*	*21*	17	15	13	40
1000-lb, SAP	*24*	*19*	17	13	11	10	35
2000-lb, GP	*45*	*37*	*30*	24	20	18	50
2000-lb, SAP	*30*	*24*	*21*	17	15	13	40
12000-lb, GP	*95*	*80*	*70*	*52*	44	29	*90*
22000-lb, GP	*125*	*100*	*90*	*67*	*57*	51	*105*

Values in *italics* are extrapolations

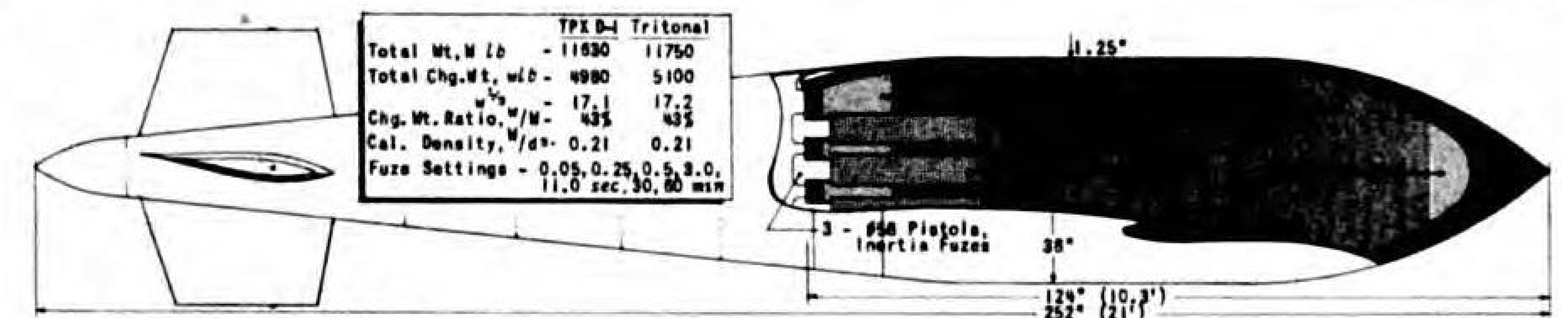
3. The vulnerable area will be greatest if the penetration is to the level of the tunnel. The fuzing should be a delay of 0.1 sec for deep tunnels or whatever is required for this penetration for shallow tunnels. This attack, which may call for an SAP bomb to penetrate difficult strata, requires a knowledge of the overburden and cannot be used against deep tunnels. Against tunnels under rivers or canals, the bomb must pass through the depth of the channel and then penetrate into the soil or else form a crater large enough to reach the tunnel lining.
4. Advantage may often be taken of the steep slopes usually present at tunnel portals to cause considerable landslides, thus blocking the tunnel entrance. This type of attack is most efficiently carried out by smaller bombs on the basis of results per unit weight of charge, but, bomb for bomb, a larger one, in general, will produce a somewhat greater slide. The probability of striking the target is increased by dropping the larger number of smaller bombs. The fuzing for this attack should be that required to produce the largest crater, 0.1 sec or more for the larger bombs and 0.025 sec for the 100- or 250-lb GP bombs.

TENTATIVE

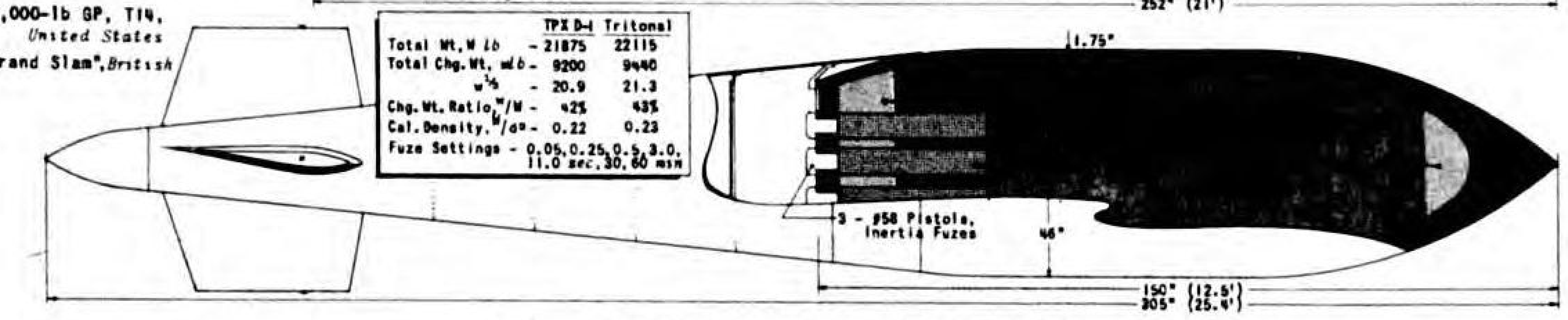
7 A1
PERFORMANCE:
12000-lb GP & 22000-lb GP

BOMB PERFORMANCE
12,000-lb GP, T10 AND 22,000-lb GP, T14

12,000-lb GP, T10,
United States
"Tallboy-M", *British*



22,000-lb GP, T14,
United States
"Grand Slam", *British*



		12,000-lb GP, T10 (Tallboy-M)						22,000-lb GP, T14 (Grand Slam)						
FLIGHT CHARACTERISTICS	Plane Speed, *mph*	Altitude, *ft.* 5000	10000	15000	20000	25000	30000	Altitude, *ft.* 5000	10000	15000	20000	25000	30000	REMARKS
Striking Velocity, *ft/sec*	250	670	870	1030	1160	1260	1350	670	875	1035	1170	1275	1375	
Angle of Impact, *degrees*	250	33°	24°	20°	17°	16°	14°	33°	24°	20°	17°	16°	14°	
HOMOGENEOUS ARMOR:	BHN													
Max. Thickness Perforated, *in*	250-300	5.0	5.5-6.6	5.5-6.6	Estimated max. for no case break-up			6.4	7-9.0	7-9.0	Estimated max. for no case break-up			
REINFORCED CONCRETE:	Concrete Strength													
Max. Thickness Perforated, *ft.* *Inert*	5000 *psi*	6.6*	8.6	10.1				8.2	11.0	13.0				*Ricochet is likely, so these values may not be realized. Shaded values indicate zone of probable case break-up or premature detonation..values for 20,000 ft. may be considered as limiting thicknesses for higher altitudes.
	3000 *psi*	7.1*	9.6	11.2				8.8	12.3	14.8				
Max. Thickness Scabbed, *ft.* *Inert*	5000 *psi*	10.1	12.2	13.8				12.4	15.3	17.5				
	3000 *psi*	10.6	13.2	15.3				13.0	16.7	19.4				
Max. Depth Penetrated, *ft.* *Inert*	5000 *psi*	2.5	4.4	5.8				3.2	5.8	7.7				
	3000 *psi*	3.0	5.3	7.1				3.9	7.0	9.5				
Max. Thickness Perforated, *ft.* *Impact + Expl. + Scab*	5000 *psi*	8.0*	10.0	11.5	12.9			10.2	13.0	15.0	16.9			
	3000 *psi*	8.5*	11.0	12.6	14.7			10.8	14.3	16.8	19.2			
Max. Thickness Scabbed, *ft.* *Impact + Expl. + Scab*	5000 *psi*	11.6*	13.7	15.3	16.8			14.5	17.4	19.6	21.6			
	3000 *psi*	12.1*	14.7	16.8	18.7			15.1	18.8	21.5	24.0			
Max. Depth Penetrated, *ft.* *Impact + Explosion*	5000 *psi*	3.8*	5.7	7.1	8.4			5.0	7.6	9.5	11.3			
	3000 *psi*	4.3*	6.6	8.4	10.1			5.7	8.8	11.3	13.5			
Ave. Entrance Crater Diam., *ft*	3-5000 *psi*	27	30	33	35	35	35	32	36	40	42	43	43	
Back Crater (Scab) Diameter, *ft*	~3-5000 *psi*	Varies from heavy cracks at scab limit to 40 *ft.* when perforated.						Varies from heavy cracks at scab limit to 50 *ft.* when perforated.						
EARTH:	Soil Type													
Penetration Depth, *ft.* *(With long delay fuze)*	Sand	26	33	39	43	45	47	33	41	49	53	56	59	For penetration *path length* add 20% to 30% to *depth*. Values are given for uniform soil.
	Loam	39	48	54	60*	62	65	48	62	67	75	77	80	
	Clay	56	67	76	81	85	87	70	85	95	100	105	111	
Cratering Effect	Explosive	Sand		Sandy Loam		Clay		Sand		Sandy Loam		Clay		
Max. Crater Radius, *ft.*	Torpex D-1	39 - 44		45 - 49		50 - 55		45 - 51		52 - 57		62 - 68		Performance values in EARTH dependant upon explosion, are based on *estimated* ratios for relative effectiveness of explosives.
	Tritonal	37 - 41		41 - 45		48 - 53		44 - 50		50 - 55		59 - 65		
Max. Apparent Crater Depth, *ft*	TPX or Trit	23 - 27		25 - 29		28 - 31		28 - 33		31 - 36		34 - 38		
Displacement in Clay, *inches*		Distance from Explosion, *ft.*						Distance from Explosion, *ft.*						
		70	80	90	100	110	120	80	90	100	110	120	130	
Horizontal:	Torpex D-1	21.2	11.1	7.6	3.4	2.7	2.3	28.6	19.2	13.1	9.3	7.1	5.3	
	Tritonal	20.4	10.5	7.2	3.2	2.5	2.2	27.0	18.0	12.4	8.8	6.7	5.1	
Vertical:	Torpex D-1	13.0	8.3	5.4	3.2	2.1		20.6	14.4	9.7	6.3	5.0	3.3	
	Tritonal	12.4	7.8	5.2	3.0	2.0		19.5	13.4	9.2	6.2	4.7	3.1	
Damage of Underground Piping		Cast Iron			Ceramic			Cast Iron			Ceramic			
Dist. from Explosion, *ft.*	Torpex D-1	63'			104'			77'			128'			
	Tritonal	60'			99'			73'			121'			
Underground R/C Wall Damage *(Average Soil)*		Distance from Explosion, *ft.*						Distance from Explosion, *ft.*						Damage will be *greater* in wet, or clayey soil; *less* in loose or sandy soil.
		0	10	20	30			0	10	20	30	40		
Max. Thickness of Wall Breached, *ft.*:	Torpex D-1	17	16	9				21	20	15	8			
	Tritonal	16	15	9				20	19	14	8			
Max. Thickness of Wall Heavily Damaged, *ft.*:	Torpex D-1	25	23	16	8			30	29	23	14	8		
	Tritonal	23	22	15	8			28	27	22	13	8		
UNDERWATER:		Depth Below Surface of Water, *ft.*						Depth Below Surface of Water, *ft.*						
Maximum Bubble Radius, *ft.*		90	110	130	150			90	110	130	150	170		
	TPX or Trit	50	48	46	45			62	61	57	55	51		
Peak Pressure, *lbs/sq.in.*		Distance from Explosion, *ft.*						Distance from Explosion, *ft.*						
		100	200	300	400	500	1000	100	200	300	400	500	1000	
	Torpex D-1	3050	1360	850	630	500	220	3700	1700	1100	780	600	270	
	Tritonal	2730	1210	760	565	445	198	3340	1530	980	697	536	242	
Impulse, *lb.msec/sq.in.*	Torpex D-1	5290	2660	1750	1350	1060	530	7950	3980	2680	1980	1590	795	
	Tritonal	5000	2560	1650	1250	997	500	7500	3750	2520	1870	1500	750	
AIR:														
Peak Pressure, *lbs/sq.in.*	Torpex D-1	26	5.6	3.2	2.1	1.6	0.8	44	8.2	4.1	2.7	2.0	0.9	
	Tritonal	24	5.3	3.0	2.0	1.5	0.7	42	7.8	3.9	2.6	1.9	0.9	
Impulse, *lb.msec/sq.in.*	Torpex D-1	170	85	57	42	34	17	256	128	86	64	51	26	
	Tritonal	165	82	55	41	33	16	248	124	82	62	99	25	
FRAGMENTATION														
Thickness Perforable by Fragments at Distance 100 ft, *in.*	TPX or Trit	Mild Steel		Concrete		Brick		Mild Steel		Concrete		Brick		
		2 - 3		18 - 26		20 - 30		2½ - 3½		21 - 30		25 - 38		

SOURCE: Physical Characteristics from Ordnance Department, U.S.Army; Performance Data from various British and American model tests

SOURCES OF INFORMATION FOR THE DATA SHEETS, *page three*

ARMOR PERFORATION; MILD STEEL PERFORATION

Sheets 2C3, 2C3a, 2C4, 2C5*, 2C5a, 2C6, 2C7, and 2C8 are based on empirical relations between the scaled variables e/d and $w/d^3\ V^2$ where e is the thickness of plate perforated in inches, d is the diameter of the projectile in inches, w is the weight of the projectile in pounds, and V is the striking velocity of the projectile in ft/sec. For small caliber jacketed bullets, projectiles with cap or windshield which come off on impact, or tungsten carbide cored projectiles w and d are the weight and diameter of the core, or part of the projectile which penetrates the plate. An attempt was made to find an empirical equation relating the variables, but the results were unsatisfactory. The sheets show the experimental data in the form of bands which include most of the data for projectiles perforating without shatter of the missile. The curves for individual weapons, given in sheets 2C3a and 2C5a, end at the combination of plate thickness, striking velocity, and obliquity at which shatter or body break up begins. The other sheets are averages of a large quantity of data for various projectiles and bombs, and the shatter limit is obscured by the method of presentation. The references for all sheets are listed below. References 31 - 34 are for sheet 2C3; reference 35 is for sheet 2C3a; references 36 and 37 are for sheet 2C4; references 38 and 39 are for sheet 2C5*; sheet 2C5a is based on an earlier edition of reference 39 and should be revised; references 40 - 45 are for sheet 2C6; references 46 and 47 are for sheet 2C7; references 48 and 49 are for sheet 2C8.

31. *Mechanism of Armor Perforation - 2nd Partial Report.* Watertown Arsenal Report 710/492. May 1943.
32. *Penetration of Homogeneous Armor by Uncapped Projectiles at 0° Obliquity.* Naval Proving Ground Report 1-43. U.S. Naval Proving Ground, Dahlgren, Va. April 1943.
33. *Armor Penetration Data. Armor Penetration Graphs.* Canadian Military Headquarters, Department of National Defense 1943.
34. *Ballistic Tests of STS Armor Plate Using 37mm Projectiles.* NDRC Report No. A-156. Ballistic Research Group, Princeton University Station, Division 2, National Defense Research Committee. March 1943.
35. *Armor Perforation Curves.* Ballistic Section, Technical Division, Office of the Chief of Ordnance, U. S. Army. Most of these curves are also published in reference 22.
36. *Armor Piercing Bullet Cores.* Watertown Arsenal Report No. 762/203. May 1943.
37. *Seventh Partial Report on Light Armor Investigation,* and *Eighth Partial Report on Light Armor.* Naval Research Laboratory Reports Nos. 0-1600 and 0-1745. U. S. Naval Research Laboratory.
38. *Compilation of Data Resulting from Trials to Determine the Explosive Effects of Aircraft Bombs and Means of Protection Therefrom.* Research Department, Woolwich, England. October 1938.
39. *Armor Perforation by Service Bombs.* BuOrd Sketch No. 124400, Rev. B. U. S. Navy Department, Bureau of Ordnance, 1944.
40. *High Velocity Armor Piercing Ammuntion.* Ordnance Department, U. S. Army. August 1944.
41. *High Velocity Development.* Ordnance Department, U. S. Army. October 1943.
42. *Proving Center Firing Record P-33104, Ordnance Program 5962.* Aberdeen Proving Ground, Md.
43. *S. D. Technical Artillery Report No. 21.* Canadian Military Headquarters. June 1943.
44. *Trials Carried out in Connection with A.T.D.B. Projects Number 6 and 7.* Army Technical Development Board, Canada. 1944.
45. *Ordnance Board Proceedings* (British). Nos. Q995, Q1471, Q1546, Q1716, Q1834, Q1838. Q1953, Q2521, 25242.
46. *Tactical and Technical Trends.* No. 17. Military Intelligence Division, War Department, Washington. January 1943.
47. *Ordnance Board Proceedings* (British). Nos. Q1834, 26433.
48. *Second Partial Report on Light Armor Investigation.* Naval Research Laboratory Report No. 0-1429. U.S. Naval Research Laboratory. March 1940.
49. *The Ballistic Properties of Mild Steel* NDRC Report No. A-111. Ballistic Research Group, Princeton University Station, Division 2, National Defense Research Committee.

AIR BLAST

Sheets 3A1, 3A2*, and 3A2a are based on analysis of a large quantity of data from various tests of explosives. Individual sets of data were taken from a number of references, and the separate references are not listed here. All data for pressure or impulse were averaged for the sheets. The data for pressure were compared by relating the pressure P in pounds per square inch to the scaled distance from the charge, $r/w^{1/3}$, where r is the distance in feet and w is the charge weight in pounds. The data for impulse were compared by relating the scaled impulse, $I/w^{1/3}$ to the scaled distance from the charge, $r/w^{1/3}$. I being the impulse in pound-milliseconds per square inch and the other variables as above. The effects of different types of explosive were taken into account by means of multiplicative factors, based on equivalent weight of explosive. The effect of the bomb case on impulse is described in sheet 3A2a and in reference 51 below. The effect of the bomb case on peak pressure has not been determined.

Sheet 3A1 is a nomogram of the equation $P = 4120\ z^{-3} - 105\ z^{-2} + 39.5\ z^{-1}$ where P is the pressure in pounds per sq.in. and $z = r/w^{1/3}$, r being the distance from the explosion in feet and w being the weight of explosive in pounds. This equation is based on averaging a large number of pressure measurements, all made prior to June 1943, on bombs filled with various explosives and detonated on the ground. When this is compared to recent pressure-distance curves obtained from explosion of small bare TNT charges in the air it is found to predict pressures which are lower than those that would be expected if ground detonation is taken into account by replacing the weight of charge by twice the weight used for the free air curve. The amount by which the nomogram is lower than the values predicted from the free air curve varies with the distance from the bomb from 50% at $z = 10$ to 3% at $z = 30$. In view of the fact that the peak pressure is different for different explosives and that there may be an effect of the bomb case thickness on pressure, the difference in shape of the pressure-distance curve given by the nomogram and the pressure-distance curve given by the bare TNT charges is not unexpected, since the nomogram is based on simple averaging of measurements involving various types of explosive in cases of various thickness.

A pressure-distance curve for bare TNT charges is given in the upper figure of sheet 3A9.

Experiments using small bare charges of various explosives indicate that the pressures due to detonation of equal weights of various explosives have the following relative values: Torpex 2, 1.15; HBX, 1.13; Minol 2, 1.09; Composition B (RDX/TNT 60/40), 1.08; Tritonal, 1.07; TNT, 1.00; Amatol (50/50), 0.93.

Sheet 3A2* and sheet 3A2a are based on the equations given on the sheets. The equations are based on averaging a large quantity of data for charges detonated on the ground. The effect of explosive type on impulse and on pressure, the dependence of pressure and impulse on distance, and the effect of the bomb case on impulse are discussed in the following papers.

50. *Small Charge Air Blast Experiments.* NDRC Report No. A-191; OSRD No. 1518. Division 2, National Defense Research Committee. June 1943.

SOURCES OF INFORMATION FOR THE DATA SHEETS, *page four*

51. *Dependence of Positive Impulse of Blast on Charge/Weight Ratio.* AES-4; OSRD No. 4356. Air and Earth Shock, Vol. 4. p. 43. National Defense Research Committee. November 1944.

52. *Relation between Positive Blast Impulse and Charge/Weight Ratio for Bombs.* AES-4; OSRD No. 4356. Air and Earth Shock, Vol. 4, p. 51. National Defense Research Committee. November 1944.

53. *Order of Effectiveness of Explosives, IV.* AES-6; OSRD No. 4649. Air and Earth Shock, Vol 6, p. 1. National Defense Research Committee. January 1945.

54. *The Air Blast Performance of Some High Explosives.* AES-7; OSRD No. 4754. Air and Earth Shock, Vol. 7, p. 9. National Defense Research Committee. February 1945.

Sheet 3A3 gives a curve for the relation between side-on and face-on blast pressures in air. This curve is calculated from the requirement that the velocity imparted to the gas particles by the oncoming wave is just cancelled by the velocity imparted by the reflected wave. The value of these velocities may be found from the Rankine-Hugoniot equations, which give, among other things, particle velocities as a function of pressure (see for instance, *Aerodynamic Theory,* edited by W. F. Durand. Division H by G. I. Taylor and J. W. Maccoll. J. Springer, Berlin. 1935).

CONTACT EXPLOSIONS

Sheet 3A4 was prepared directly from reference 55, which describes measurements of the impulse due to explosion of small charges of various shapes in contact with an impulse pendulum.

55. *Impulse Delivered to a Plane Slab by a Contact Explosion, II.* AES-13d; OSRD No. 5506d. Air and Earth Shock, Vol. 13, p. 41. Division 2, National Defense Research Committee. August 1945.

CONE END CHARGES

Sheet 3A5 was prepared on the basis of the available experimental data on penetration and perforation of reinforced concrete slabs by cone end hollow charges detonated under controlled conditions. An attempt to correlate the data was made by plotting the depth of penetration as a function of the weight of explosive used, on log-log paper as shown on the sheet. The straight line giving a best fit to the data, as determined by the method of least squares, has a slope of 0.43. The large scatter in the data is such that this is not significantly different from the value 1/3 for the slope, given by model laws. An attempt to reduce the scatter in the data by finding correlations with other variables such as type of explosive, thickness and material of cone liner, cone angle, etc. failed. References used include:

56. *Shaped Charges for the Perforation of Concrete.* Eastern Laboratory, Explosives Department, E. I. duPont de Nemours & Co. Inc. Gibbstown, N. J. May 1943.

57. *Theory and Application of the Cavity Effect.* Report for November 1943. E. I. duPont de Nemours & Co. Inc. December 1943.

58. *Sixth Interim Report on Demolition of German Pillboxes.* Road Research Laboratory, Ministry of Supply (British) April 1942.

59. *Fourth and Final Report on Demolition Tests on Concrete Bridge Piers.* Road Research Laboratory, Ministry of Supply (British). August 1942.

Sheet 3A6 is based on reference 60. The sheet is essentially an abstract of the reference.

60. *Performance of Hollow Charge Weapons.* OTB-12f; OSRD No. 5350f. Ordnance and Terminal Ballistics, Vol. 12. Division 2, National Defense Research Committee. July 1945.

EFFECT OF AIR-BURST ON BLAST.

Sheets 3A7, 3A8, and 3A9 are based on experimental studies of small bare charges and of bombs detonated at various heights above ground. The sheets are based on the following references. Some of the graphs given in the sheets are based on new adjustments of data given in the references.

61. *The Effect of Air-Burst on the Blast from Bombs and Small Charges: I. Experimental Results.* OSRD Report No. 4246. Underwater Explosives Research Laboratory, Woods Hole Massachusetts with collaboration from Stanolind Oil and Gas Company, Tulsa, Oklahoma. Division 8, National Defense Research Committee. October 1944.

62. *The Effect of Air-Burst on the Blast from Bombs and Small Charges: II. Analysis of Experimental Results.* NDRC Report No. A-320; OSRD No. 4899. Division 2, National Defense Research Committee. April 1945.

63. *Air Burst for Blast Bombs.* NDRC Report No. A-322; OSRD No. 4943. Division 2, National Defense Research Committee. April 1945.

64. *The Effect of Height of Burst on the Blast Characteristics from 67-lb Bare Cylindrical Charges of RDX/TNT 60/40.* A.R.D. Explosives Report 16/45. Armament Research Department, Ministry of Supply (British). February 1945.

65. *Peak Pressure Dependence on Height of Detonation.* AES-1; OSRD No. 4076. Air and Earth Shock, Vol. 1, p. 1. Division 2, National Defense Research Committee. August 1944.

66. *Impulse Dependence on Height of Detonation.* AES-2; OSRD No. 4147. Air and Earth Shock, Vol. 2, p. 17. Division 2, National Defense Research Committee. September 1944.

67. *Mach Reflection of Shock Waves from Charges Detonated in Air.* AES-3; OSRD No. 4257. Air and Earth Shock, Vol 3, p. 17, Division 2, National Defense Research Committee. October 1944.

68. *The Effect of Height of Detonation on Peak Pressure and Positive Impulse Measured Close to the Ground.* AES-5; OSRD No. 4514. Air and Earth Shock, Vol. 5, p. 49. Division 2, National Defense Research Committee. December 1944.

69. *Dependence of Optimum Impulse on Height of Gauge in Air Burst.* AES-9c; OSRD No. 5011c. Air and Earth Shock, Vol. 9, p. 17. Division 2, National Defense Research Committee. April 1945.

UNDERGROUND EXPLOSIONS

Sheet 3B1a* is based on analysis of a large amount of data for craters formed in various soils by explosive charges ranging from a fraction of a pound to more than 3000 pounds. The variables used in plotting the data were suggested by model theory. Separate graphs were made for each soil, and although there was a large scatter in the data a smooth curve was drawn for each set of data. The final curves are shown on sheet 3B1a*. Data were taken from a large number of reports, and most of the measurements are of individual craters made in tests for purposes other than the study of cratering. Since most of the sources list only a few craters, individual references are not listed here. Reference 70 describes extensive tests of cratering by 100-lb and 1000-lb GP bombs. The other references describe tests made with small charges to determine the effect of different types of explosive and the effect of charge shape on crater dimensions.

70. *Supplementary Test of Selection of Bombs and Fuzes for Bombardment Targets.* AAF Proving Ground Command, Project No. 4249C471.6. The Army Air Forces Board. December 1944.

71. *Effect of Charge Shape and Orientation on Cratering in Soil* AES-3 OSRD No. 4257. Air and Earth Shock, Vol. 3 p. 1. Division 2, National Defense Research Committee. October 1944.

72. *Weight of Material Required to Fill Bomb Craters (Model Experiments).* BRL Report No. 488. Ballistic Research Laboratory, Aberdeen Proving Ground, Md. September 1944.

73. *The Comparative Performance of Various Bomb Fillings - Crater and Earthshock Effects. Part I.* REN 452. Research and Experiments Departmeht, Ministry of Home Security (British).

74. *The Order of Effectiveness of Various Explosives in Earth.* AES-13b; OSRD No 5506b. Air and Earth Shock, Vol.13, p. 13. Division 2, National Defense Research Committee. August 1945.

Sheet 3B1b gives diameter of craters formed by detonation of line charges on the surface of the ground. Data from a number of tests were correlated by means of the scale factor $w^{1/2}$ suggested by model theory. The analysis, data, and sources of data are given in reference 75.

75. *Cratering by Line Charges.* AES-13a; OSRD No. 5506a. Air and Earth Shock, Vol. 13, p. 1. Division 2, National Defense Research Committee. August 1945.

Sheet 3B2 gives earth displacements due to underground explosions, based on analysis of a large number of tests on bombs and bare charges. The data were plotted in terms of the model law variables $u/w^{1/3}$ and $r/w^{1/3}$ where u is the displacement, r is the horizontal distance from the explosion, and w is the weight of explosive. Separate curves were obtained for the maximum transient horizontal, maximum transient vertical, permanent horizontal, and permanent vertical displacements. The permanent displacements were determined by measuring the displacement of stakes in the ground. The transient displacements were measured by photographing the motion of a lamp fastened to a stake, or by using an inertia trolley. Data for charges at small depths showed appreciable departure from the other values, and data for detonations in chalk gave smaller displacements than those observed in clay soil. Only the data for charges buried deeper than $1.1w^{1/3}$ in clay soil were used. The data came from the following sources:

76. *Earth Movements due to Explosions.* Data Compilation No. 14. Research and Experiments Branch, Ministry of Home Security (British) February 1940.

77. *Earth Movement due to 50-kg Bombs Exploded in Clay Soil at Richmond Park.* RC 328. Road Research Laboratory Report to the Ministry of Home Security (British). May 1942.

78. *Earth Movements in Different Directions due to Explosion of Buried 50-kg Bombs in Clay Soil.* RC 314. Road Research Laboratory Report to the Ministry of Home Security (British) February 1942.

79. *Earth Movements due to German Bombs Exploded below Ground.* RC 259. Road Research Laboratory Report to the Ministry of Home Security (British) August 1941.

80. *Earth Movement due to German and British Bombs Exploded below Ground.* RC 153. Road Research Laboratory Report to the Ministry of Home Security. (British) November 1940.

81. *Earth Movements due to 250-kg Bombs Exploded in Clay Soil.* RC 312. Road Research Laboratory Report to the Ministry of Home Security (British) February 1942.

82. *Earth Movement due to German 250-kg Bombs Exploded below Ground in Chalk Soil.* RC 313. Road Research Laboratory Report to the Ministry of Home Security (British) February 1942.

83. *Earth Movements due to Buried Standard Charges.* RC 416. Road Research Laboratory Report to the Ministry of Supply (British) November 1943.

Sheet 3B3* gives nomograms for the pressure and impulse underground due to explosions underground. The nomograms are based on extensive tests of underground explosions described in reference 83. Values of the soil constants are from reference 85. Factors for pressure and impulse due to explosives other than TNT are from reference 86. A recent series of tests on the pressure and impulse at different depths due to explosions at various depths is described in reference 87.

84. *Effects of Underground Explosions.* (in three volumes). Interim Report No. 26. Committee on Fortification Design. National Research Council. June 1944.

85. *The Seismic Method of Explorations Applied to Construction Projects.* Military Engineer, September-October 1939.

86. *The Order of Effectiveness of Various Explosives in Earth.* AES-13b; OSRD No. 5506b. Air and Earth Shock, Vol. 13, p. 13. Division 2, National Defense Research Committee. August 1945.

87. Division 2, National Defense Research Committee report on underground explosions, to be published.

UNDERWATER EXPLOSIONS

The nomogram given on sheet 3C1 is taken directly from reference 88. Data sheet 3C2 was prepared from material in references 89 and 90, as described on the sheet.

88. *Underwater Explosives and Explosions.* Report UE-15, page 3. Division 8, National Defense Research Committee. December 1943.

89. *Theory of the Pulsations of the Gas Bubble Produced by an Underwater Explosion.* Report No. C4-sr20-010. Columbia University, Division of National Defense Research. New London, Connecticutt. October 1941.

90. *On the Best Location of a Mine Near the Sea Bed.* AMP Report 37.1R. Applied Mathematics Group, New York University. Applied Mathematics Panel, National Defense Research Committee. May 1944.

IMPULSE CRITERION-DAMAGE LEVELS

The method of analysis used in arriving at the conclusions given in sheet 6A0 is described in the sheet. The sheet is based on the references listed below. A discussion of the impulse criterion may be found in pages 17-24 of reference 63.

91. *House Damage by HE Weapons Acting by Blast.* REN 214 Revised. Research and Experiments Department, Ministry of Home Security (British). March 1944.

92. *A Modification of the Impulse Criterion for Blast Damage.* RC 349. Research and Experiments Department, Ministry of Home Security (British). September 1942.

VULNERABILITY OF COMPONENTS OF STRUCTURES

Sheet 6A1a* and 6A1b* are based on analysis of column damage taken from reports of building damage. The data for various incidents were correlated by plotting the scaled distance from the explosion as abscissae and the index of column slenderness and aspect as ordinates and separating the plotted values corresponding to different degrees of damage, as shown on the sheet. The index of slenderress and aspect is defined as the area of cross sectioh of the column material divided by the free area of the column exposed directly to the blast. This definition is suggested by a semiquantitative theory which ascribes the damage to air blast impulse, with the blast wave assumed to act for the length of time required for the diffracted wave to make its way around the column. Data are from the following references:

93. *Effect of German HE Bombs on Industrial Structures.* REN 224. Ministry of Home Security (British). May 1943.

94. *Damage to Single Story Buildings.* R.E. 4. Data Compilation No. 2. Ministry of Home Security (British). May 1942.

95. *Air Raid Damage Report - Dolphin Court Flats.* Ministry of Home Security (British). November 1940.

96. *Air Raid Damage Report, Serial No. C4.* Ministry of Home Security (British). 1942.

97. *Blast Effect of Bomb on Steelwork.* R.E. 4. Data Compilation No. 27. Ministry of Home Security (British)

98. *Damage to R. C. Framed Buildings.* Data Compilation No. 32. Ministry of Home Security (British). February 1942.

SOURCES OF INFORMATION FOR THE DATA SHEETS, *page six*

Sheet 6A2 is based on examination of data on bomb damage to British buildings. The data showed a rough correlation between the area of concrete floor slab removed and the location and size of the bomb. For a given bomb size it was found possible to make separate analyses of the data for area of floor destroyed for the floors adjacent to the bomb, the floor next above or below the bomb, and the third floor above or below the bomb. The separate curves are shown on the sheet. The curve labeled *Total Area, all floors* is twice the sum of the areas given by the three curves for individual floors. A recent analysis, made since publication of the sheet, shows that although the three lower curves represent the data very well, the damage is not always symmetrical above and below the bomb, and the curve for the total area of all floors does not fit all incidents. This later analysis indicates that a better approach to the problem might be made by correlating the *volume* made unusable with the weight of explosive. If the volume destroyed is determined as the height of each story multiplied by the area of destruction of the floor immediately above or below, whichever is greater, these separate volumes being summed for the entire building, then the relation $V = 140\ w$ fits the data very well, where V is the volume destroyed and w is the weight of explosive in the bomb. For American GP bombs this relation becomes $V = 70\ W$, where W is the weight of the bomb. Data on destruction of floor slabs by HE bombs may be found in the following references:

99. *Air Raid Damage Report, Serial No. A_4.* Ministry of Home Security (British). February 1943.
100. *Air Raid Damage Report, Serial No. C1.* Ministry of Home Security (British). February 1943.
101. *Air Raid Damage Report, Serial No. C_2.* Ministry of Home Security (British). February 1943.
102. *Air Raid Damage Report, Serial No. D_4.* Ministry of Home Security (British). February 1943.
103. *Damage to Steel Framed Buildings.* R.E. 4. Data Compilation No. 26. Ministry of Home Security (British). February 1943.
104. *Model (1/8 scale) and Full Scale Tests of Resistance of Reinforced Concrete to Attack by Bombs Nearby and in Contact.* RC 358. Road Research Laboratory Report to the Ministry of Home Security (British). September 1942.
105. *Interim Report of a Portion of Bomb Tests Conducted by the Ordnance Department on the Reinforced Concrete Test Structure at Area H, Gunpowder Neck, Aberdeen Proving Ground, Md.* Corps of Engineers, U. S. Army. December 1942.

See also references 95, 96, and 98.

Sheet 6A3* is based on analysis of available incidents of explosions inside and outside steel framed factory type buildings. The maximum radius of removal of roofing was plotted as a function of the weight of explosive in the bomb for both asbestos cement and sheet steel roofing. It was found possible to draw separate curves for internal and external explosion for each type of roofing, as shown on the sheet. The second graph on the sheet is a more detailed study of the effect of a German 50-kg SC bomb on the roofs of buildings of different size. Data were from the following sources:

106. *Damage to Light Roofing and Walling Materials.* R.E. 4. Data Compilation No. 8. Ministry of Home Security (British). May 1943.
107. *Damage to Walls.* R.E. 4. Data Compilation No. 10. Ministry of Home Security (British). May 1943.
108. *Variations in the Behavior of Factory Roof Sheetings Subject to Blast.* REN 220. Research and Experiments Department, Ministry of Home Security (British). May 1943.

Sheets 6A4*, 6A5*, and 6A6* are based on references 109, 110, and 111 respectively. These references describe the methods of analysis and give references to original sources:

109. *Rupture of Glass by Blast.* EWT-5e; OSRD No. 5405e. Effects of Weapons on Targets, Vol. 5. National Defense Research Committee. August 1945.
110. *Damage to Underground Reinforced Concrete Walls.* EWT-5g; OSRD No. 5405g. Effects of Weapons on Targets. Vol. 5. National Defense Research Committee. August 1945.
111. *Damage to Reinforced Concrete Wall Panels by Detonation of Contact and Remote Charges.* EWT-3h; OSRD No. 5176h. Effects of Weapons on Targets, Vol. 3. National Defense Research Committee. June 1945.

TARGET VULNERABILITY

The sheets in sections 6B through 6F are studies of the physical vulnerability of various target types. All of these.. sheets except numbers 6D2 and 6E1 are based on source material and methods of analysis described in various articles published in the NDRC Report *Effects of Weapons on Targets.* Sheet 6D1 is based on a study of references listed on the sheet. Sheet 6E1 is based on a study of references 123 and 124 listed below. The separate references for each sheet in this group are listed below in the order in which the sheets appear in the book. Sheet numbers are given immediately after the reference number.

112. 6B1 *Direct-Hit Effects of U.S. 500-lb GP Bombs on European Industrial Buildings: H.E. Structural Damage.* EWT-2f OSRD No. 5045f. Effects of Weapons on Targets. Vol. 2. National Defense Research Committee. May 1945.
113. 6B1 *Incendiary Effects of U. S. 500-lb GP Bombs on European Industrial Buildings: Probability of Initiation of Destructive Fires.* EWT-3b; OSRD No. 5176b. Effects of Weapons on Targets. Vol. 3. National Defense Research Committee. June 1945.
114. 6B1 *Spread of Fire within Single-Story European Industrial Fire Divisions, Mixed HE-IB Attacks.* EWT-3c; OSRD No. 5176c. Effects of Weapons on Targets. Vol. 3. National Defense Research Committee. June 1945.
115. 6B2 *The Probability of Fire-Starting by Incendiary Bombs, I: General Principles and Methods.* EWT-5b; OSRD No. 5405b. Effects of Weapons on Targets. Vol. 5. National Defense Research Committee. August 1945.
116. 6B2 *The Probability of Fire-Starting by Incendiary Bombs, II: Estimates for the M47 Incendiary Bomb.* EWT-5c; OSRD No. 5405c. Effects of Weapons on Targets. Vol. 5. National Defense Research Committee. August 1945.
117. 6B2 *The Probability of Fire-Starting by Incendiary Bombs, III: Estimates for the M50 Incendiary Bomb.* EWT-5d; OSRD No. 5405d. Effects of Weapons on Targets. Vol. 5. National Defense Research Committee. August 1945.
118. 6C1 *Air Attack on Steel Mills.* EWT-6d; OSRD No. 5657d. Effects of Weapons on Targets. Vol. 6. National Defense Research Committee. September 1945.
119. 6C2a *Attack on Dams.* EWT-5f; OSRD No. 5405f. Effects of Weapons on Targets. Vol. 5. National Defense Research Committee. August 1945.
120. 6C2b *Attack of Penstocks.* EWT-2b; OSRD No. 5045b. Effects of Weapons on Targets, Vol. 2. National Defense Research Committee. May 1945.
121. 6D1 *Attack on Open Gun Emplacements.* EWT-6a; OSRD No. 5657a. Effects of Weapons on Targets, Vol. 6. National Defense Research Committee. September 1945.
6D2 References are listed on the Data Sheet.
122 6D3 *MAE's Calculated from Ashley Walk Trials.* EWT-6b; OSRD No. 5657b. Effects of Weapons on Targets, Vol. 6. National Defense Research Committee. September 1945.
123. 6E1 *The Radius of Damage for Underground Services.* RC 290. Ministry of Home Security (British). November 1941.
124. 6E1 *Final Report of Bombing Tests on Underground Piping.* Corps of Engineers, U. S. Army. May 1942.

SOURCES OF INFORMATION FOR THE DATA SHEETS

Each data sheet is based on the best information available to the Division at the time the sheet was prepared. The important sources are listed on each sheet, or are noted by a reference in the lower left corner of the sheet. The references *AES*, *EWT*, and *OTB* followed by numbers refer to the Division 2, NDRC, reports *Air and Earth Shock*, *Effects of Weapons on Targets*, and *Ordnance and Terminal Ballistics*; the reference *PTM* refers to *Princeton Technical Memoranda* published by the Princeton University Station of Division 2, NDRC. The numbers following each of these references refer to a particular issue of the report. Some of these references are reports of original research. Others are studies of information from a number of reports and include references to original sources.

The most important sources of information for each sheet are listed below, with no attempt to list all sources. Some remarks on the method of analysis used, and any information that might be useful in extrapolating the information to new weapons or in making further study of the subject are included.

EXPLOSIVES

Sheet 1A1 summarizes the best available information on the properties and uses of currently used high explosive fillings for bombs and demolition charges. Information from the following sources was used:

1. *Table of Military High Explosives.* Explosives Research Memorandum No. 10 (first revision). Navy Department, Bureau of Ordnance.
2. *Introduction to Explosives.* OSRD Report No. 5401. Division 8, National Defense Research Committee. August 1945.
3. *Report on HBX and Tritonal.* OSRD Report No. 5406. Committee on Fillings for Aerial Bombs. Divisions 2 and 8, National Defense Research Committee. July 1945.
4. Informal communication from Explosives Research Laboratory, Bruceton, Pa. Division 8, National Defense Research Committee. July 1945.

PHYSICAL CHARACTERISTICS OF WEAPONS

Sheets 1A3, 1A3a*, 1A3b, 1A3c, 1A3d, 1A4a, 1A5a, 1A5b, 1A6*, 1A7a, 1A7b, 1C1 are simple tabulations of the physical characteristics of weapons. Sheets giving characteristics of United States weapons were submitted to the relevant Service organizations before publication. Those listing characteristics of foreign weapons were checked by using several independent references where possible, and certainly are not complete. In using these sheets manufacturing tolerances must be allowed for and it must be remembered that total weights and weights of explosive fillings may vary by 5% from the values given. The most important references for physical characteristics of weapons are listed below.

5. *Catalogue of Standard Ordnance Items.* Technical Division, Office of the Chief of Ordnance, U. S. Army. Continuing loose leaf publication. 3 volumes and Limited Procurement Supplement.
6. *Catalogue of Enemy Ordnance Material.* Office of the Chief of Ordnance, U. S. Army. Continuing loose leaf publication.
7. *United States Bombs and Fuzes*, *British Bombs and Fuzes*, *Enemy Bombs and Fuzes* and similar publications. United States Navy Bomb Disposal School. Washington. Additions and revisions issued frequently.
8. *Advanced Fuze and Explosive Ordnance Bulletin.* United States Navy Bomb Disposal School. Washington. Published monthly.
9. *Intelligence Bulletin.* United States Navy Bomb Disposal School. Washington. Bi-weekly publication.
10. *Bomb Disposal Technical Information.* Army Service Forces, Ordnance Department, Ordnance Bomb Disposal Center, Aberdeen Proving Ground, Md. Semi-monthly publication.
11. Technical Manuals issued by the War Department. Manuals are published on a variety of subjects. Pertinent manuals were used for each sheet.
12. Ordnance Pamphlets issued by the Bureau of Ordnance, U. S. Navy. Pamphlets are issued for various weapons. Pertinent pamphlets were consulted for each sheet.
13. *Engineer Intelligence Bulletins.* Technical Intelligence Branch, Military Intelligence Division, Office of the Chief of Engineers, Army Service Forces, U. S. Army. Several bulletins on mines and demolition charges. Bulletin No. 3 and revisions tabulate dimensions of United States and Foreign mines and demolition charges.

FLIGHT DATA FOR BOMBS

Sheet 1B4 is based on calculations of the trajectory of bombs falling in a vacuum. These calculations neglecting air resistance are considered as accurate as more elaborate calculations for bombs dropped from altitudes below 5000 ft. The equations used are given on the sheet. Sheets 1B5* - 1B21 give striking velocity and angle of impact for bombs as calculated using ballistic coefficients and condensed bombing tables furnished by the Ordnance Department, U.S.Army, and the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. The striking velocities were determined by plotting the striking velocity as abscissa and the reciprocal of the ballistic coefficient for time of flight as ordinate, values being taken from condensed bombing tables. Separate graphs were made for each plane speed, and curves were drawn on the graphs for each altitude. Knowing the ballistic coefficient for time of flight of a given bomb as a function of altitude, a curve was drawn through the points determined by the reciprocal of the ballistic coefficient and the intersection of this value with the corresponding line for each altitude. From this curve, plotted on each of the graphs described above, the striking velocity of the bomb dropped from any altitude at any horizontal plane speed could be determined. A similar method was used for determining the angle of impact, plotting the angle of fall as the abscissa and the reciprocal of the ballistic coefficient for range as ordinate, values being taken from condensed bombing tables. Separate graphs were made for each plane speed, and lines were drawn for each altitude. The procedure described above was followed to determine the angle of impact of the bomb for various combinations of altitude and plane speed, using the ballistic coefficient for range for each bomb. The results were used in drawing the sets of curves shown on the data sheets. The accuracy of 15% in striking velocity and 4° in impact angle is due to inaccuracies in ballistic coefficients and not to inaccuracies in the method of presentation.

CONCRETE PENETRATION, SCABBING, AND PERFORATION

Sheet 2A1 is a nomogram of the equation $x/d = [\frac{1}{2} + 282\, S^{-\frac{1}{2}}\, (w/d^3)\, d^{0.215}\, (V/1000)^{3/2}]\, \varphi(\theta)$ where x is the penetration measured normal to the surface in inches, d is the projectile diameter in inches, S is the compressive strength of the concrete as measured by cylinders in lb/in², w is the weight of the projectile in pounds, V is the striking velocity of the projectile in ft/sec, and θ is the striking obliquity measured from the normal. In constructing the nomogram a graphical function of the projectile diameter, which is very nearly $d^{0.218}$ was used instead of $d^{0.215}$ given in the equation. A graphical function of the obliquity, based on averaged data for a large number of firings of projectiles of various sizes and shapes was used for $\varphi(\theta)$.

Sheet 2B1 is based on the nomogram of sheet 2A1 and the relation $s/d = 2.12 + 1.36\, x/d$ where x/d is from the equation above, s is the thickness of target that can just be scabbed, and d is the projectile diameter; here s, x, and d are measured in the same units.

Sheet 2C1 is based on the nomogram of sheet 2A1 and the relation $e/d = 1.32 + 1.24\, x/d$ where x/d is from the equation for sheet 2A1, e is the thickness of target that can be perforated, d is the projectile diameter, and e, x, and d are all measured in the same units.

SOURCES OF INFORMATION FOR THE DATA SHEETS, *page two*

The equations are empirical relations based on analysis of approximately 600 rounds fired in tests of 37mm, 75mm, 3-inch, 155mm, 12-inch, and 16-inch armor piercing projectiles, and about 75 rounds of inert bombs dropped on reinforced concrete targets. Data are from the following sources:

14. *Penetration and Explosion Tests on Concrete Slabs. Report I: Data.* Interim Report No. 20 of the Committee on Passive Protection Against Bombing, National Research Council. January 1943.

15. *Armor Piercing Projectile Tests on Concrete Slabs.* San Francisco District U. S. Engineer Office at the direction of the Chief of Engineers, U. S. Army. May 1942.

16. *Report of Bomb Tests on Materials and Structures.* Passive Defense Bulletin No. 1. War Department, Office of the Chief of Engineers. September 1941.

17. *Armor Piercing Bomb Test.* Protection Tests, Bulletin No. 3. War Department, Office of the Chief of Engineers. 1941

18. *Report of Bomb Tests on Burster Slabs, Second Series.* Passive Protection Bulletin No. 8. War Department, Office of the Chief of Engineers. February 1943.

Since these sheets were published, new data have been obtained and a revision of the sheets is desirable. Analysis of recent data indicates that the relations used in sheets 2B1 and 2C1 for scabbing and perforation should be $s/d = 2.28 + 1.13\ x/d$ and $e/d = 1.23 + 1.07\ x/d$ instead of the equations given above. Data also show that the dependence of penetration on the strength of the concrete is not as simple as given by the equation above, that the size of the aggregate has a small but definite effect on penetration, that the effect of nose shape of the projectile on penetration is greater and more complicated than indicated by the correction factor of ½ used in the penetration equation, and that if a larger factor is used for nose effect the exponent of velocity in the empirical equation is greater than 3/2. Progress has been made towards a theory of penetration to replace the empirical interpolation formulae used for the nomograms but this has not reached a satisfactory stage at present. The following references contain new material on terminal ballistics of concrete:

19. *Effect of Concrete Properties on Penetration Resistance.* Interim Report No. 27 of the Committee on Fortification Design, National Research Council. July 1944.

20. *Ballistic Tests on Concrete Slabs.* Interim Report No. 28 of the Committee on Fortification Design, National Research Council. July 1944.

21. *Penetration Theory: Separable Force Laws and the Time of Penetration.* NDRC Report No. A-333; OSRD Report No. 5258. Division 2, National Defense Research Committee. June 1945.

Sheet 2C1a is based on calculations from sheet 2C1, with some corrections using data described in the paragraph above. Striking velocities and obliquities were obtained from sheets 1B5* - 1B10*. The data on penetration in soil is included for comparison purposes and is taken directly from sheets 2A2* and 2A2a. The data on bomb case break up was taken from reference 22 below. The values for perforation of combination targets of soil and concrete were computed by the method described in reference 23, based on small scale test data. The information on bomb case break up and on perforation of composite targets is limited, so the values given on the sheet should be treated as approximations.

22. *Ballistic Data - Performance of Ammunition.* Technical Manual TM 9-1907. War Department. 1945.

23. *Composite Slabs.* Interim Memorandum No. M-13 of the Committee on Fortification Design, National Research Council. July 1945.

The crater profiles shown in sheet 2A3 are copied directly from the following report:

24. *Penetration and Explosion Tests on Concrete Slabs. Report II: Crater Profiles.* Interim Report No. 21 of the Committee on Passive Protection Against Bombing, National Research Council. January 1943.

SOIL PENETRATION

These sheets are based on analysis of penetration tests using small caliber projectiles, and penetration data for inert bombs dropped on various soils. The graphs in sheet 2A2* are based on an empirical relation between the caliber penetration, x/d, and the striking velocity, where x is the penetration measured along the path of the missile and d is the diameter of the missile, both measured in the same units. It was found that for projectiles having different caliber densities (weight/diameter^3) the caliber penetration at a given velocity was very nearly proportional to the cube root of the caliber density for a range of caliber density from 0.15 to 0.65 pounds per cubic inch. Thus penetration is approximately proportional to the cube root of the projectile weight, as shown on the sheet. The figures given for the relation between the depth below the surface and the length of the curved underground trajectory are based on a small number of measurements of actual bomb penetrations and a large number of measurements of penetration of small caliber bullets. These figures are used in sheet 2A2a, and are not of great accuracy. Changing these figures by 25% has small effect on the penetration values given in sheet 2A2a. Sheet 2A2a is based on sheet 2A2*, using striking velocities from various altitudes as in sheets 1B5* - 1B9*. The data and analysis for both sheets are given in the following reference:

25. *Penetration in Soils.* Interim Report No. 30 of the Committee on Fortification Design, National Research Council. July 1944.

RICOCHET

Sheet 2A5 is based on data for small caliber projectiles, medium and large artillery shell, and bombs dropped from low altitude. Using the impact angle and striking velocity as variables, a graph was made by plotting each round fired, with indication to show whether ricochet did or did not occur. It was found that a band could be drawn separating the regions of ricochet and no ricochet, for each material. The data are for ricochet or no ricochet from thick targets. Ricochet from steel is not treated, since the limit is between ricochet and perforation instead of between ricochet and penetration, and is therefore different for every plate thickness. Most of the ricochet data are from the following sources:

26. *Ricochet off Land Surfaces.* BRL Report No. 535. Ballistic Research Laboratory, Aberdeen Proving Ground, Md.

27. *Ricochet of Bombs off Various Surfaces when Released at 300 Miles per Hour.* BRL Report No. 256. Ballistic Research Laboratory, Aberdeen Proving Ground, Md.

28. *The Ricochet of Bombs.- Targets on Water.* Service Branch, Technical Division, Office of the Chief of Ordnance, War Department.

29. *The Connexion between Striking Velocity and Ricochet Angle at Low Striking Velocities.* Twenty-fifth Interim Report on Concrete for Defence Works. Road Research Laboratory, Ministry of Supply (British)

30. Unpublished data on concrete penetration at various obliquities. Princeton University Station, Division 2, National Defense Research Committee.

See also references 14, 20, and 24.

PLASTIC PROTECTION

Sheet 2C2 is based on British and American data on the performance of plastic armor in stopping small caliber bullets. These data were used to determine the thickness plastic protection required for "adequate protection" (5% or less of the bullets perforating). Most of the data came from the following report:

30a. *On the Probability of Perforation of Plastic Protection by Caliber .30 AP M-2 Bullets.* NDRC Report No. A-246; OSRD Report No. 3231. Division 2, National Defense Research Committee. February 1944.

SOURCES OF INFORMATION FOR THE DATA SHEETS, *page seven*

125. 6F1 *Aerial Bombing Attacks Against Aerodromes--Runways and Landing Grounds.* EWT-1c; OSRD No. 4918c. Effects of Weapons on Targets, Vol. 1. National Defense Research Committee. April 1945.

126. 6F2 *Attack of Railroads.* EWT-2d; OSRD No. 5045d. Effects of Weapons on Targets, Vol. 2. National Defense Research Committee. May 1945.

127. 6F3 *Air Attack on Bridges.* EWT-3j; OSRD No. 5176j. Effects of Weapons on Targets, Vol. 3. National Defense Research Committee. June 1945.

128. 6F4 *Attack of Tunnels.* EWT-2c; OSRD No. 5045c. Effects of Weapons on Targets, Vol. 2. National Defense Research Committee. May 1945.

TENTATIVE DATA - PERFORMANCE OF LARGE BOMBS

Sheet 7A1 gives tentative data for performance of the 12,000-lb GP bomb T10 and the 22,000-lb GP bomb T14. These bombs are essentially the same as the British bombs *Tallboy-M* and *Grandslam* except that the US bombs are filled Tritonal instead of Torpex D-1. Performance predictions are estimated by extrapolation of the data given in the sheets in sections 2, 3, and 6 of this book, with use being made of the observed performance of the British bombs where possible. The estimated performance in perforation of concrete, perforation of armor, and cratering in soil agrees very well with the observed performance of the British bombs. No observations of performance for other effects have been reported. Copies of principal papers describing the characteristics and performance of the British *Tallboy-M* and *Grandslam* and a critical discussion of these bombs may be found in reference 129.

129. *Study of the Requirements, Employment, and Effectiveness of Large Bombs.* AAF Project No. 4614A471.6. The Army Air Forces Board, Orlando, Florida. April 1945.

MISCELLANEOUS INFORMATION

Sheet OM1 gives a graphical method for solving the spherical triangle by which the altitude of the sun is determined at any point on the earth's surface and at any date. From the graphs, the ratio of object height to length of shadow on level ground can be determined to a good approximation. The only information that is needed is the latitude and longitude of the place in question, and the date and Greenwich Civil Time when the shadow was measured. This sheet is useful in determining heights of buildings from aerial photographs. Data on solar declination and Greenwich Hour Angle are from reference 130.

130. *Marine and Air Navigation.* J. Q. Stewart and N. Pierce. Ginn & Co. New York. 1944.

The detailed calculations for sheet OM2 are given in reference 131.

131. *Bombing Density Calculations for Sloping Targets.* EWT-3g; OSRD No. 5176g. Effects of Weapons on Targets, Vol.3, National Defense Research Committee. June 1945.

INCIDENT SUMMARIES

The incident summaries are based on the references listed below, the number of the incident summary being listed with the reference number.

132. A500 Air Raid damage report, Serial No. A.2, Ministry of Home Security, February 1943.
133. A1100 Air raid damage report, Serial No. A.3, Ministry of Home Security, February 1943.
134. A3100 Air raid damage report, Serial No. A.5, Ministry of Home Security, February 1943.
135. A-pm Air raid damage report, Serial No. A.7, Ministry of Home Security, February 1943.
136. B110 Air raid damage report, Serial No. B.1, Ministry of Home Security, February 1943.
137. B550 Air raid damage report, Serial No. B.2, Ministry of Home Security, February 1943.
138. B2200 Air raid damage report, Serial No. B.4, Ministry of Home Security, February 1943.
139. B-pm Air raid damage report, Serial No. B.7, Ministry of Home Security, February 1943.
C110 See reference 100.
C550 See reference 101.
C1000 See reference 105.
C1100 See reference 95.
C2200 See reference 96.
140. D110 Air Raid Damage Report, Serial No. D.1. Ministry of Home Security, February 1943.
141. D1100 Air Raid Damage Report, Serial No. D.3. Ministry of Home Security, Febbuary 1943.
D2200 See reference 102.
142. D-pm Air Raid Damage Report, Serial No. D.7. Ministry of Home Security, February 1943.

GENERAL REFERENCES

The following publications contain much general material similar to that in *Weapon Data - Fire, Impact, Explosion* or contain information of general interest on the effectiveness of weapons. Much of the material in these works and in the present report is based on the same sources, and in many instances the interpretation used in one of the reports is taken directly from one of the others. Such repetition of information and interpretation should by no means be interpreted as lending authenticity to the material.

143. *Selection of Bombs and Fuzes for Bombardment Targets.* The Army Air Forces Board. Project No. 3554A471.6. The Army Air Forces Board, Orlando, Florida. October 1944.

144. *The Relative Effectiveness of Various Type Bombs and Fuzes Against Strategic and Tactical Objectives.* Army Air Forces Evaluation Board, Mediterranean Theatre of Opdratins. October 1944.

145. *Selection of Bombs and Fuzes to be Used Against Various Targets.* OPNAV-16-V #A6. Air Intelligence Group, Division of Naval Intelligence, Office of the Chief of Naval Operations, Navy Department, Washington. March 1944.

146. *Selection of Bombs and Fuzes for Destruction of Various Targets.* FM 1-110; FTP 224. War and Navy Departments, Washington. April 1945.

147. *Ballistic Data, Performance of Ammuntion.* TM 9-1907. War Department, Washington. September 1944.

148. *Selection of Weapons for Fighter Bombers against Tactical Targets.* Operations Research Section, Ninth Air Force. Memorandum No. 70. February 1945.

149. *Effects of Explosion of HE Bombs: I. General and Air Blast.* BRL Report No. 554. Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. June 1945.

150. *Performance of Bombs and Projectiles against Shore Installations.* Ordnance Pamphlet 1172. Bureau of Ordnance, Navy Department, Washington. May 1944.

151. *Air Attack of Japanese Coast Defense Batteries. Target Analysis.* CINCPAC-CINCPOA Bulletin No.17-45. Feb. 1945.

152. *Effects of Weapons on Targets.* Volumes 1-6. Div. 2, Div. 11, and the Applied Mathematics Panel, National Defense Research Committee. Monthly publication. April - September 1945.

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Table of Contents
as of June 1944

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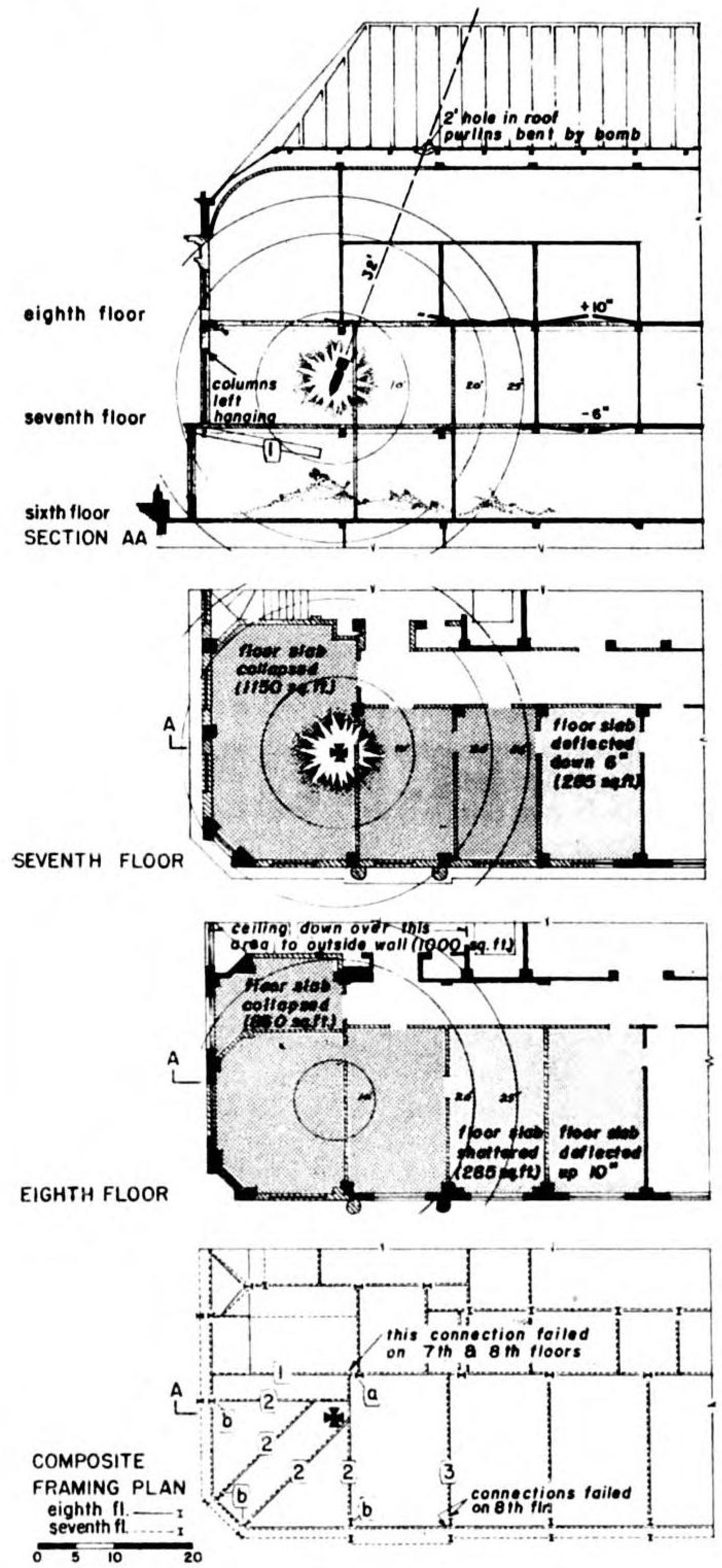
INCIDENT SUMMARY

A-550 MS-SF INCIDENT ONE

MULTI-STORY, STEEL FRAME OFFICE BUILDING STRUCK BY A 550 lb. G.P. BOMB

PF-5902/14

(GERMAN 250 K.g. S.C.? chg. wt. 50%)



BUILDING

Office Building - basement, sub-basement and eight upper floors.

Construction: Frame - concrete-encased steel frame with bolted connections.
Floor slabs - hollow tile and reinforced concrete joists.
Exterior walls - 13½ in. brick, stone.
Interior partitions - 3" and 4", some 4½ in. and 9" brick.

DAMAGE

Bomb perforated the roof and 8th flr. near one corner of the building and exploded just above the 7th floor. The extensive collapse of the 7th and 8th floor slabs was due to the failure, on both floors, of the connection of beam (1) at column (a) (see framing plan). This connection provided the only interior support for the entire corner bay floor framing.

On the 7th floor, beams (1) and (2) hinged down from their connections at the exterior wall. Columns (b), extending through the 7th and 8th floors, were left hanging from the roof structure, when these supporting beams hinged down. Beam (3) was deflected downward 3 inches.

On the 8th floor, connections at the exterior wall ends of beams (2) failed allowing the entire floor structure to collapse. Beam (3) was deflected upward 4 inches.

Blast damage to doors and windows extended for some distance through building. Exterior walls were blown out where shown crosshatched on the plans and section. Similarly, partitions shown crosshatched were destroyed.

Note: Circles represent the intercept of sphere of designated radius with the floor in question......the center of the sphere being at the estimated position of the explosion.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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March 1943

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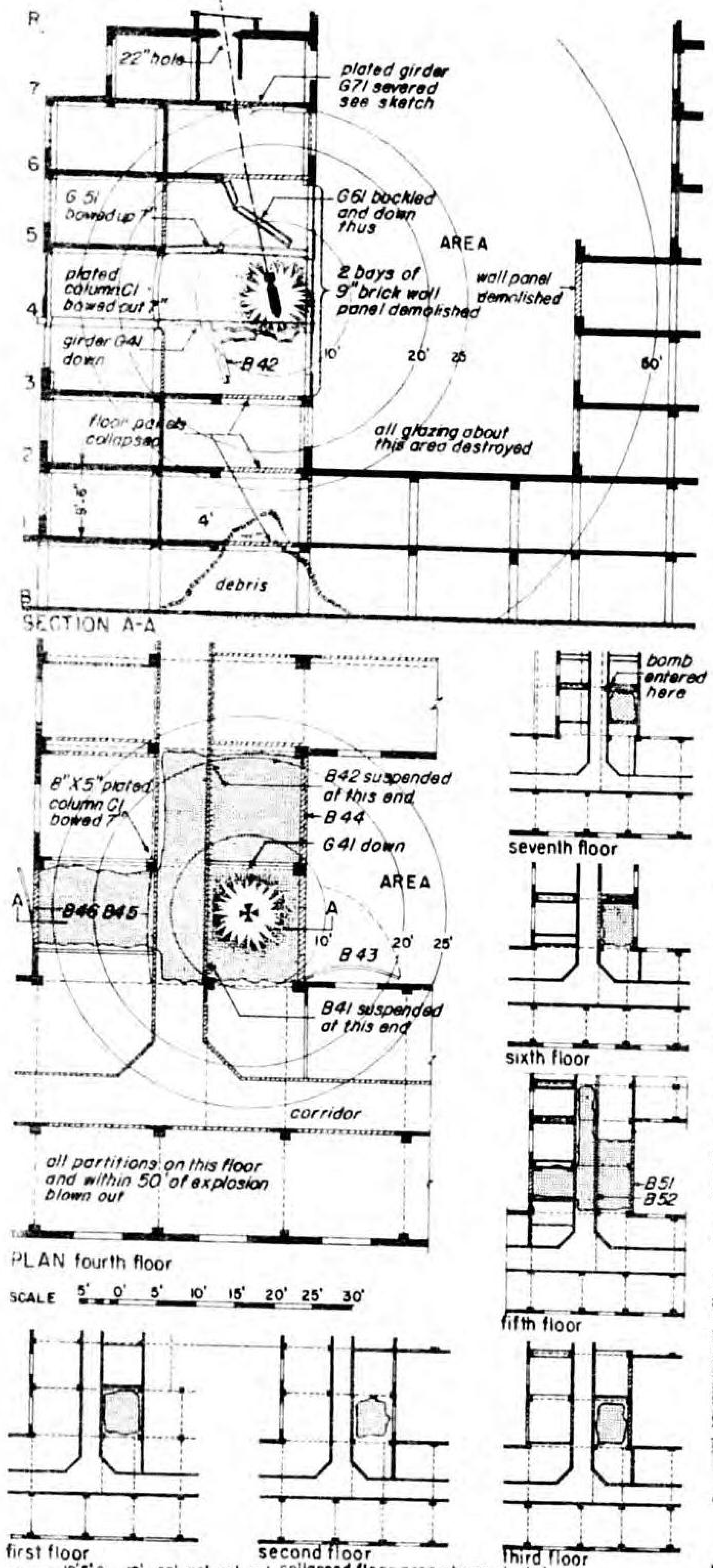
INCIDENT SUMMARY

MULTI-STORY STEEL FRAME APARTMENT BUILDING STRUCK BY A 1100 lb. G.P. BOMB

A 1100 MS-SF INCIDENT ONE

PF 5902/15

(German 500 Kg S.C. chg.wt 50%)



BUILDING

Type: Apartment building consisting of basement and seven upper floors.

Construction: Concrete encased, high tensile steel (Chromodor) frame. Floors: 6" hollow tile and 3½" concrete including finish: 1" plaster. Roof: Similar, plus 1" asphalt surface. Exterior Walls: 9" brick with outside tile facing. Partitions: 3" brick or breeze block and 7/8" plaster.

Girders: G71-plated, 10"x12": others 14"x 5½"

Beams : All beams 5" x 12" I-beams.

DAMAGE

The bomb perforated the roof and three floors; detonated just above the fourth floor.

Roof: Punched a 22" hole; no structural damage.

Seventh Floor: Plated girder, G71, severed by impact of bomb. Approx. areas of damage in sq. ft. to: floor - 100; partitions - 400; exterior walls - 0.

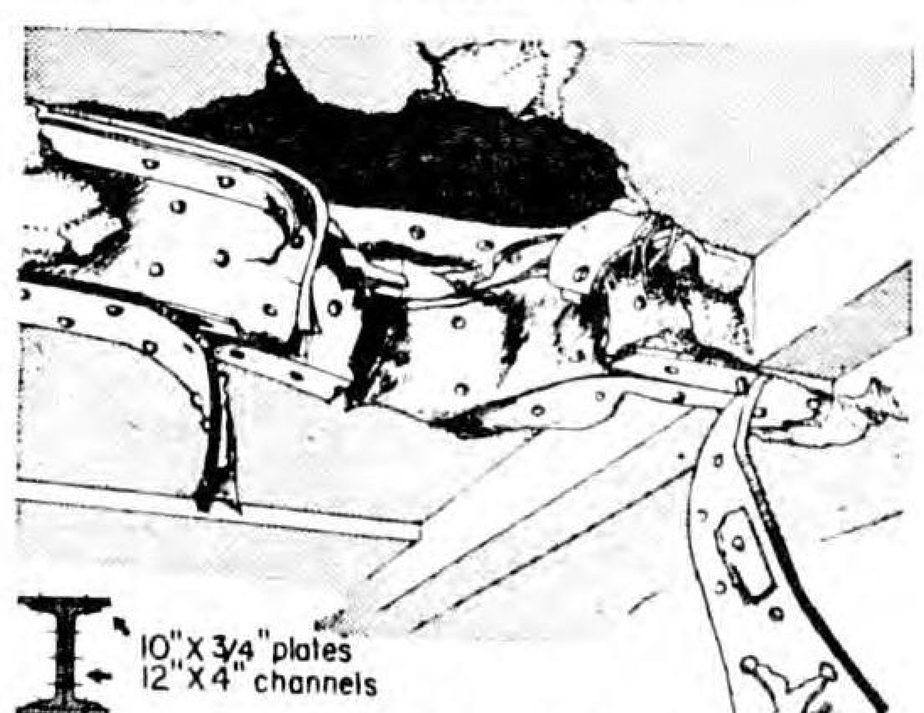
Sixth Floor: G61 buckled, end connections were torn but flange held up one end. Approx. areas of damage in sq. ft. to: floor - 190; partitions - 340; exterior walls - 0.

Fifth Floor: G51 deflected up 7"; beam B51 was bowed out 3", B52 was bowed up and one column connection severed. Approx. areas of damage in sq. ft. to: floor - 650; partitions - 1500; exterior walls - 230.

Fourth Floor: G41 blown down; B41 and B42 were left hanging by far-end connections. Wall beam B43, one end torn loose, was wrapped back 90°; B44 and B45 were bowed out 1½"; B46, one end torn loose, was bent out. Column C1 was bowed 7" and twisted 2". Approx. areas of damage in sq. ft. to: floor - 700; partitions - 5000 or all within radius of 50 ft.; exterior walls - 400.

Third, Second, First Floors: No structural damage. Approx. areas of damage in sq. ft. to: Floors: 3rd - 150; 2nd - 120; 1st - 120
Partitions : 3rd - 1000; 2nd - 400; 1st - 180
Ext. Walls : 3rd - 360; 2nd - 0 ; 1st - 0

The 5th floor slab was blown up; the 4th was blown down. The single bay of the 3rd, 2nd and 1st floors undoubtedly collapsed under the impact of the debris load. Doors and frames along corridors were damaged; all windows around the area were broken.



DETAIL showing impact damage to girder G71

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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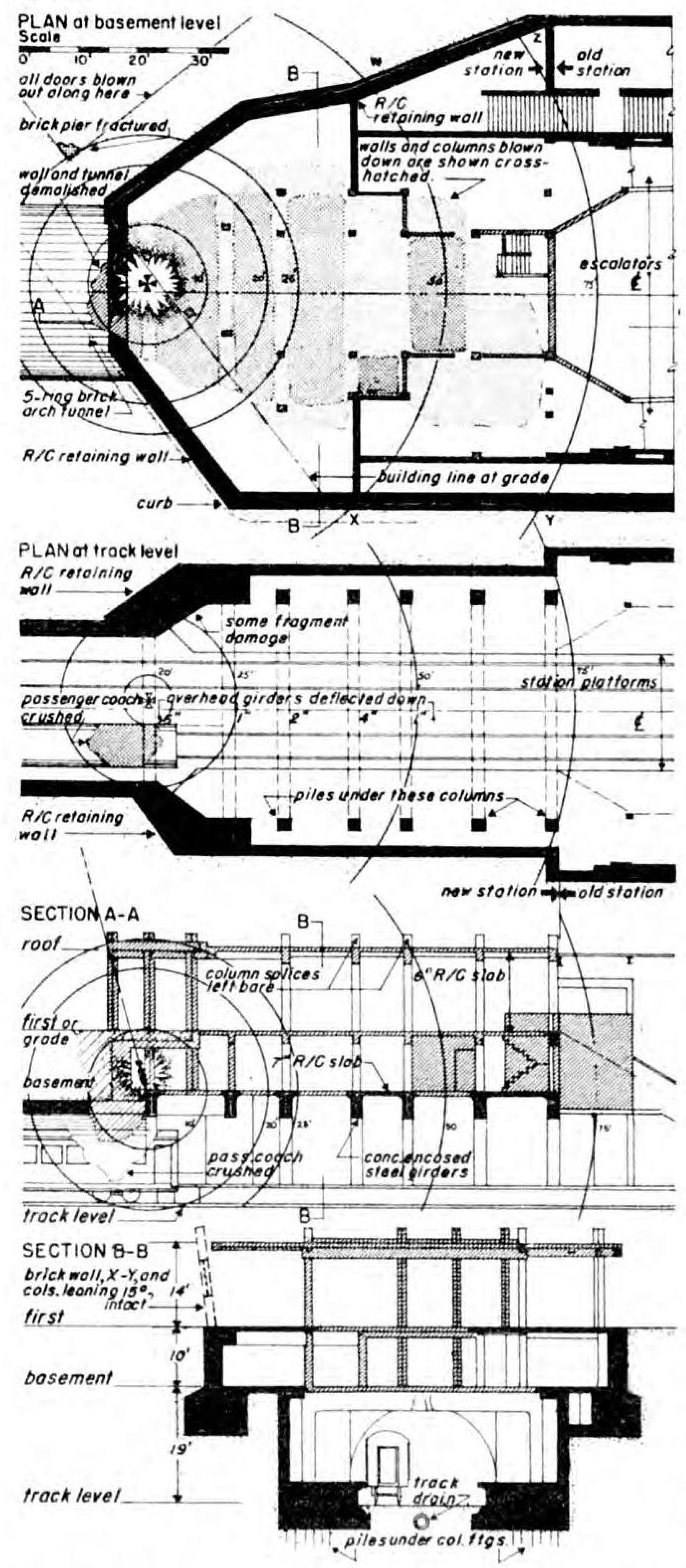
INCIDENT SUMMARY

MULTI-STORY, STEEL FRAME RAILWAY STATION STRUCK BY A 3100 lb. A.P. BOMB

A-3100 MS-SF INCIDENT ONE

PF-5902/17

(German 1400-kg, S.D..Chg.Wt.-22%)



BUILDING

Type: Railway station ticket office, a recent addition to existing old station, consisting of one story above ground, a basement, and the track-level subbasement.

Construction: Concrete encased steel frame, beam and girder system, 6 inch and 7 inch two-way R/C floor and roof slabs. Outstanding feature of the construction was the very heavy girders (4'-2' I-beams with cover plates) spanning the tracks. These girders were supported by steel columns set on piles and were designed to carry a proposed 10-story building (see exposed col. splices shown on sections). Heavy R/C retaining walls formed the foundation for the exterior walls of the building above grade. The old station was built of single girder, steel arches and light lattice purlins, covered with a patent glazing and corrugated sheathing. Underground tracks were housed in a five-ring brick arch tunnel.

DAMAGE

The bomb perforated the street level or first floor, struck the girder as shown, and exploded. The girder was severely damaged -- I-beam badly bent, plates torn, 8'-10' of concrete encasing stripped off, girder deflected 4". The other girders were deflected (am't shown on plan) and the concrete encasings were extensively cracked. Deflections were apparently caused by violent and heavy debris loads. The entire first floor and roof slabs were completely demolished.

A few of the columns and beams remained standing, though twisted and bent. The columns and roof and floor beams between Y and Z remained standing -- connection at Y failed. Failures occurred in the bolted connections between beams and columns -- apparent from the fact that many concrete encased members were strewn about but damaged only at the ends.

The exterior brick walls of the building were blown out except between X-Y and Z-W. (See plan at basement level.) The wall, X-Y, and integral columns leaned outward 15° with the vertical but remained intact. A small portion of the brick tunnel was demolished. Adjacent buildings suffered some blast damage.

Damage to the old station was limited to the removal of all sheathing and glazing -- no structural damage.

The bomb was identified by a fragment, 15" x 12" x 3" thick in size. Retaining walls suffered some fragmentation damage. Damage to the retaining walls and girders might have been greater if the bomb had not been stopped by the girder.

Note Circles represent the intercept of sphere of designated radius with the floor in question ... the center of the sphere being at the estimated position of the explosion.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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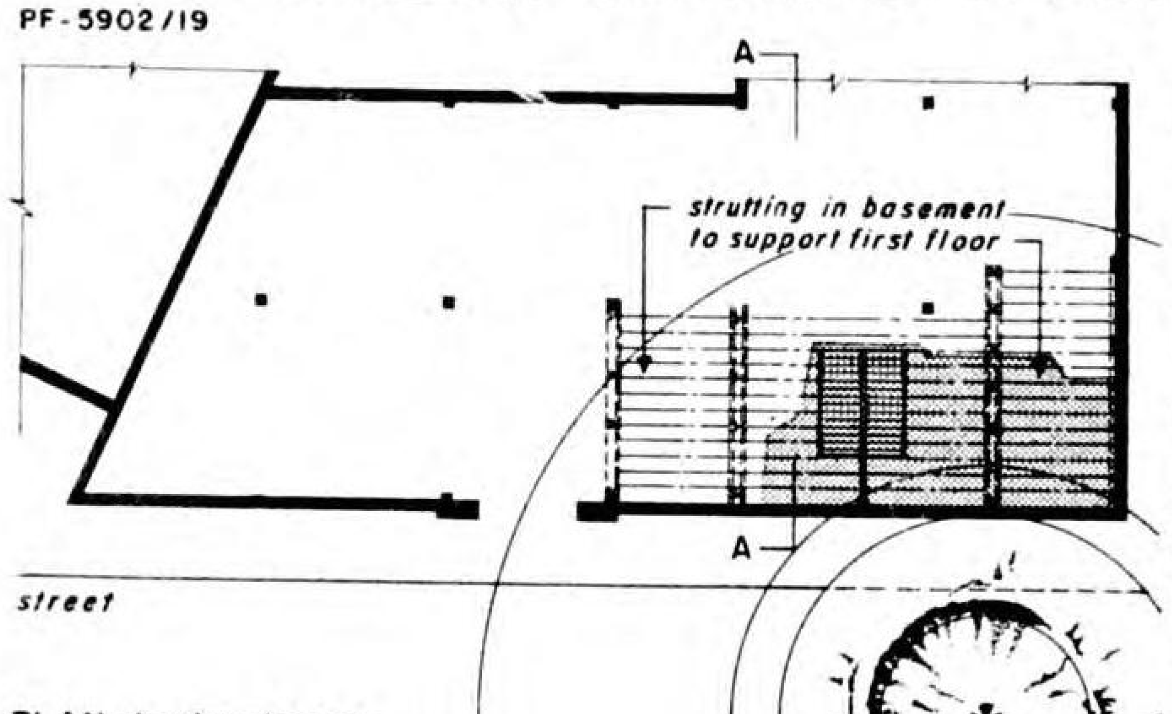
INCIDENT SUMMARY

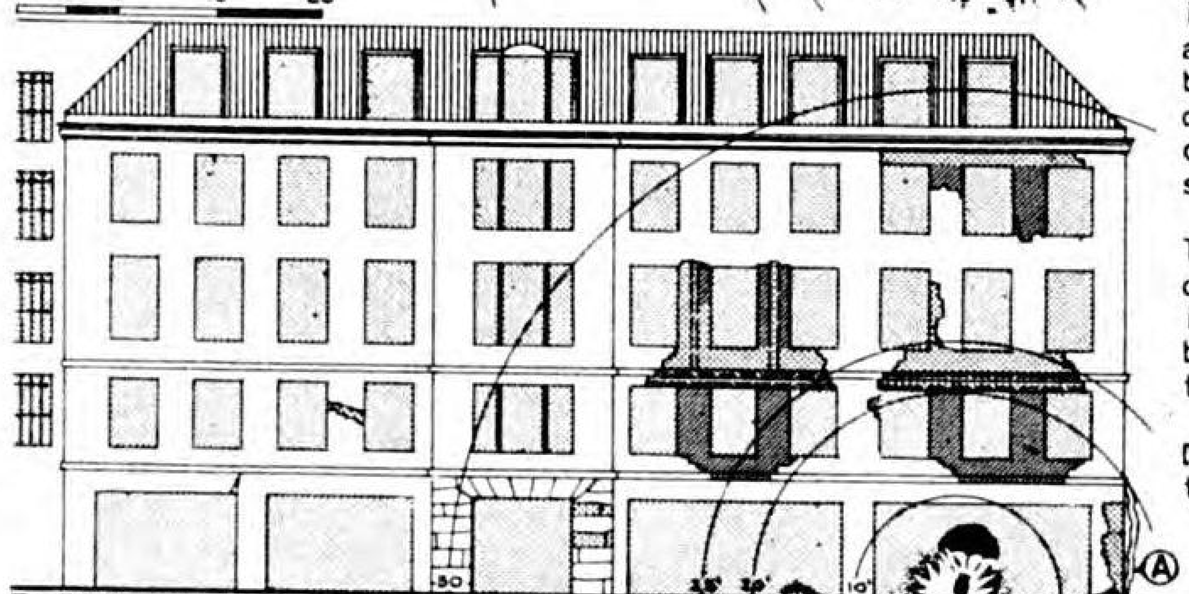
A PARA-MINE MS - SF INCIDENT ONE

MULTI-STORY, STEEL FRAME OFFICE BUILDING STRUCK BY A PARACHUTE MINE

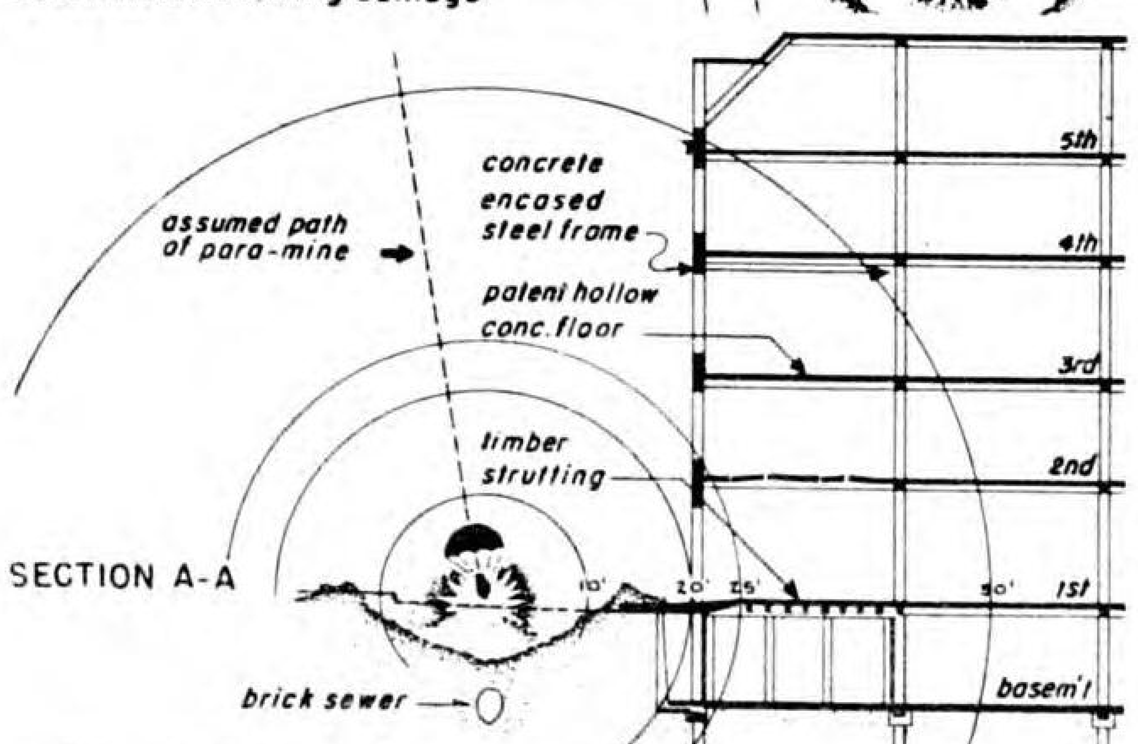
PF-5902/19



PLAN showing damage
basement strutting shown dotted
Scale: 0 5 10 20

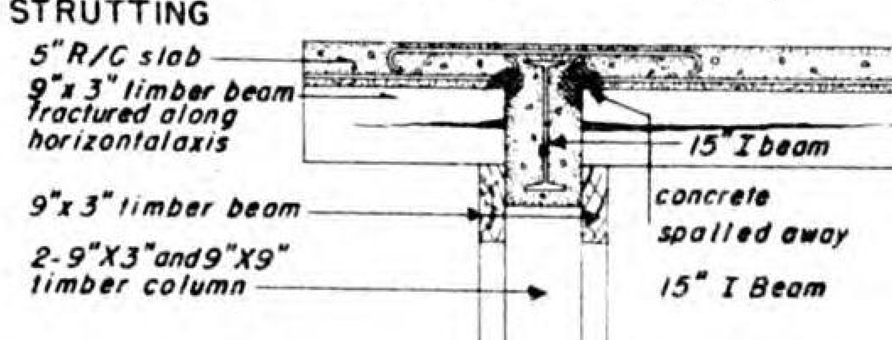


ELEVATION showing damage



SECTION A-A

DETAIL OF STRUTTING



BUILDING
Type: Commercial building consisting of a basement and five upper floors.

Construction: Concrete encased steel columns and beams. First floor slab of 5-inch R/C; upper floors of patent hollow concrete slabs. Walls of 13-1/2-inch brick.

DAMAGE
The parachute mine fell in the street near one corner of the building, forming a crater about 25 ft. in diameter. The structural framework was generally undamaged. There was some slight spalling at the junction of the floor slab and beams at the first floor. The slab was undamaged but the second floor was broken up directly over the blast.

The basement walls nearest the crater were covered with fine cracks and leaked slightly. Basement partitions were demolished and blast damage to doors, windows and brick facing was considerable. Attention is called to (A) on the elevation showing the characteristic damage to the face-brick and stone caused by the interval of low pressure (suction phase) which directly follows the high pressure (positive phase) of the blast wave; the facing appears to have been sucked from the wall.

The basement was adapted and used as the A.R.P. central control. Wood beams and struts, 3"x9" and 9"x9", were installed to support the concrete floor. Some of the beams were split along the horizontal axis. (See detail of strutting.)

Damage to the oil burner lead to localized fires throughout the building.

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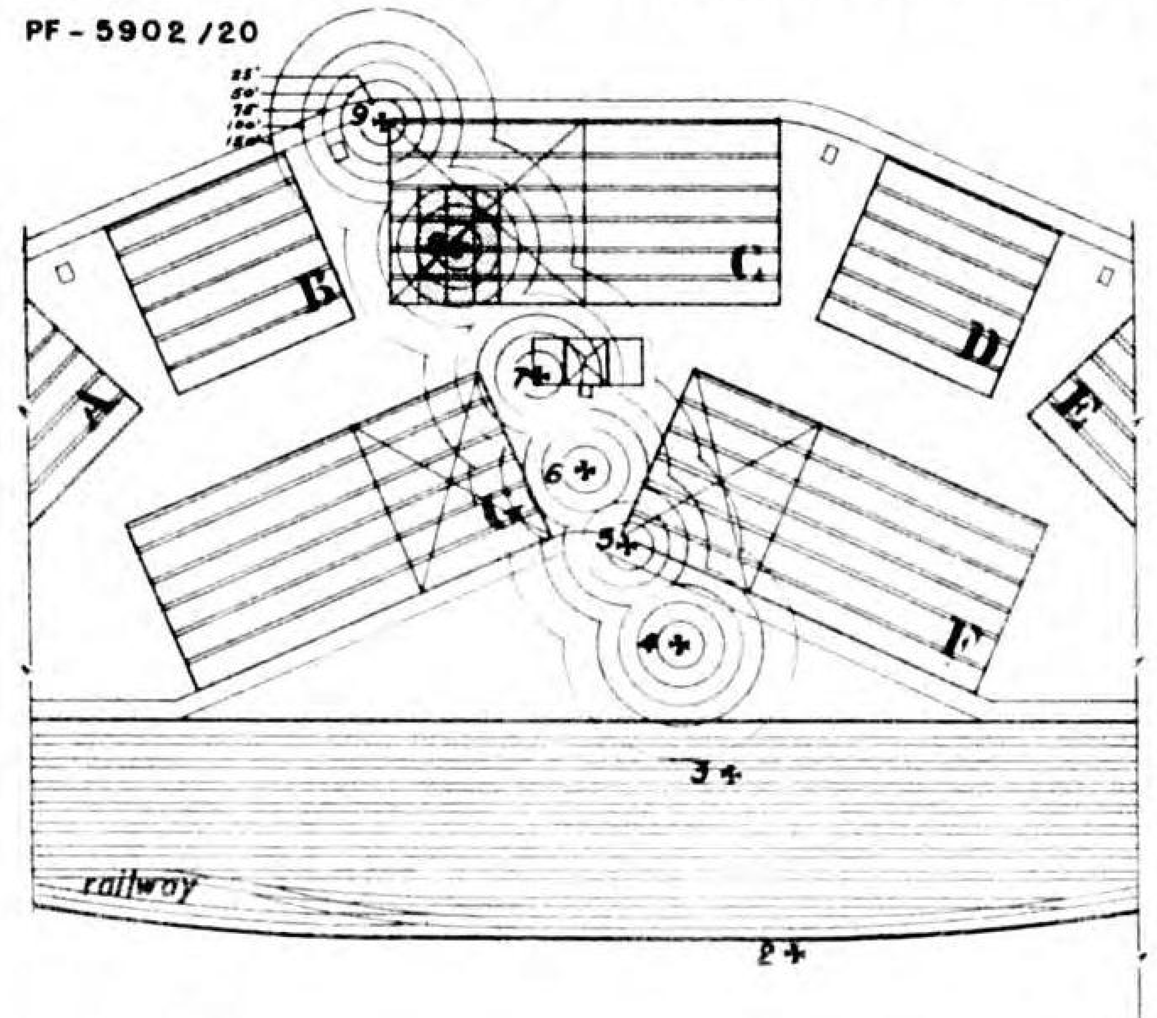
INCIDENT SUMMARY

B-110 SS-SF INCIDENT ONE

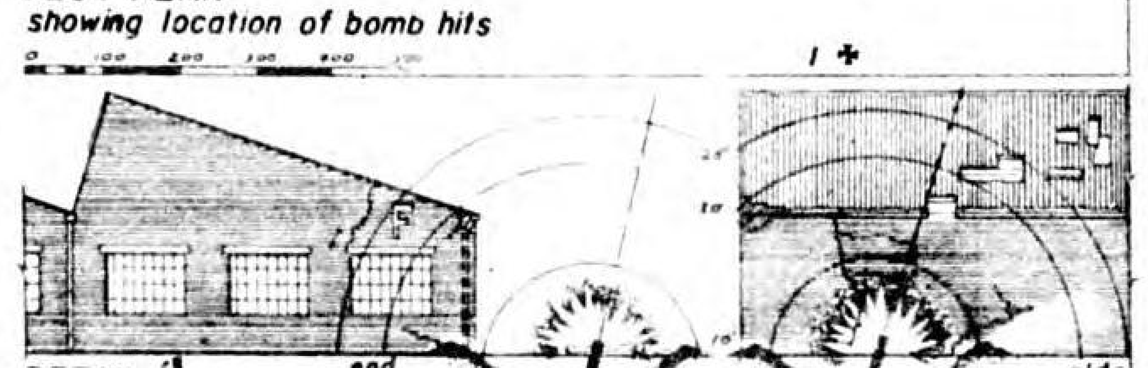
SINGLE STORY, STEEL FRAME SHED BUILDINGS STRUCK BY 110 lb. G.P. BOMBS

PF-5902/20

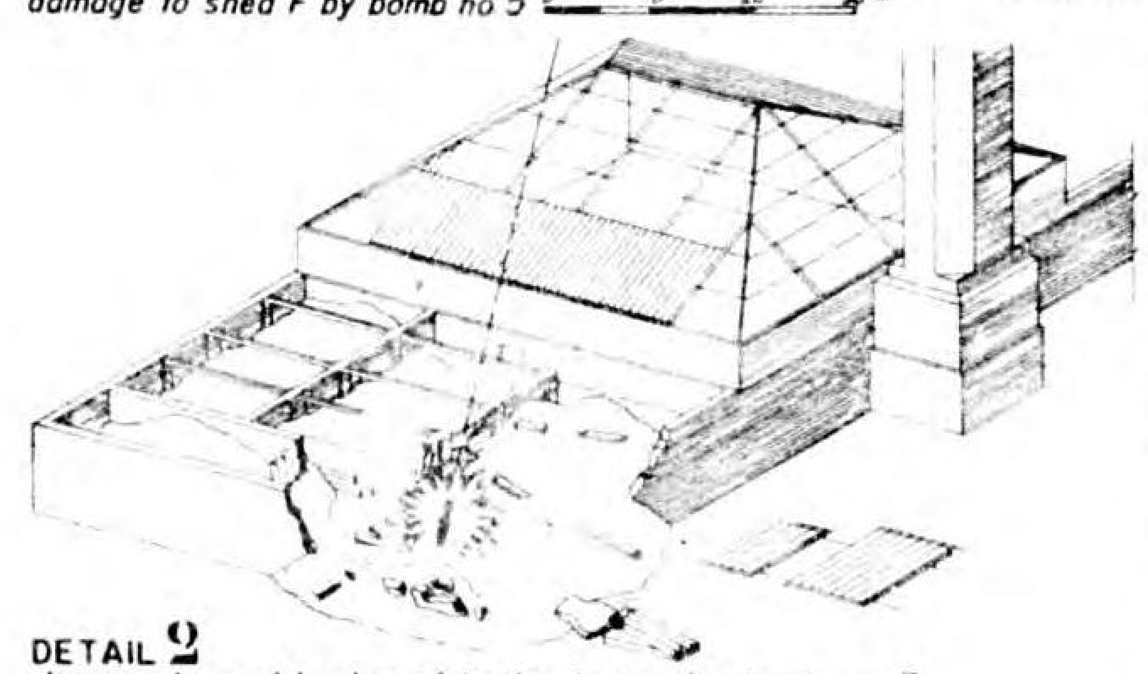
(German 50 kg S.C. 7 chg. wt. 50%)



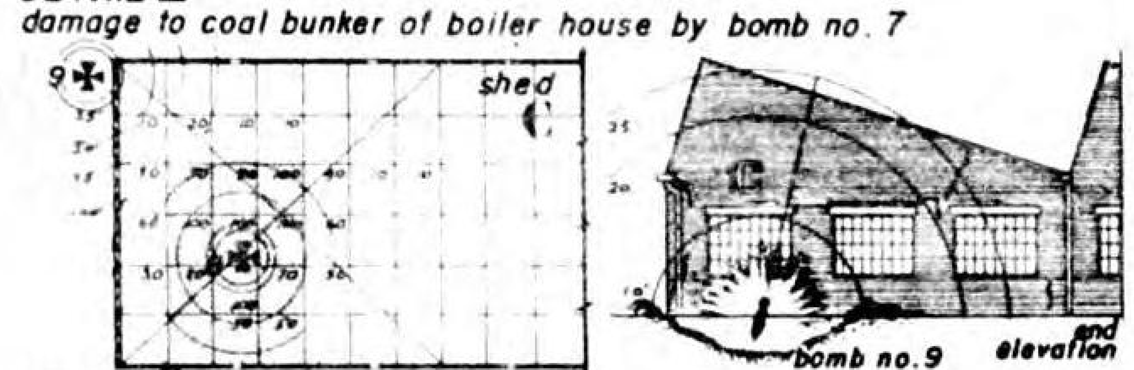
PLOT PLAN
showing location of bomb hits



DETAIL 1 end elevation side elevation
damage to shed F by bomb no 5



DETAIL 2
damage to coal bunker of boiler house by bomb no. 7



DETAIL 3
damage to shed C by bombs nos 8 & 9

BUILDINGS
A group of seven single story, steel framed shed buildings and a boiler house with adjoining coal bunkers was the target of a stick of nine 110 lb G.P. bombs. Sheds A, C, E F and G measured 504'x 240'x 13½' (to eaves); sheds B and D measured 252'x 240'x 13½'.
Construction: Steel saw-tooth trusses, 40' long spaced 12' o.c. with timber purlins, and valley beams 36' long formed 40'x 36' bays. Columns were 8"x 6" rolled steel Roof was sheathed with corrugated asbestos cement sheets. The lower half of the north face of trusses was glazed. Brick walls, 9" thick, had glazing in short, end walls and roller shutter doors (10'x 12') in long side walls

DAMAGE
Bomb no. 1, 2, 3, and 4; see Plot Plan. No damage to buildings, killed one cow.

Bomb no. 5; see Detail 1: A crater, 20' in diameter, 3'9" deep, was formed at the corner of shed F in the 5" R/C road slab. The slab was cracked and lifted for a maximum distance of 15' from crater edge. The 9" brick walls were cracked by earth shock and the roofing damaged by falling debris to the extent shown. The shutter doors in the side wall were not damaged.

Bomb no 6; see Plot Plan: Damaged sheds F and G by blast, breaking 80% of the end wall glazing and approximately 5% of the north-light glass in the crossed area The chimney, 130' high, was marked by about 6 fragments all striking above a point 80' from the ground.

Bomb no. 7; see Detail 2: Direct hit on unfinished, filled coal bunker. Destroyed 13½" brick walls and dislodged several steel roof joists. Roofing on unfinished boiler house was not damaged.

Bomb no. 8; see plan of Detail 3: Direct hit on shed C, perforated roofing and formed a crater 7½' in diameter, 3' deep, in 6 inch R/C floor slab. Bomb just missed valley beam. Only 5 timber purlins were destroyed and the valley beam was cut by a few fragments. Stacks of picks and shovels were thrown about. Asbestos cement roofing was completely destroyed in the shaded area (approximately 1728□') and less seriously damaged in the crossed area: The figures indicate the percentage of north-light glazing broken in each 40'x 36' bay.

Bomb no 9; see elevation of Detail 3: Bomb hit near corner of shed C forming crater 16'-20' in diameter; nearest edge 4' from wall. The 9 inch brick wall in this bay was extensively cracked as shown. The front wall (at left) was moved out over one inch, sliding on its damp-proof course. There was some roof damage evidently caused by debris. No fragmentation damage. Approximately 80% of the end wall glazing in this shed was broken by bombs no. 8 and 9.

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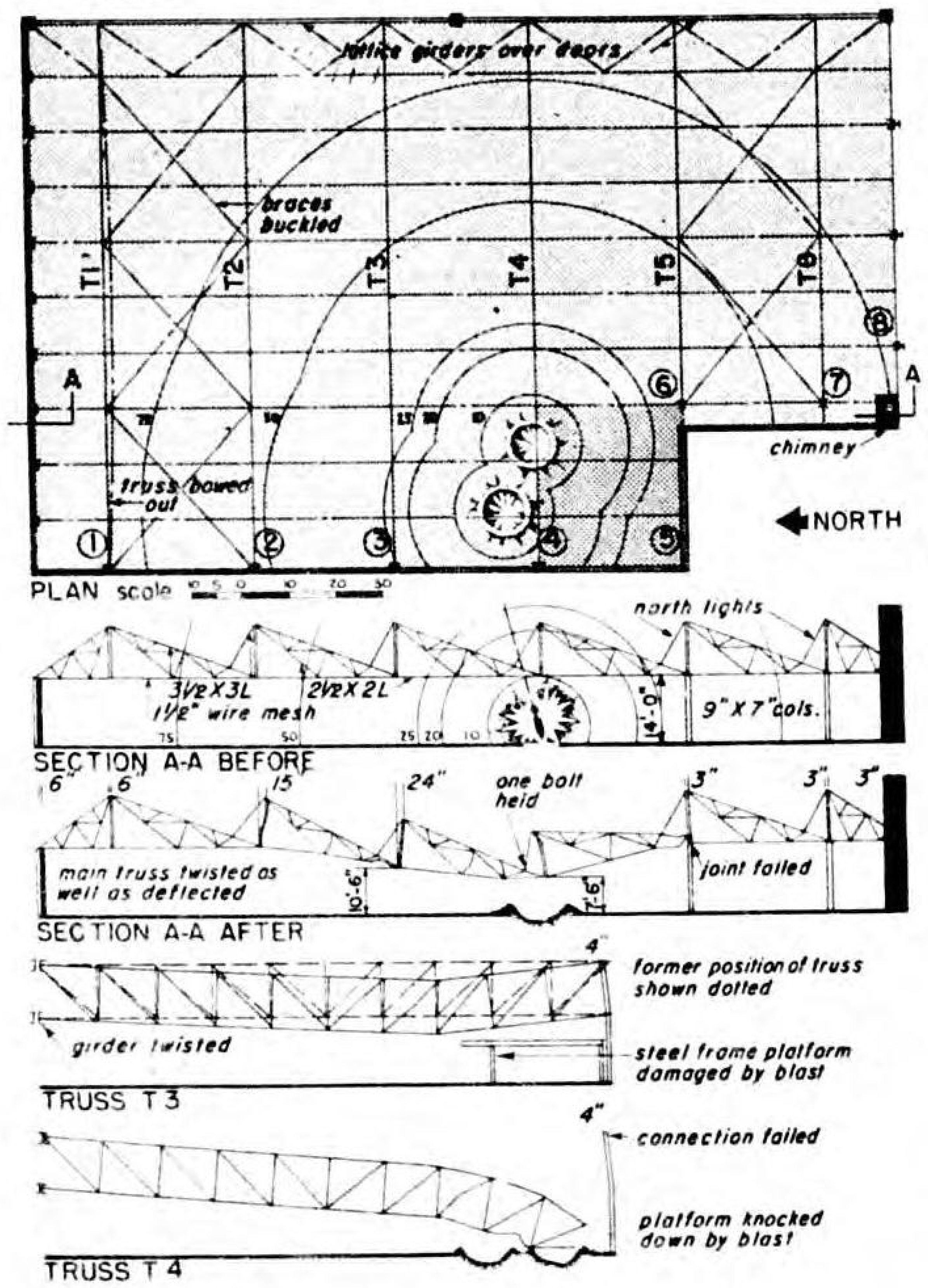
INCIDENT SUMMARY

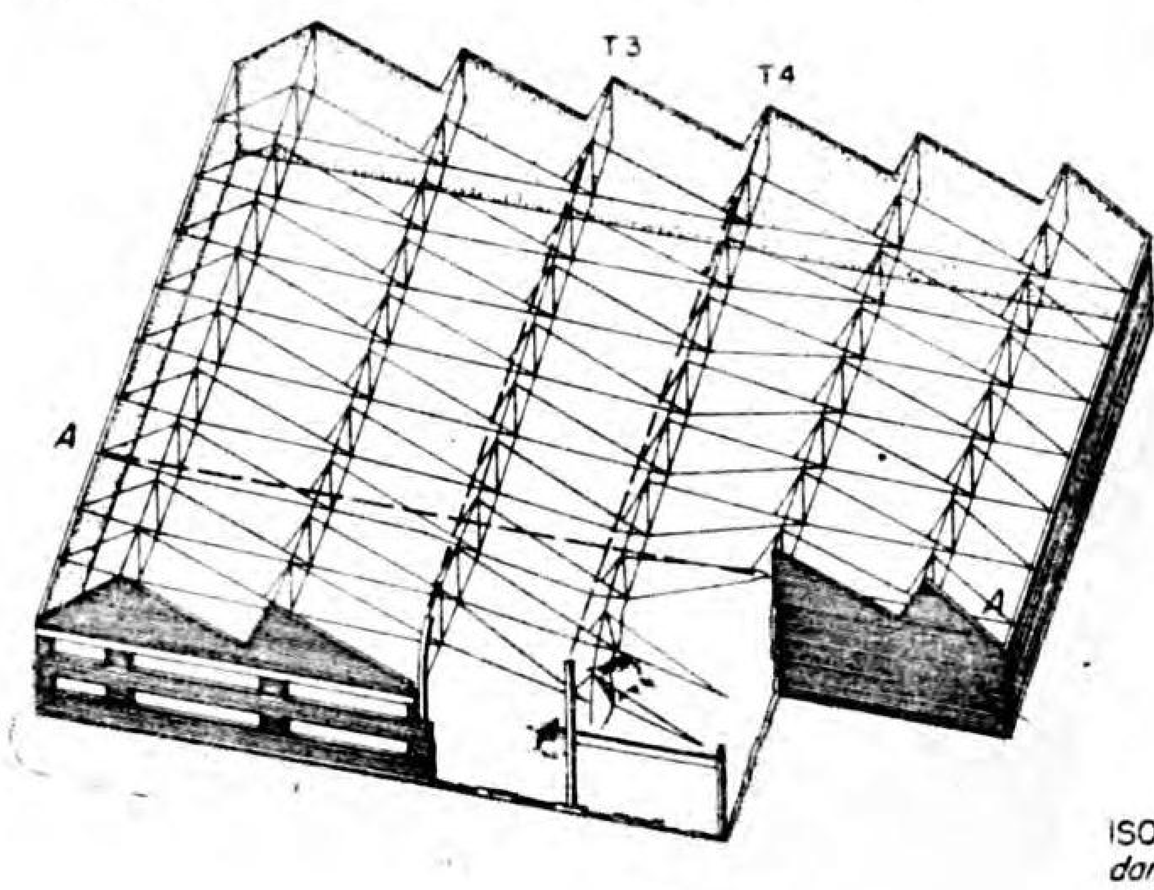
B - 550 SS-SF INCIDENT ONE

SINGLE STORY, STEEL FRAME FACTORY BUILDING STRUCK BY 2-550 lb. G.P. BOMBS

PF - 5902 / 21

(GERMAN 250 kg. S.C. chg. wt. 55 %)





ISOMETRIC *of damaged building*
dotted lines indicate former position of trusses A-A, T3, T4

BUILDING

Type: Single story factory building forming part of an industrial complex.
Dimensions: 181'-6" x 115'-6"

Construction: Outside walls are of brick. Trusses span the 115-ft. width of the building and are supported on the west side by 9"x7" steel columns, and on the east side by girders spanning 90-ft. door openings. Saw-tooth trusses, spanning 30 ft. and spaced 11.5 ft. apart, were supported on the 115-ft. trusses. North and south end walls supported the ends of the saw-tooth trusses. Roof covering was asbestos sheets supported on steel angle purlins. Ridge plate was of timber. North lights of saw-tooth trusses were enclosed with ¼" wire glass.

DAMAGE

The two bombs perforated the roof and exploded upon contact at the floor. The explosions lifted truss T4 and severed its connection with column 4. That end of truss subsequently collapsed. Three bays of the brick wall were blown down; the saw-tooth trusses, supported there, collapsed.

The saw-tooth trusses along section A-A operated as a chain of tension members allowing a decreasing amount of sag toward the outside walls. The amount that each truss shifted toward the center is shown on the section. All saw-tooth trusses east of section A-A acted similarly but to lesser degree. Columns 3 to 8 were bent toward the collapse, varying in amount from 3" to 5".

The chain of tension members depended on one bolt for its support. However, if it had failed it is probable that the next line of trusses would have taken the load with a correspondingly greater amount of secondary collapse.

All asbestos roofing and glazing were blown off. In general, the purlins remained in place preventing the lateral collapse of the saw-tooth trusses. In the area over the blast, however, the purlins collapsed with the trusses.

One bay of a platform, which was independent of the main structure, was blown down and the adjoining bay was badly bent and deflected by the blast.

The 1½" wire mesh which had been attached to the bottom chords of the trusses caught most of the debris from the roof (except in the area over the blast) and prevented many casualties.

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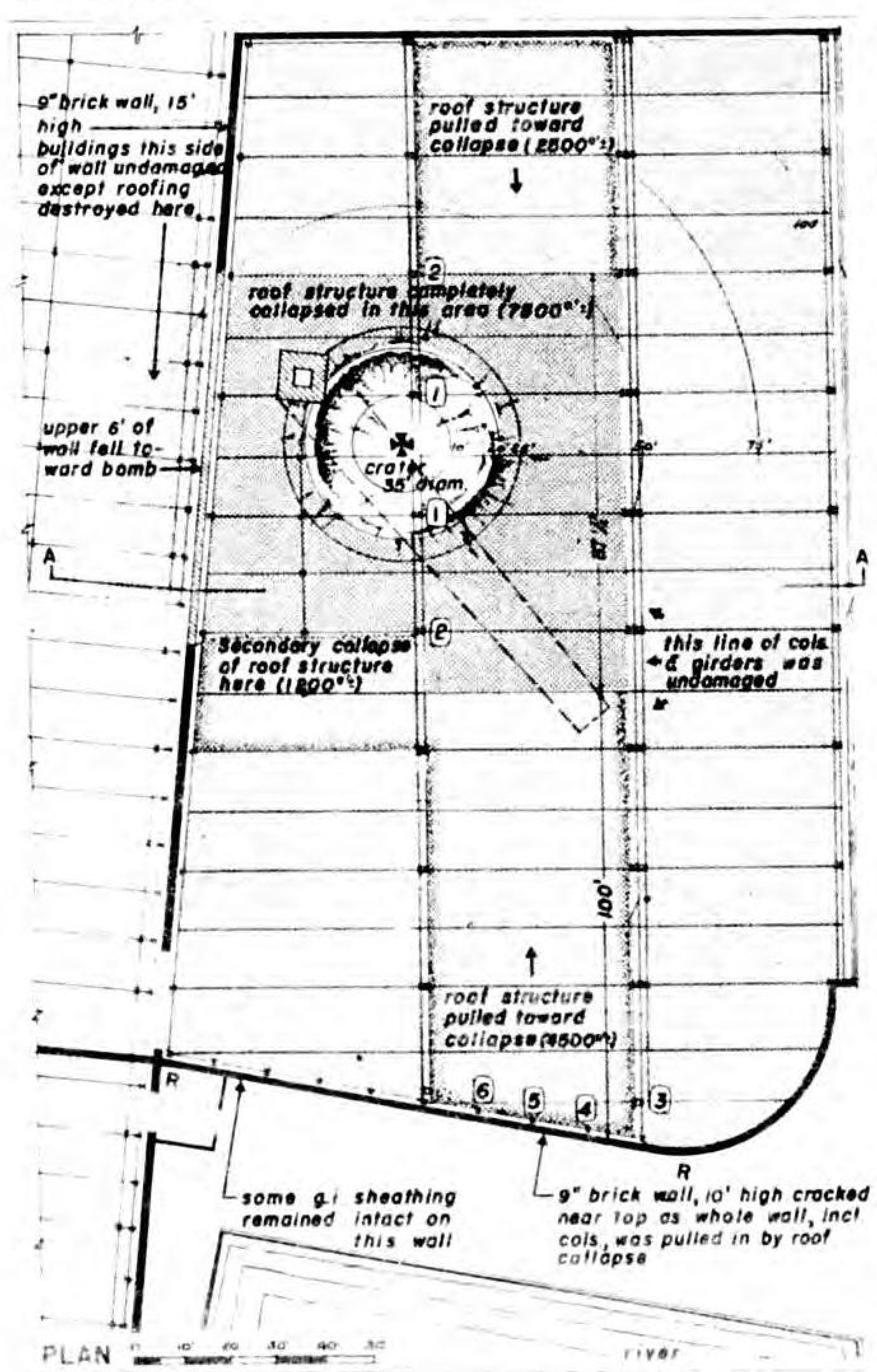
INCIDENT SUMMARY

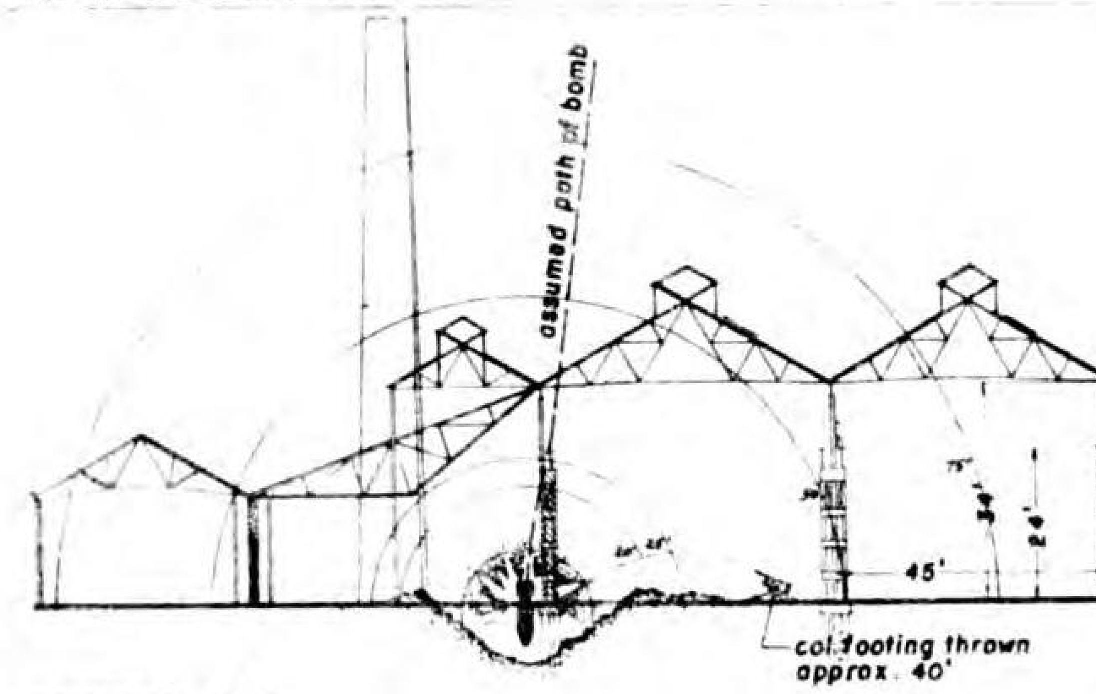
B -2200 SS-SF INCIDENT ONE

SINGLE STORY, STEEL FRAME FACTORY BUILDING STRUCK BY A 2200 lb. G.P. BOMB

PF-5902/23

(GERMAN 1000 K.g. S. C. ? Chg. wt. 50 %)





SECTION A-A

DETAIL *showing piles after explosion*

BUILDING

A 90'x 225' fully-framed steel shed. Asbestos cement sheathing on steel ∠ purlins. Monitored roof trusses spaced at 12½' on 45' spans carried by braced valley beams. Beams span 25' between columns, 34' to tie level. Columns have extra legs to carry crane girders at 24' level (see sec. A-A), and stand on concrete blocks set on reinforced concrete piles.

DAMAGE

Bomb hit crane girder 1-1 and exploded below level of col. footings. Cols 1,1 and crane girders 2-1, 1-1 & 1-2 were blown upward. The col footings were stripped from their piles and the girders were torn upwards from their connections. Valley beam 2-1-1-2 also came down and with it all of the roof structure within the area shown by the heavy shading. The adjacent roof structure, within areas shown in heavy shading at edge, was pulled toward the collapsed area. At the top of the wall at the river end of the building (R-R) this amounted to approx. 3'-4'. The top of col. 3 (between crane girder & roof) was bent inward about 4"-5". The lighter cols. 4, 5 & 6 bent inward approx. 3'-4' with the wall but remained vertical at bases. The crane girders that fell remained virtually undamaged, failure occurring within the bolts of the connections rather than the members. The chimney, collapsed by earth-shock and blast, crashed through the roof carrying with it a considerable portion of the roof structure.

All of the glazing and all g.i. roofing in entire building gone. Many purlins and light roof members were bent and twisted — their connections also suffering. All exterior wall sheathing, except in end wall R-R, also gone. Attention is called to the displacement of the col. footing (see sec. A-A). It is to be noted that this block of concrete was securely anchored to the R/C piles.

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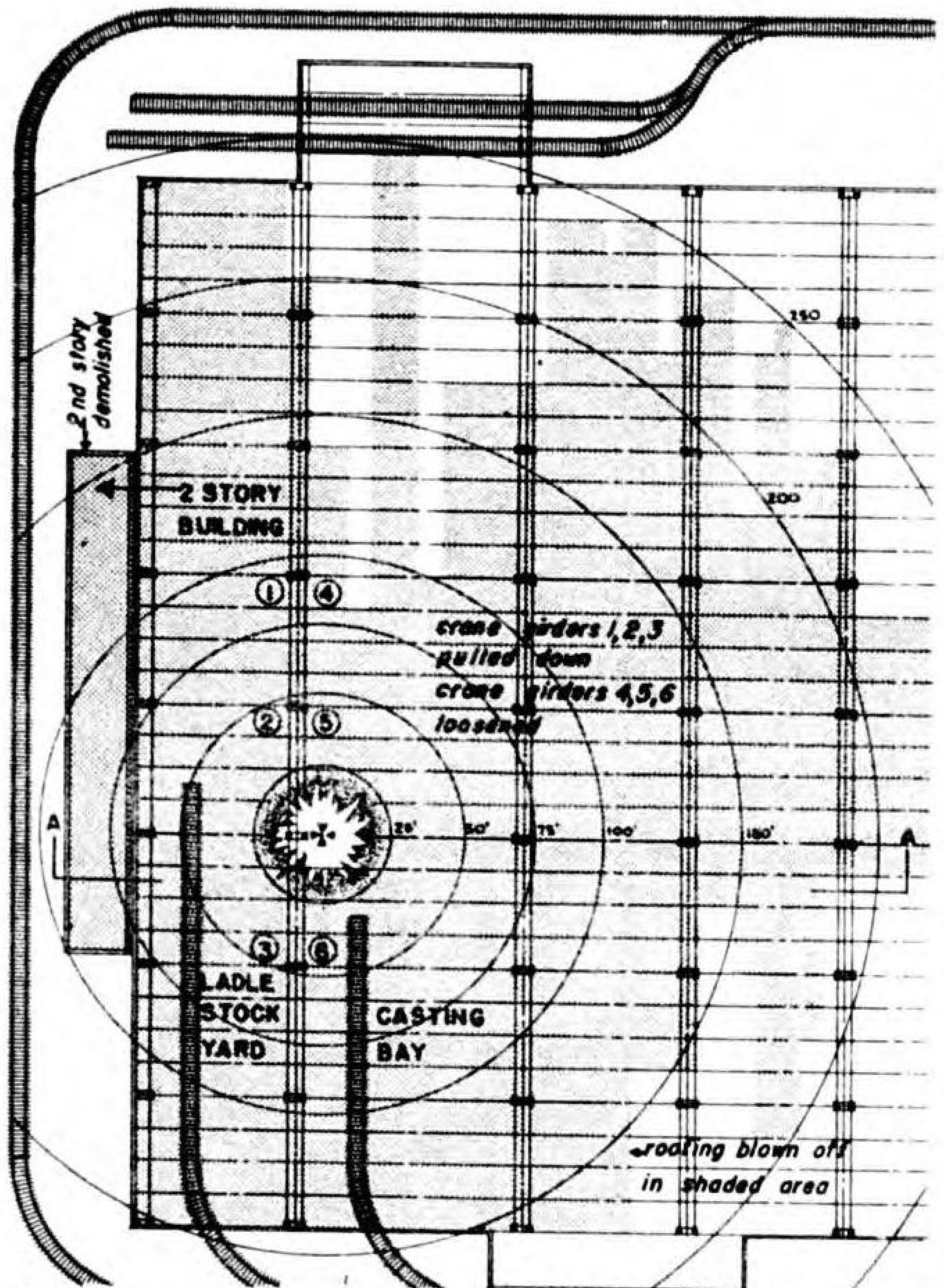
INCIDENT SUMMARY

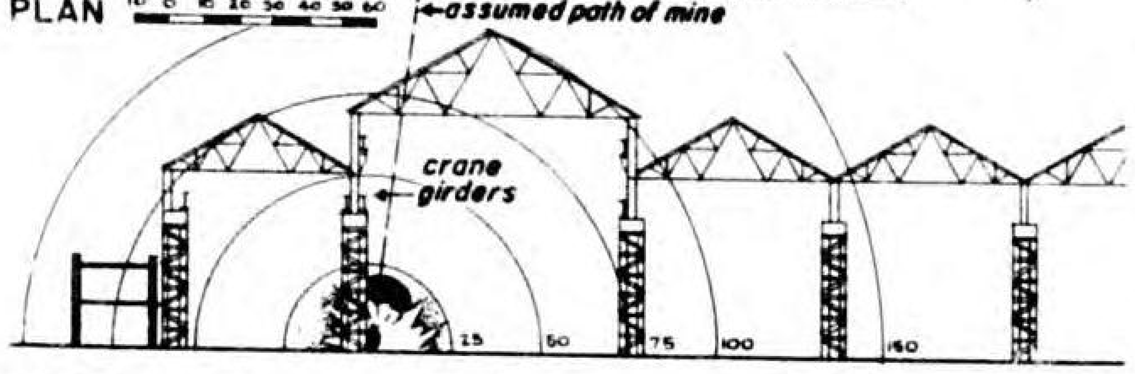
B PARA MINE SS-SF INCIDENT ONE

SINGLE STORY, STEEL FRAME FACTORY BUILDING STRUCK BY A PARACHUTE MINE

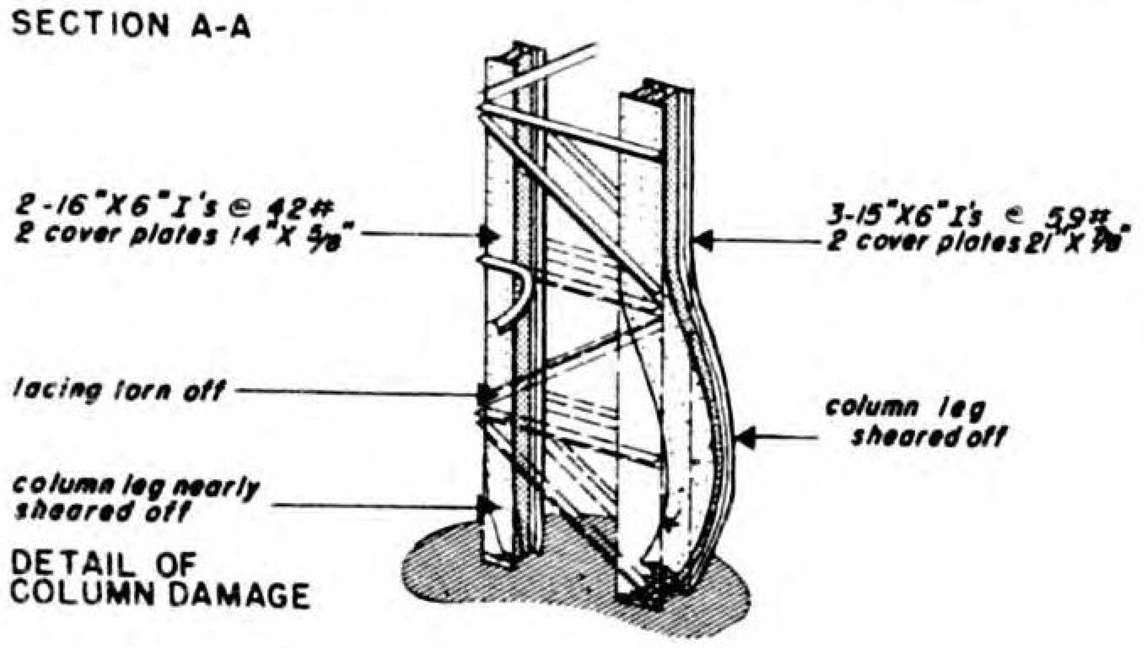
PF-5902/24



PLAN



SECTION A-A



DETAIL OF COLUMN DAMAGE

BUILDING

Type: Single story, steel frame main shop of a steel mill: approximately 375 ft. x 500 ft.

Construction: Interior columns (affected area) - heavy, lattice type; one leg consisting of 3 - 15"x6" I @ 59# with 21"x7/8" cover plates and the other leg of 2 - 16"x6" I @ 42# with 14"x5/8" cover plates. These legs were laced together with steel angles and spaced 5'-7 1/2" o.c. A single built-up column extended upward to the roof and was centered on the lattice column cap.

Girders and Trusses - crane girders, about 5'-6" deep spanning 46'-9" between columns, ran the full length of the building on each side of the columns. They were bolted thru their bottom flanges to the column caps. Above these a third crane girder, facing the Casting Bay, was supported on brackets from the center column. Longitudinal flat trusses, also attached to this center column carried the light pitched roof trusses.

Roofing and Sheathing - corrugated galvanized iron sheets, secured by 5/16" hook bolts to side rails and purlins. The side rails and purlins were 3 1/2"x 3"x3/8" angles.

Two-story Building - brick wall-bearing construction, about 20 ft. x 180 ft., R/C floor slabs, roof of R/C ribs and hollow tile filler.

DAMAGE

The parachute mine perforated the roofing and fell close to the lattice column, detonating upon contact with the floor. Only slight structural damage was done to the main shop building. The column nearest the explosion was distorted considerably: one leg, consisting of three I-sections, was sheared off at the base; the other leg, two I-sections, was almost severed.

Crane girders 1, 2 and 3 (see plan) were blown down when their bolted connections failed in tension. Girders 4, 5 and 6 were torn loose but did not fall down. A few roof purlins and truss members were bent and torn loose by the falling mine. No roof trusses came down.

Almost all of the roofing and wall sheathing was blown off of the building. The hook bolts straightened out but did not tear out of the sheathing.

The two-story brick building, adjacent to the Ladle Stockyard suffered considerable damage. The roof slab and second floor walls were completely demolished by the blast.

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INCIDENT SUMMARY

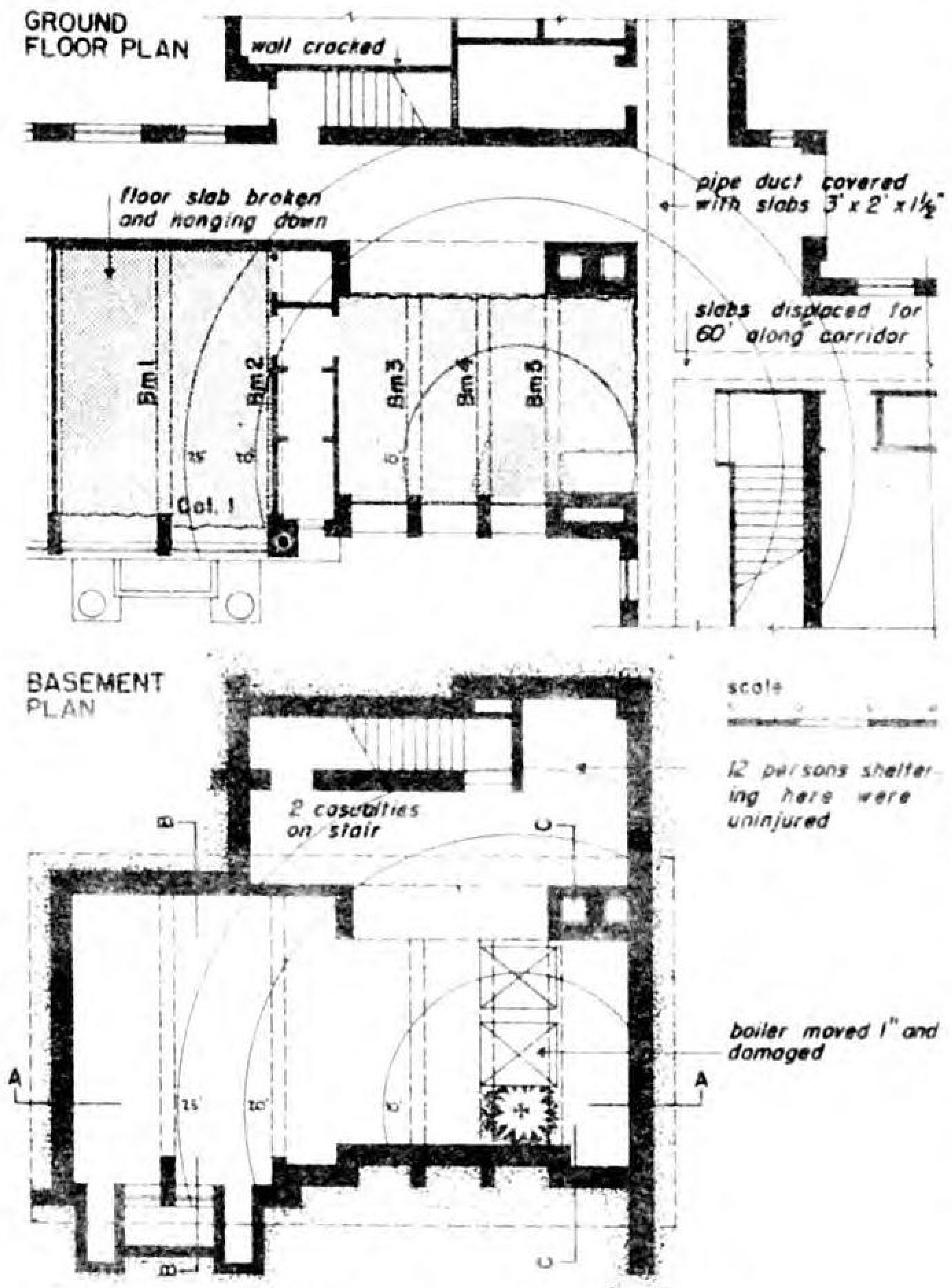
C 110 MS-RCF INCIDENT ONE

TWO STORY, REINFORCED CONCRETE FRAME SCHOOL BUILDING STRUCK BY A 110 lb. G.P. BOMB

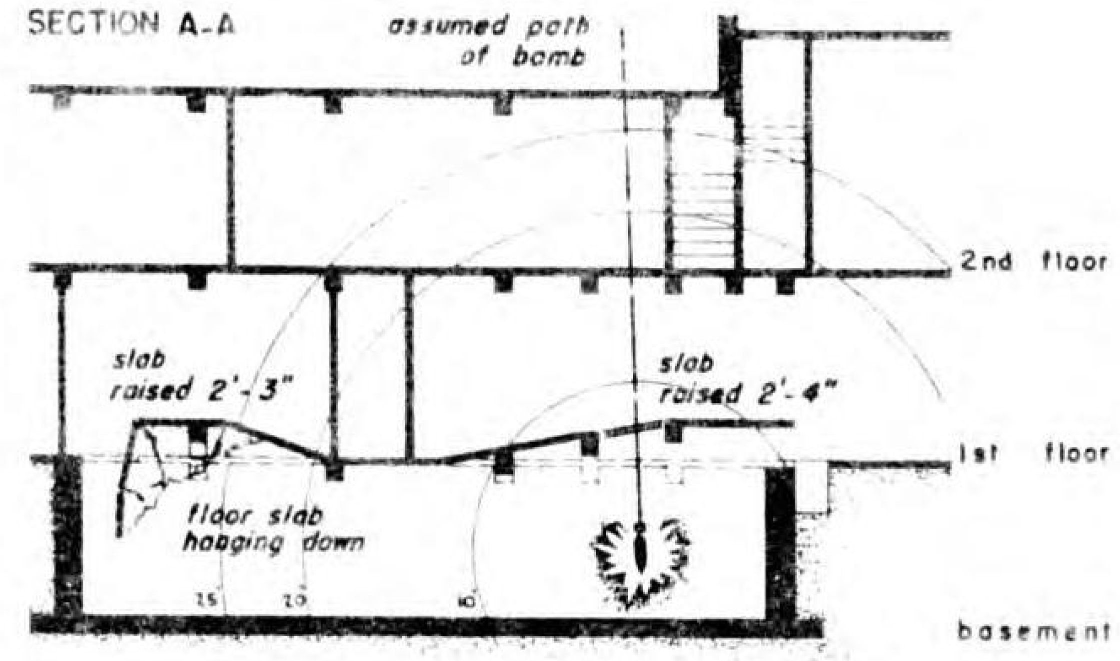
PF-5902/25

(German 50 kg S.C. chg wt 50%)

GROUND FLOOR PLAN

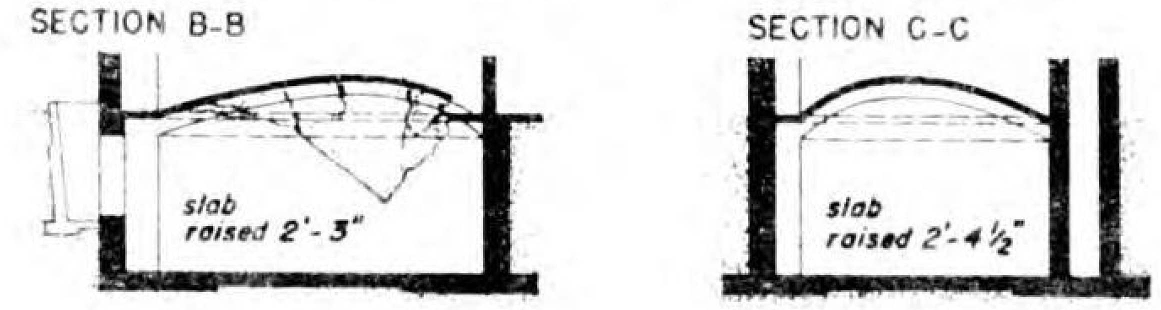


SECTION A-A



SECTION B-B

SECTION C-C



BUILDING

Type: School building consisting of basement and two upper floors in area affected by bomb. Construction: Reinforced concrete frame. Floor slabs 5" concrete. Basement 18" brick walls, exterior walls above basement 15" brick. Partitions 4½" brick.

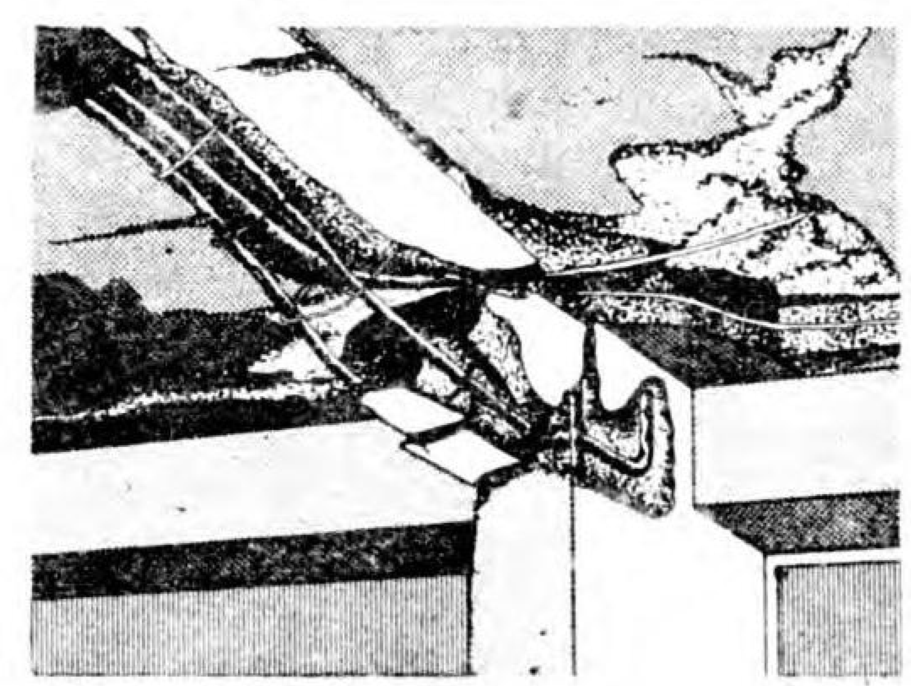
DAMAGE

The bomb perforated the roof and two floors detonating in the basement. Structural damage was confined to the boiler room (7000 cu. ft.) in which the explosion occurred. The bomb exploded in the 4½ft. space between the boiler and the heavy outside wall. The first floor beams (Bm 1,3,4, and 5) were raised upward. Floor slab over Bm1, having pulled away from its 4½-in. bearing along the wall, was broken and left hanging down. The floor slab over beams Bm3, 4, and 5 was also raised but beam Bm2 remained in place being supported by the 1st. floor partition. A hole (about 85 sq. ft.) was blown in the floor slab immediately over the blast.

Other damage to the building was minor, consisting of an 11-in. diameter hole in the roof, a small portion of the parapet wall demolished, an 11" x 19" hole in the second floor and some glass damage. A few days after the incident the school was in normal operation although no repairs had been made in the meantime.

Two casualties resulted on the stair when a door was pulled down on top of them. The boiler and chimney effectively screened 12 other persons sheltering in the basement.

The sketch below shows the broken connection of beam Bm1 to column 1 and is typical of concrete beam and column fracture under uplift loading.



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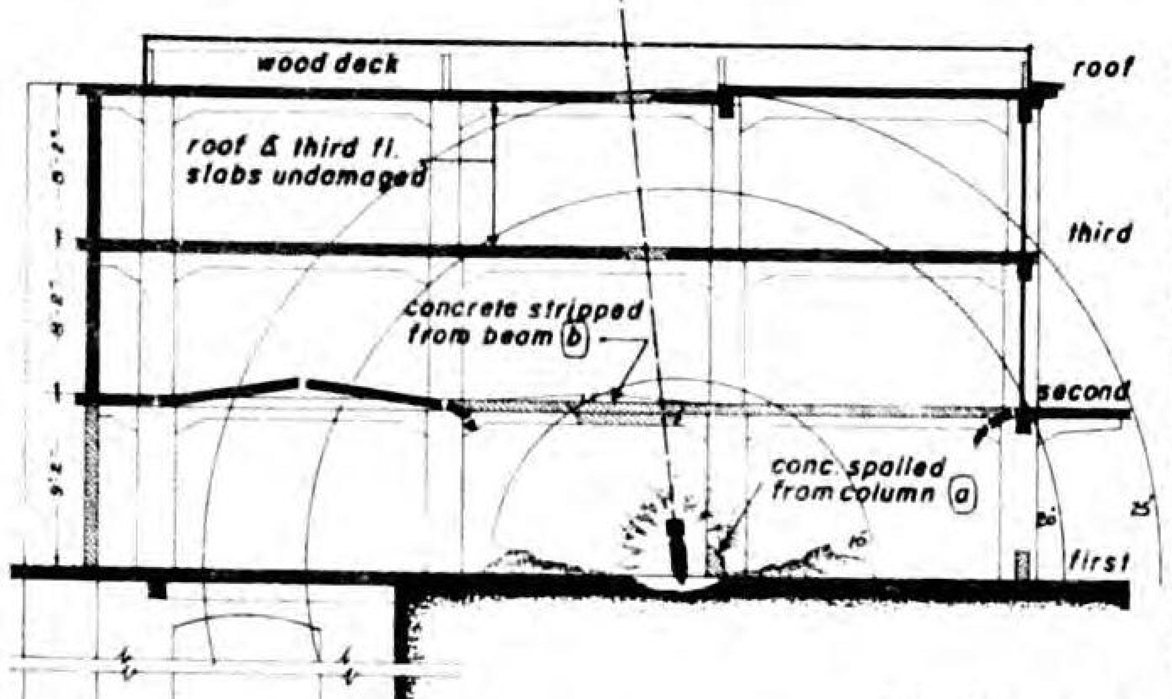
INCIDENT SUMMARY

C-550 MS-RCF INCIDENT ONE

THREE STORY, REINFORCED CONCRETE FRAME WAREHOUSE STRUCK BY A 550 lb. G.P. BOMB

PF-5902/26

(German 250-kg. S.C.! Chg. Wt. 50%)



SECTION A-A

BUILDING

Type: Wharf warehouse, first, second and third floors; brick vaulted cellar under back row of bays. Overall dimensions 45'x 130'.

Construction: Reinforced-concrete frame, beam and slab, 13'x 15' bays. Slabs - 8½" thick, designed for a live load of 336 lbs. per sq. ft. (3 cwt). Columns - first floor 24" x 24", second fl.- 21"x 21", third fl.- 18"x 18".

At the time of the incident the first flr. was loaded to within 12" of the ceiling with crates and barrels of eggs, cheese and packing mate ial. The second flr. was not loaded; the third floor was loaded.

DAMAGE

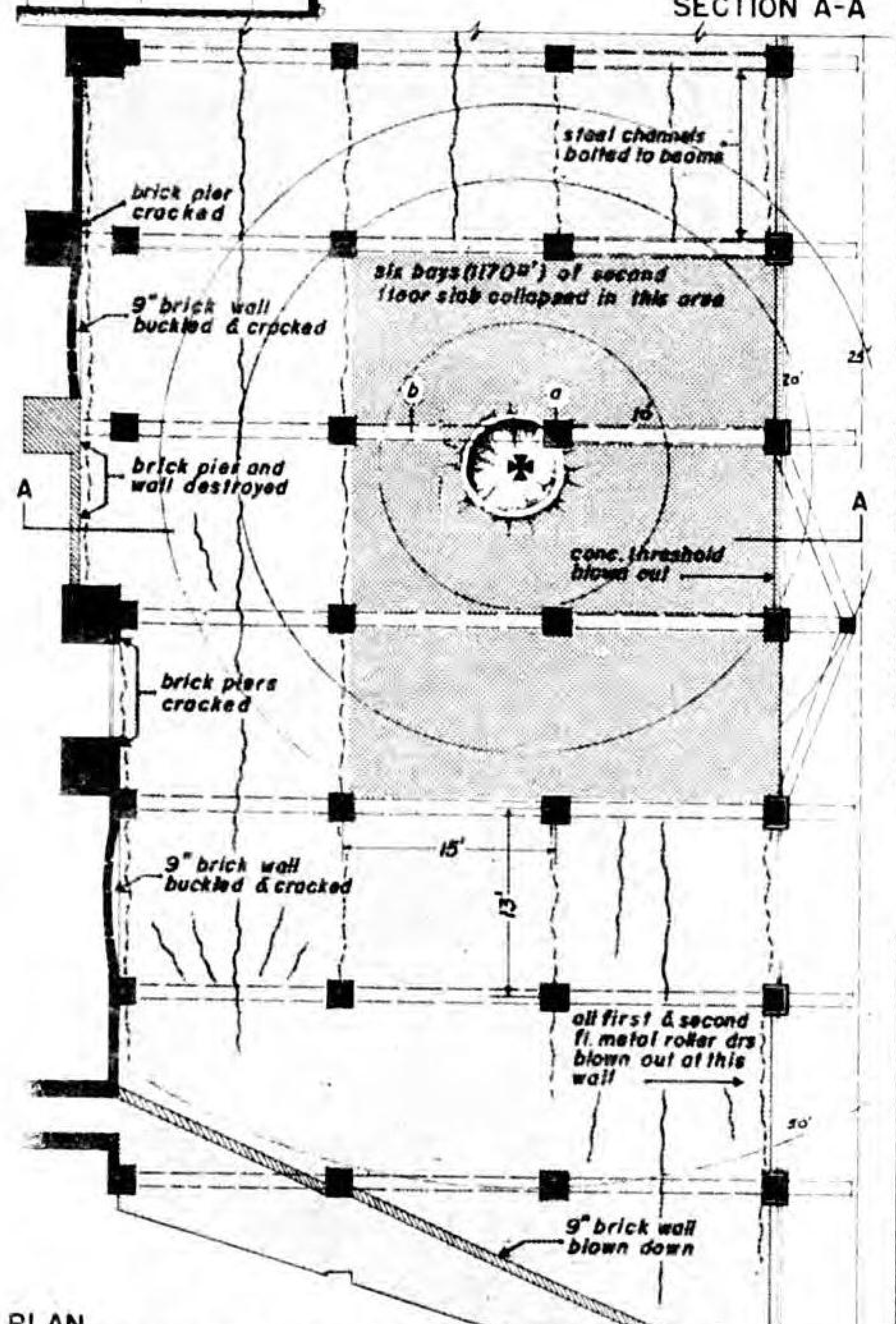
Bomb perforated roof and two floor slabs and detonated centrally in plan at the first floor, forming a small crater in the solid floor. Due to the muffling effect of the goods on this floor and the ease of lifting the unloaded second floor, the force of the blast was upwards. No damage due to fragmentation.

The entire second-floor slab (5950□') was lifted and torn from its supporting beams. Six bays (1170□') of the slab directly over the explosion collapsed. The slab cracked parallel with the one-way reinforcing and remained lifted along lines indicated thus: ——, and sagged along lines indicated thus: ----. Maximum lift occurred along the brick wall at the rear of the building. Maximum final lift was 17". Roof and third-floor slabs were not damaged.

The beams lifted with the slab and failed in reverse bending, stirrups pulled out and concrete cracked from reinforcing as shown in sketch below. All second-floor beams suffered similar damage in varying degree. Beam (b) had concrete stripped from steel to the extent shown on plan and section.

Column (a), 2 feet from the bomb, had a 1/16" metal guard blown away and concrete spalled from its base to a depth of 9" and to a height of 2'-6". No other column damage except light tension cracks at beam haunches.

Wall damage is shown cross-hatched on the plan.



PLAN
showing damage to first and second floor

TYPICAL BEAM and SLAB FAILURE

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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May 1943

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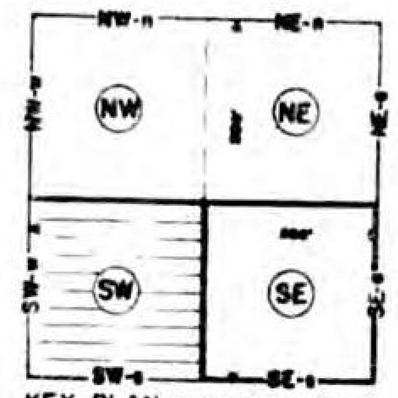
INCIDENT SUMMARY

C-1000 MS-RCF INCIDENT ONE

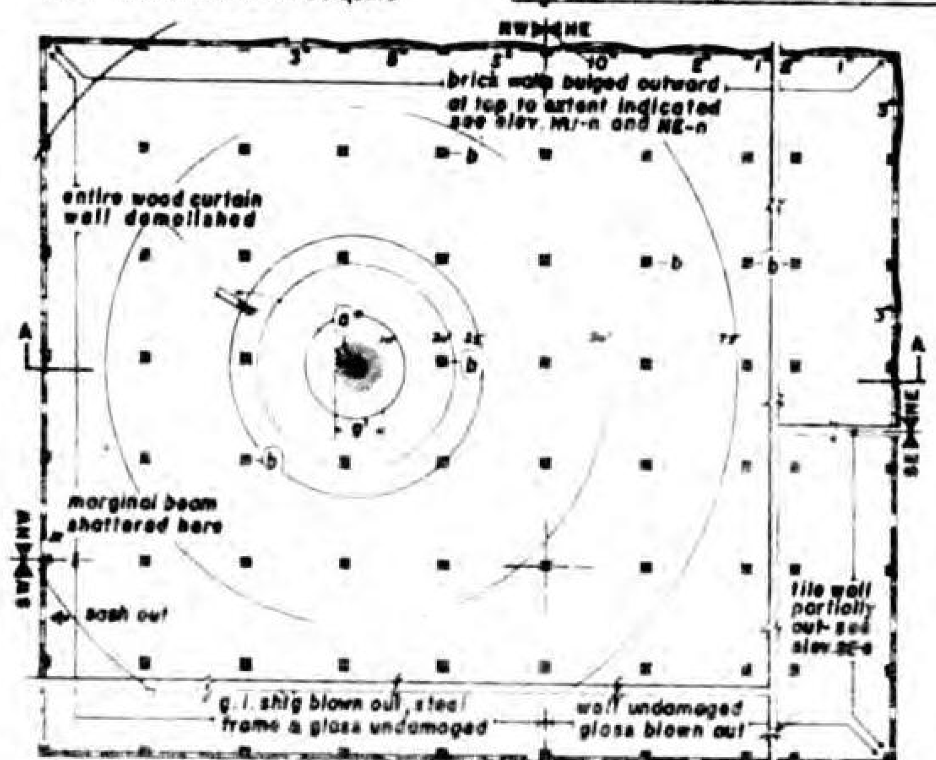
TWO STORY REINFORCED CONCRETE FRAME TEST BUILDING STRUCK BY A 1000 lb. G.P. BOMB

PF-2201/12, vols. 1-5

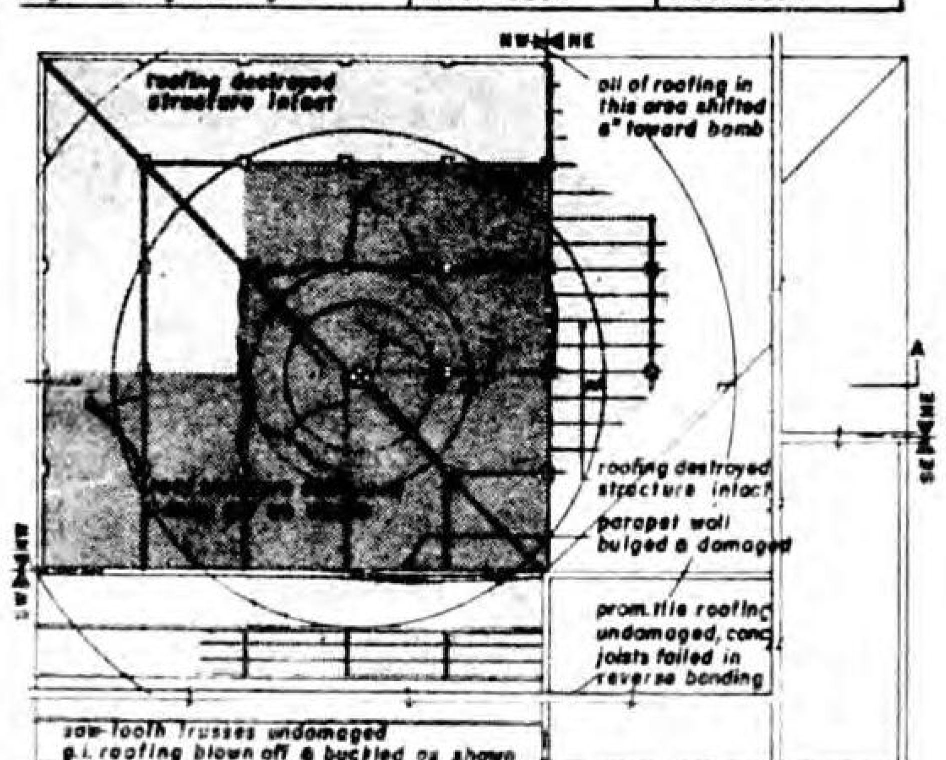


KEY PLAN COMPLETE BUILDING

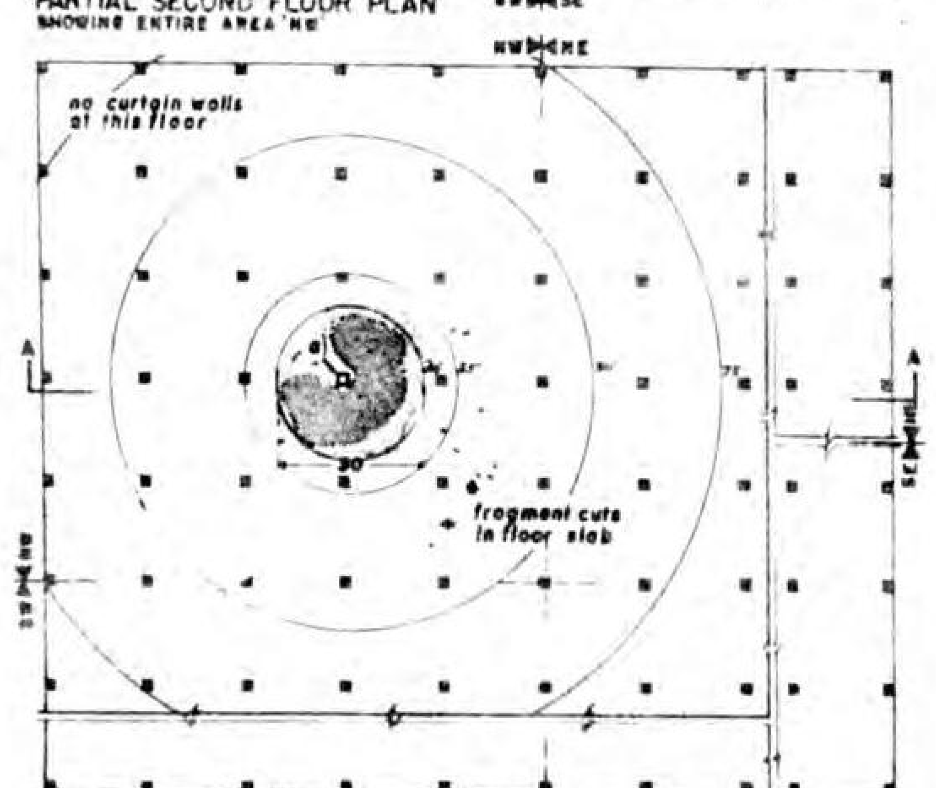
AREA	FIRST FL	SECOND FLOOR	ROOF	EXTERIOR CURTAIN WALLS-2nd FLR	
NW	8" flat slab, 2-way R/C on column capitals	7 inch slab, 2-way R/C on concrete beams	3x10 wood rafters on steel beams, 1" wood sheathing, asbestos cap, 4-ply felt rfg.	NW-w: 2x4 studs, 7/8" shtg, 7/8" clapboard, wood sash	NW-n: 12" brick, steel sash
NE		8" flat slab, 2-way R/C on column capitals	20 g. steel rib roof, steel beams & girders, 1/2" insul, 4-ply rfg.	NE-n: 8" brick, steel sash	NE-e: 8" concrete block, steel sash
SE		3" slab (exp'd metal reinf.) on R/C joists (12"x20" pans)	2" slab (exp'd metal reinf.) on R/C joists (6"x20" pans), 4-ply felt rfg. promenade tile surface	SE-e: 12" load-bearing tile, steel sash	SE-s: 12" brick, steel sash
SW		4" slab (exp'd metal reinf.) on R/C beams (5'-0" o.c.) and girders	20 g. corr. g.i. roofing on steel saw-tooth roof trusses, north-light wire-glass lights	SW-s: 20 g. corr. g.i. on steel frame, steel sash	SW-w: 20 g. corr. g.i. on steel frame, steel sash



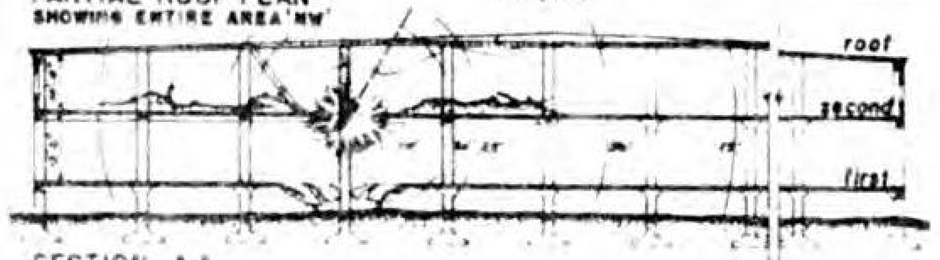
PARTIAL SECOND FLOOR PLAN
SHOWING ENTIRE AREA 'NW'



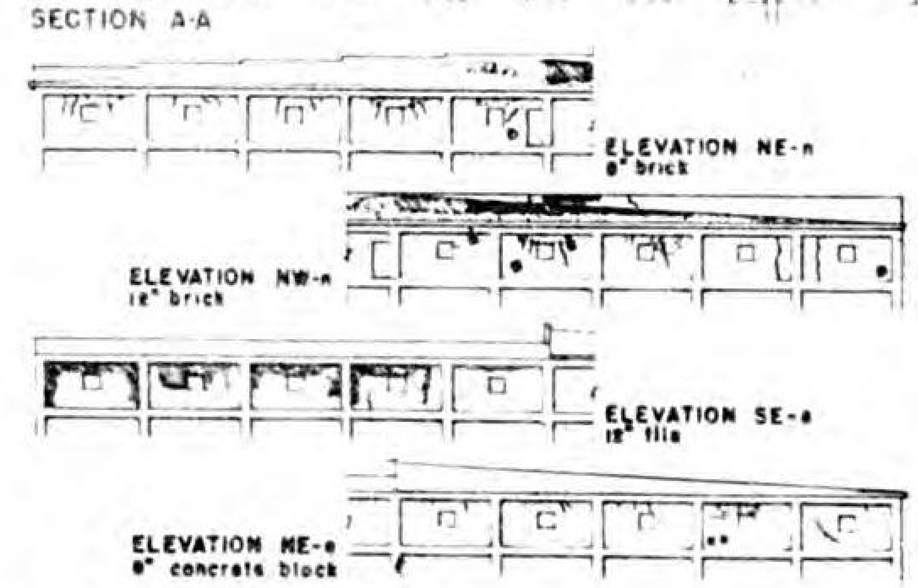
PARTIAL ROOF PLAN
SHOWING ENTIRE AREA 'NW'



PARTIAL FIRST FLOOR PLAN
SHOWING ENTIRE AREA 'NW'



SECTION A-A



ELEVATION NE-n
8" brick

ELEVATION NW-n
12" brick

ELEVATION SE-e
12" tile

ELEVATION NE-e
8" concrete block

BOMB

American 1000-lb. M44 G.P. bomb. Chg. wt. 56%. Dropped from an altitude of 4000 ft. Impact velocity - 829 ft./sec.

BUILDING

A two-story reinforced-concrete framed building prototype, 200'x200', divided into four areas, 100'x100', each employing a different type of second floor, curtain wall and roof construction as described in detail in the table at the left. The floors were designed to carry a live load of 200 lbs. per sq. ft. The columns, 26"x26" containing 12-1¼" round bars, were spaced 20 ft. on centers throughout the building. Curtain walls were built at the second floor only.

DAMAGE

The bomb perforated the roof, centrally in plan of area NW, and detonated high order at the second floor level about one foot from column (a).

Roof: Major damage occurred in area NW where approx. 6400 sq. ft. of the wood roof and steel supporting structure was completely destroyed. The remaining 3600 sq. ft. of rfg. in this area was dislodged but the structure (rafters and beams) remained intact. In area NE approx. 600 sq. ft. of the steel rib roofing was blown off and the rest shifted 6 in. toward the bomb. The steel beams and girders remained intact. Minor damage occurred also in area SW where about 1000 sq. ft. of corrugated galv. iron rfg. was completely blown off of the steel saw-tooth trusses and about 6000 sq. ft. of the roofing was buckled and torn loose. Saw-tooth trusses and purlins were not damaged. Approx. 40% of the north-light glass was broken. The only damage to the roof of area SE was slight failure in reverse bending as indicated by typical diagonal cracking of about 50% of the roof joists. Sixty feet of the parapet wall between areas NW and SW was bulged southward and about 18 sq. ft. of brick knocked out.

Second Floor: Column (a) was destroyed and a 7-ft section blown 27 feet away. A 9-foot hole was formed in the floor slab. Columns (b) received major fragmentation damage consisting of spalling of concrete (from 2 to 6 feet) and exposing reinforcing. The wood curtain wall, NW-w, was completely demolished. The 12-in. brick wall, NW-n, was cracked and bulged, all glass blown out. The 8-inch brick wall, NE-n, was cracked and bulged to a little greater degree and most of the glass blown out. The 8-in. concrete-block wall, NE-e, was bulged outward from one to three inches. Of the masonry walls, the 12-in. wall of load-bearing tile, SE-e, was damaged the most. About 10-20% of this wall was blown out and about 10% was spalled off inside. The 12-inch brick wall, SE-s, was virtually undamaged, suffering only a few small fragment hits and bending of all window sash. The corrugated galvanized iron curtain walls, SW-s and SW-w, were blown out; the steel framework and windows were not damaged.

First Floor: The top 6.5 feet of column (a) were shattered by the bomb. An area of about 800 sq. ft. of the first-floor slab was blown out.

Note: Circles represent the intercept of sphere of designated radius with the floor in question ... the center of the sphere being at the estimated position of the explosion.

NATIONAL DEFENSE RESEARCH COMMITTEE. DIVISION 2, PRINCETON UNIVERSITY STATION

Confidential

May 1943

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INCIDENT SUMMARY

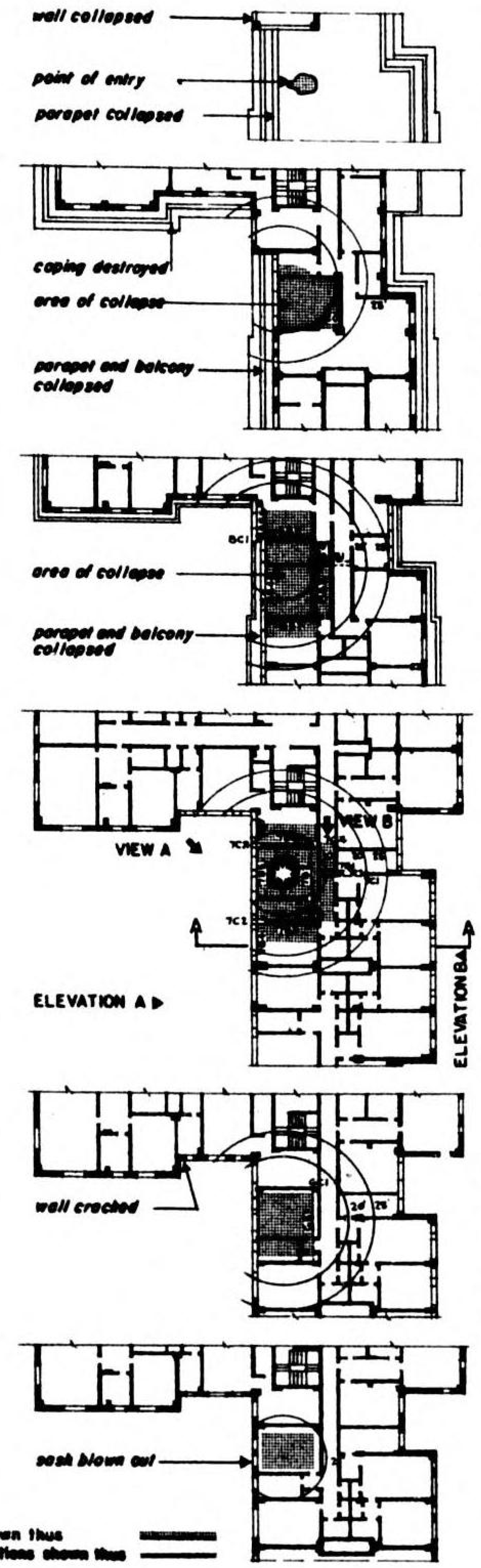
C 1100
MS-RCF
INCIDENT ONE

MULTI-STORY, REINFORCED CONCRETE FRAME APARTMENT BUILDING STRUCK BY A 1100 lb. G.P. BOMB

PF-5902/5

(GERMAN 500 Kg S.C. chg. wt 50 %)

ROOF PLAN
scale



BUILDING

Type: Apartment building consisting of basement, nine upper floors and pent-house on roof. Construction: Reinforced concrete frame. Floor slabs 5" concrete. Exterior walls 11" brick cavity. Partitions 3½" plaster secured to columns with ¼" wire 24" o.c. 2-2½" walls with 1½" cavity between apartments. Stairway walls 4½" brick. To facilitate erection the reinforcing steel was prefabricated into "cages" and droppèd into position between columns with additional straight bars being added for continuity at top and bottom prior to placing of concrete.

DAMAGE

The bomb perforated the roof and two floors detonating between the 7th and 8th floors.

Roof: Beams and columns intact. Bomb punched a 4'x3' hole. Slab bowed upward from blast. Parapet and wall of pent-house collapsed.

9th floor: Beams and columns intact. Approx. areas of damage in sq. ft. to: floor - 194; partitions - 900.

8th floor: Columns intact. 8B1 and 8B2 end connections broken, center broken up and bowed upward. 8B3 and 8B5 disintegrated. Connection of 8B4 to 8C1 severed, beam sagged down and twisted. Connection of 8B6 to 8C1 broken. Approx. areas of damage in sq. ft. to: floor - 830; exterior wall - 620; partitions - 1080.

7th floor: Beams and columns most severely damaged. 7B1, 7B2, 7B5 and 7B6 disintegrated. 7B3 and 7B4 bent downward. 7B7 cage blown up. Columns 7C1 and 7C2 bowed out. 7C3 broken and hanging from column above. Only bowed rods of 7C4 remain. Approx. areas of damage in sq. ft. to: floor - 830; exterior wall - 1240; partitions - 3060.

6th floor: 6B1 collapsed. Column 6C1 damaged. Approx. areas of damage in sq. ft. to: floor - 620; exterior walls - 590; partitions - 1170.

5th floor: No structural damage. Approx. areas of damage in sq. ft. to: floors - 120; partitions - 360; exterior walls - 0.

Excessive damage to beams and columns may be attributed in part to the use of prefabricated reinforcement "cages" and separate continuity rods. In some cases where beams disintegrated the "cages" were blown out while continuity rods remained in place.

Excessive column damage probably due to bonding partitions to columns, thereby transmitting forces on partitions to columns.

Some fragmentation damage to brick walls and window frames occurred across the courtyard. Damage extended from the third to eighth floors being most severe at the fifth and sixth floors.

Note: Circles represent the intercept of sphere of designated radius with the floor in question..... the center of the sphere being at the estimated position of the explosion.

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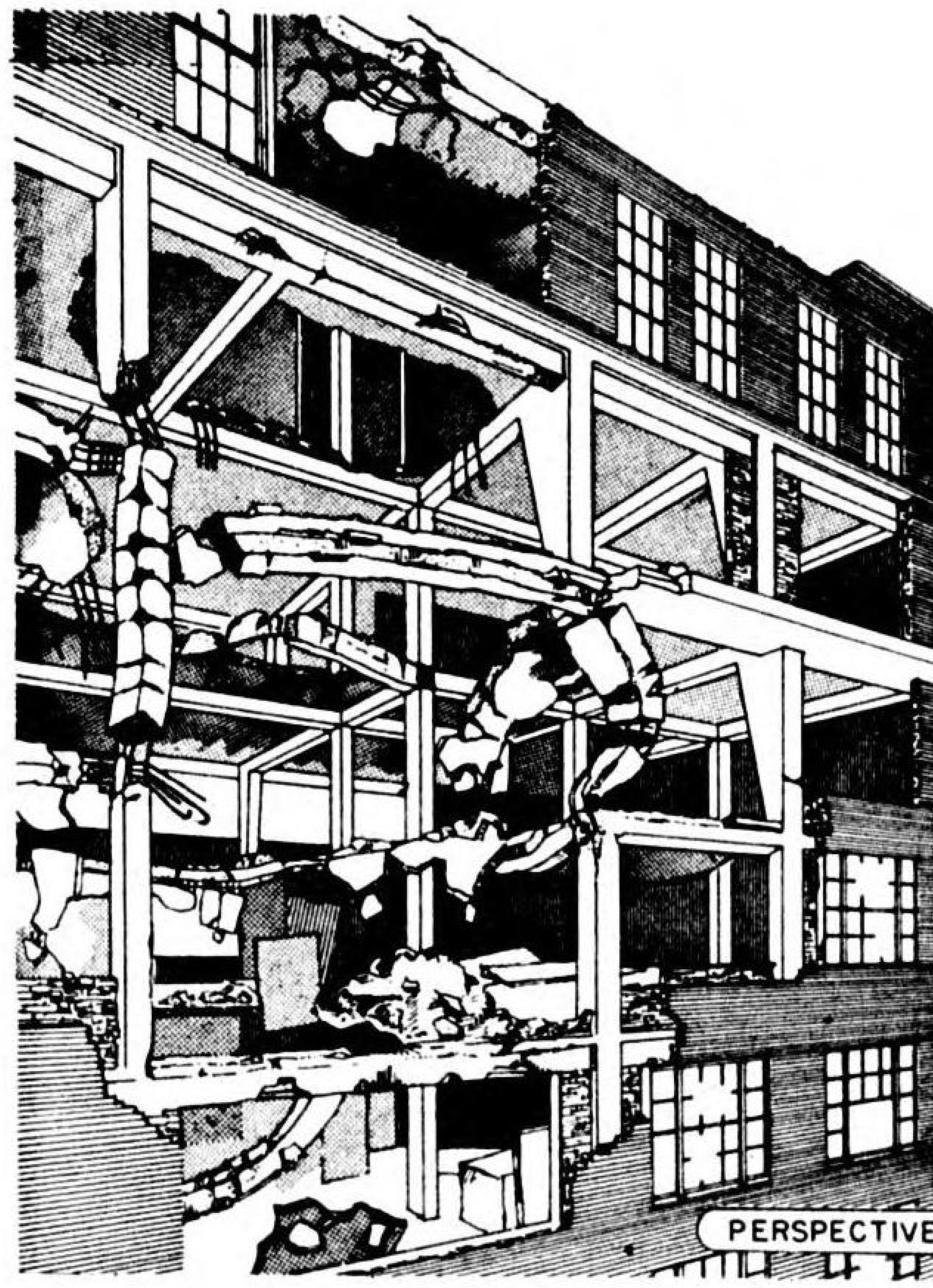
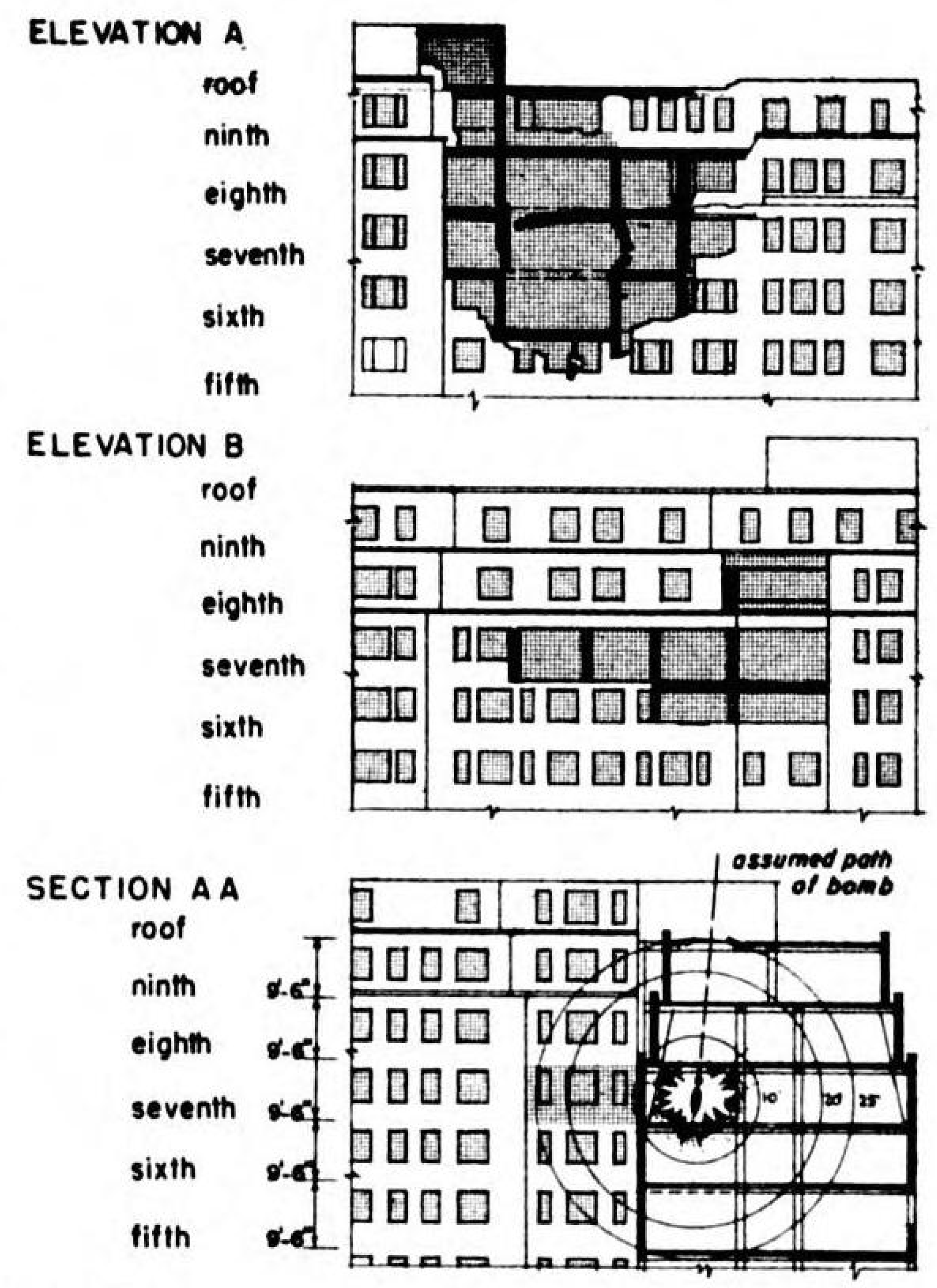
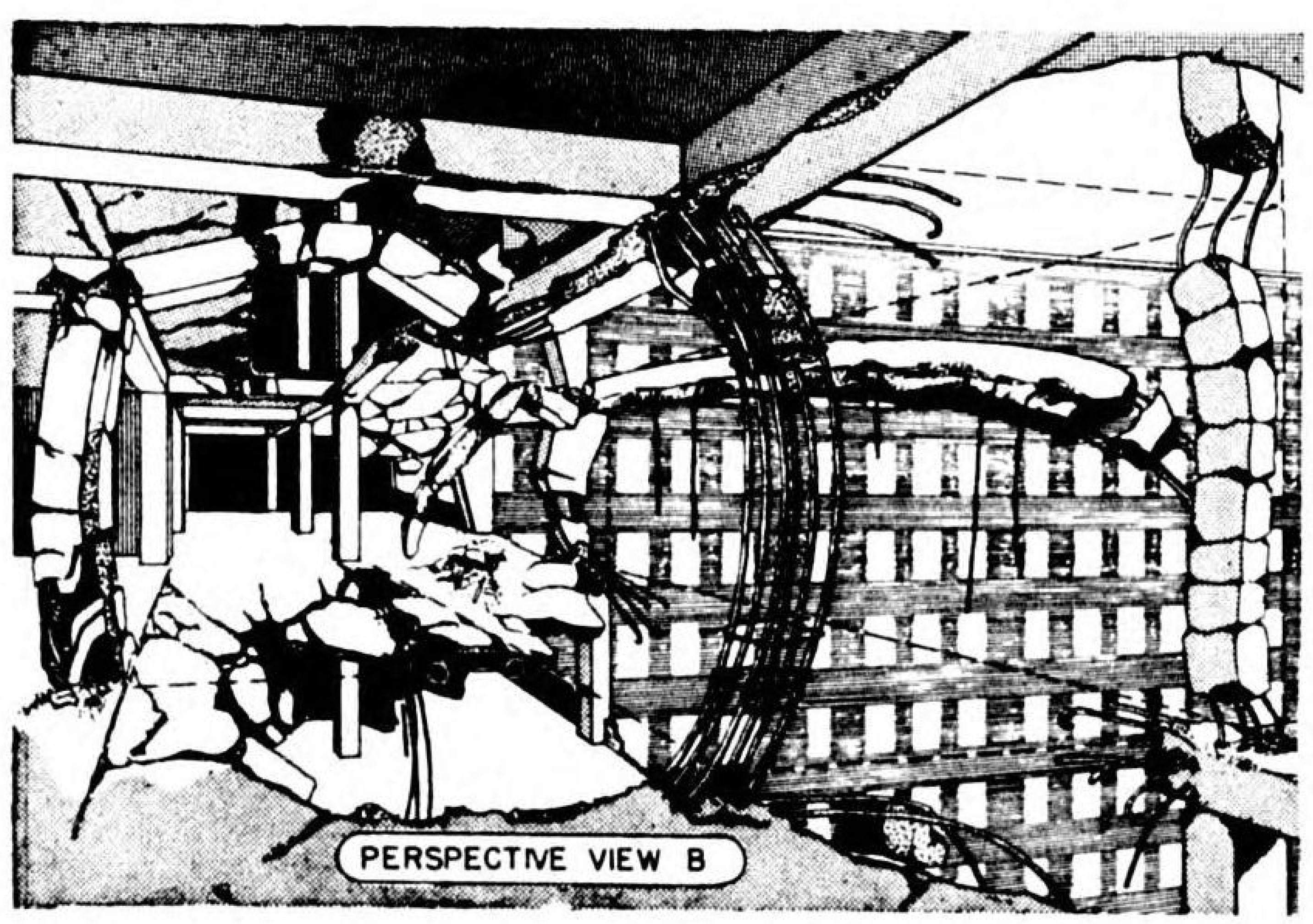
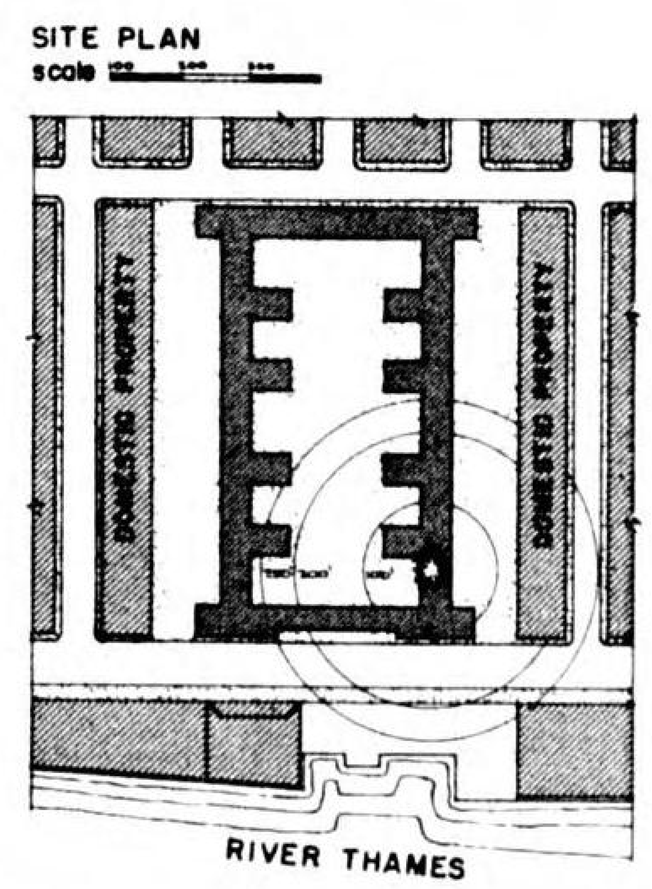


PERSPECTIVE VIEW A





PERSPECTIVE VIEW B



NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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April 1944

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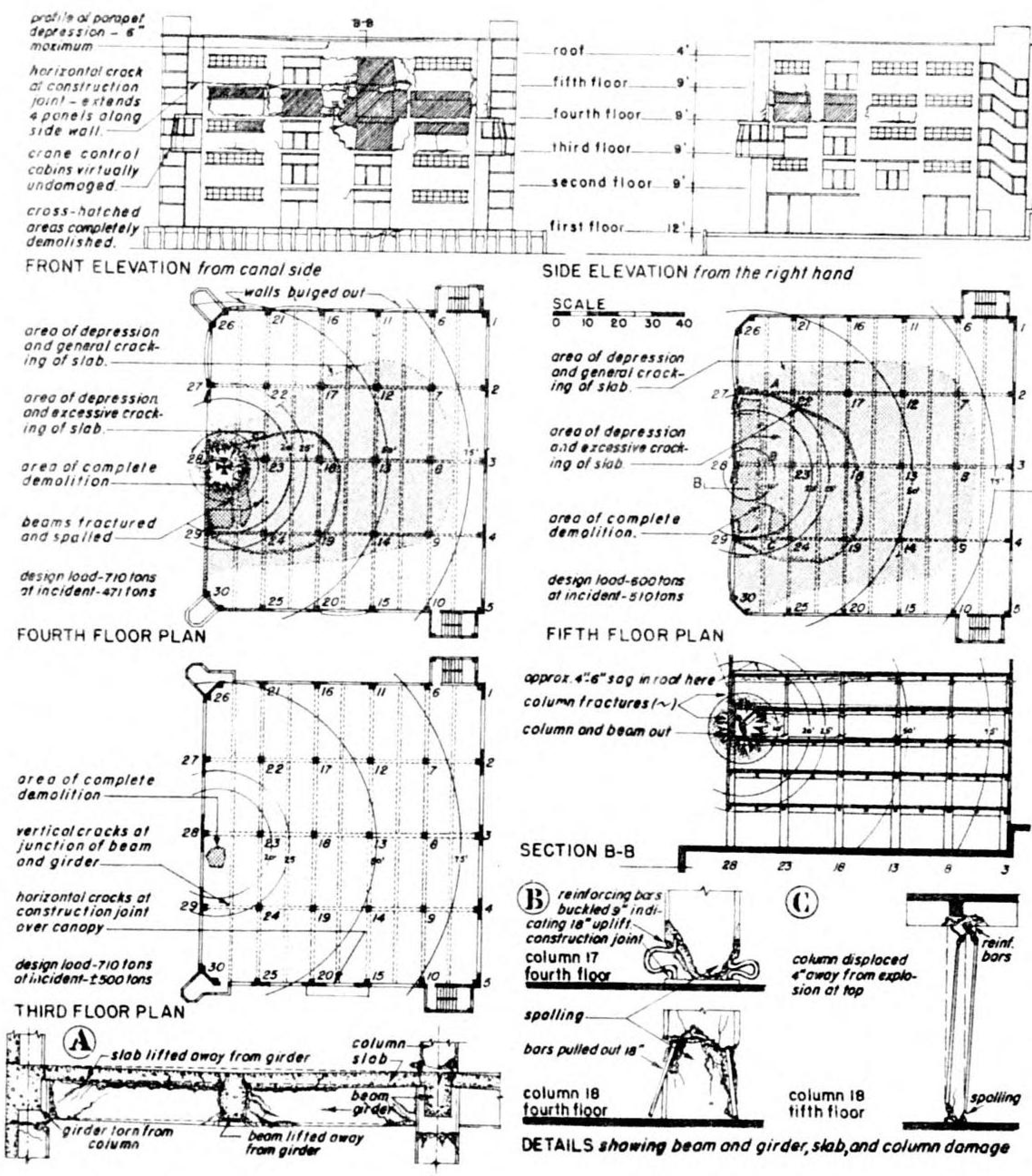
INCIDENT SUMMARY

MULTI-STORY, REINFORCED CONCRETE FRAME WAREHOUSE STRUCK BY A 2200 lb. G.P. BOMB

PF 5902/27

(GERMAN 1000-kg. S.C. Chg. Wt. 54%)

C-2200
MS-RCF
INCIDENT ONE



BUILDING

Type 5-story warehouse. Overall dimensions 75'x80'.
Construction: Reinforced concrete frame, beam and girder system, 15'x20' bays. 6" solid concrete floor slabs reinforced with metal fabric. Columns diminish from 30" sq. at 1st floor to 9" sq. at 5th floor. Beam stems-12"x15", girder stems-12"x16". Exterior walls- 5" R/C, monolithic with columns. No interior partitions. Window sash of precast R/C.

DAMAGE

Bomb entered 5th floor loading door, perforated 6" R/C 5th floor slab and exploded just above the 4th floor about 3' from front wall among bags of beans stacked almost to ceiling. Goods prevented splinter damage.

Fifth floor slab was lifted about 18" over explosion. Roof slab lifted an additional 6". Fourth floor slab was depressed and walls at this level were heavily damaged by outward blast. The uplift, producing wrong-way loading, caused failure of many beams, girders and columns. Additional damage to these members resulted when raised slabs returned to original position. With the structural frame so damaged loads were redistributed and no extensive collapse occurred.

Slab Damage Floor	Down	Shattered	Excessively Cracked	Cracked	Depressed and Slightly Cracked
Roof				1200□' ±	3000□' ±
5th	240□' ±		1000□' ±		3000□' ±
4th	170□' ±	70□' ±	650□' ±		2350□' ±
3rd	75□' ±				

5th floor slab at beam 22-23 was lifted and cracked considerably.

Beam and Girder Damage

Roof & Fifth Floor: Girder 23-28, its support removed when col. 28 was demolished, broke off at B and hung by its reinforcing bars. Front roof spandrel, aided by the parapet, carried load of col. 28 with a sag of 6". Beams A-B-C and stub of girder 23-B cantilevered load of girder 23-28. Support at C was weakened due to damage to cols. 24 and 23, and girder 24-29. Beam 28-29 was completely destroyed. In general, slabs lifted from beams and beams from girders. Roof girders were broken at B & C.
Fourth Floor: Beam 28-29 was completely destroyed. Typical R/C failures (bending in beams, diagonal tension cracks in girders at midspan and/or at supports) resulted from excessive impact damage to beams and girders. See detail A below.

Column Damage

Fifth Floor: Col. 28 was forced out at bottom with wall and left hanging from roof beams. Cols. 18, 19 and 24 failed in tension due to uplift; 18 at top and bottom, 19 at top and midheight, 24 at top and along its length. All three deflected away from explosion at the top as roof slab was torn away. Col. 18 was badly battered as roof fell back. (See detail C). Col. 7 failed at a construction joint in which sawdust was found. Twenty-one of thirty columns cracked in tension, many spalled.
Fourth Floor: Col. 28 was demolished, 29 was bowed out at top, 30 was broken at midheight. Cols. 8, 13, 17, 18, 23 and 24 lifted with 5th floor slab, failed at bottom, and were fractured when slab came down. Foot of col. 24 was displaced 11" toward explosion. Fourteen of thirty columns failed in tension. For exemplary column failure see detail B below.

Wall Damage Floor	Blown Out	Damaged, Must be Replaced
5th		100□' ±
4th	440□' ±	800□' ±
3rd		320□' ±

Horizontal crack in 5th floor wall at top of openings for the full length of left side of building. Fourth floor walls at front and two sides bulged dangerously at construction joints ... dowel bars missing.

Window and Door Damage
Doors: 5 loading doors blown out, 5 others damaged.
Window Sash: Precast R/C - all blown out on 4th floor, some out on 3rd and 5th floors.
Glass: All broken in front elevation, approximately 50% in each side.

SUMMARY
2% of goods was destroyed. About 1/3 of building was rebuilt, remainder was continuously in service.

Note: Circles represent the intercept of sphere of designated radius with the floor in question ... the center of the sphere being at the estimated position of the explosion.

1083

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INCIDENT SUMMARY

C-2200
CMS-RCF
INCIDENT ONE

MULTI-STORY, REINFORCED CONCRETE FRAME WAREHOUSE STRUCK BY A 2200 lb. G.P. BOMB

PF 5902/27 (GERMAN 1000-kg. S.C. Chg. Wt. 54%)

BUILDING
Type: 5-story warehouse. Overall dimensions 75'x80'.
Construction: Reinforced concrete frame, beam and girder system, 15'x20' bays. 4" solid concrete floor slabs reinforced with metal fabric. Columns diminish from 30" sq. at 1st floor to 9" sq. at 5th floor. Beam stems - 12"x15", girder stems - 12"x16". Exterior walls - 5" R/C, monolithic with columns. No interior partitions. Window sash of precast R/C.

DAMAGE
Bomb entered 5th floor loading door, perforated 6" R/C 5th floor slab and exploded just above the 4th floor about 5' from front wall among bags of beans stacked almost to ceiling. Goods prevented splinter damage.

Fifth floor slab was lifted about 18" over explosion. Roof slab lifted an additional 6". Fourth floor slab was depressed and walls at this level were heavily damaged by outward blast. The uplift, producing wrong-way loading, caused failure of many beams, girders and columns. Additional damage to these members resulted when raised slabs returned to original position. With the structural frame so damaged loads were redistributed and no extensive collapse occurred.

Slab Damage

Floor	Down	Shattered	Excessively Cracked	Cracked	Depressed and Slightly Cracked
Roof				1200"±	3000"±
5th	240"±		1000"±		3000"±
4th	170"±	70"±	460"±		2350"±
3rd	75"±				

5th floor slab at beam 22-23 was lifted and cracked considerably.

Beam and Girder Damage
Roof & Fifth Floor: Girder 23-28, its support removed when col 28 was demolished, broke off at B and hung by its reinforcing bars. Front roof spandrel, aided by the parapet, carried load of col 28 with a sag of 4". Beams A-B-C and stub of girder 23-B cantilevered load of girder 23-28. Support at C was weakened due to damage to cols. 24 and 29, and girder 24-29. Beam 28-29 was completely destroyed. In general, slabs lifted from beams and beams from girders. Roof girders were broken at B & C.
Fourth Floor: Beam 28-29 was completely destroyed. Typical R/C failures (bending in beams, diagonal tension cracks in girders at midspan and/or at supports) resulted from excessive impact damage to beams and girders. See detail A below.

Column Damage
Fifth Floor: Col 28 was forced out at bottom with wall and left hanging from roof beams. Cols. 18, 19 and 24 failed in tension due to uplift; 18 at top and bottom, 19 at top and midheight, 24 at top and along its length. All three deflected away from explosion at the top as roof slab was torn away. Col. 18 was badly battered as roof fell back. (See detail C.) Col 7 failed at a construction joint in which sawdust was found. Twenty-one of thirty columns cracked in tension, many spalled.
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Wall Damage

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5th		100"±
4th	440"±	800"±
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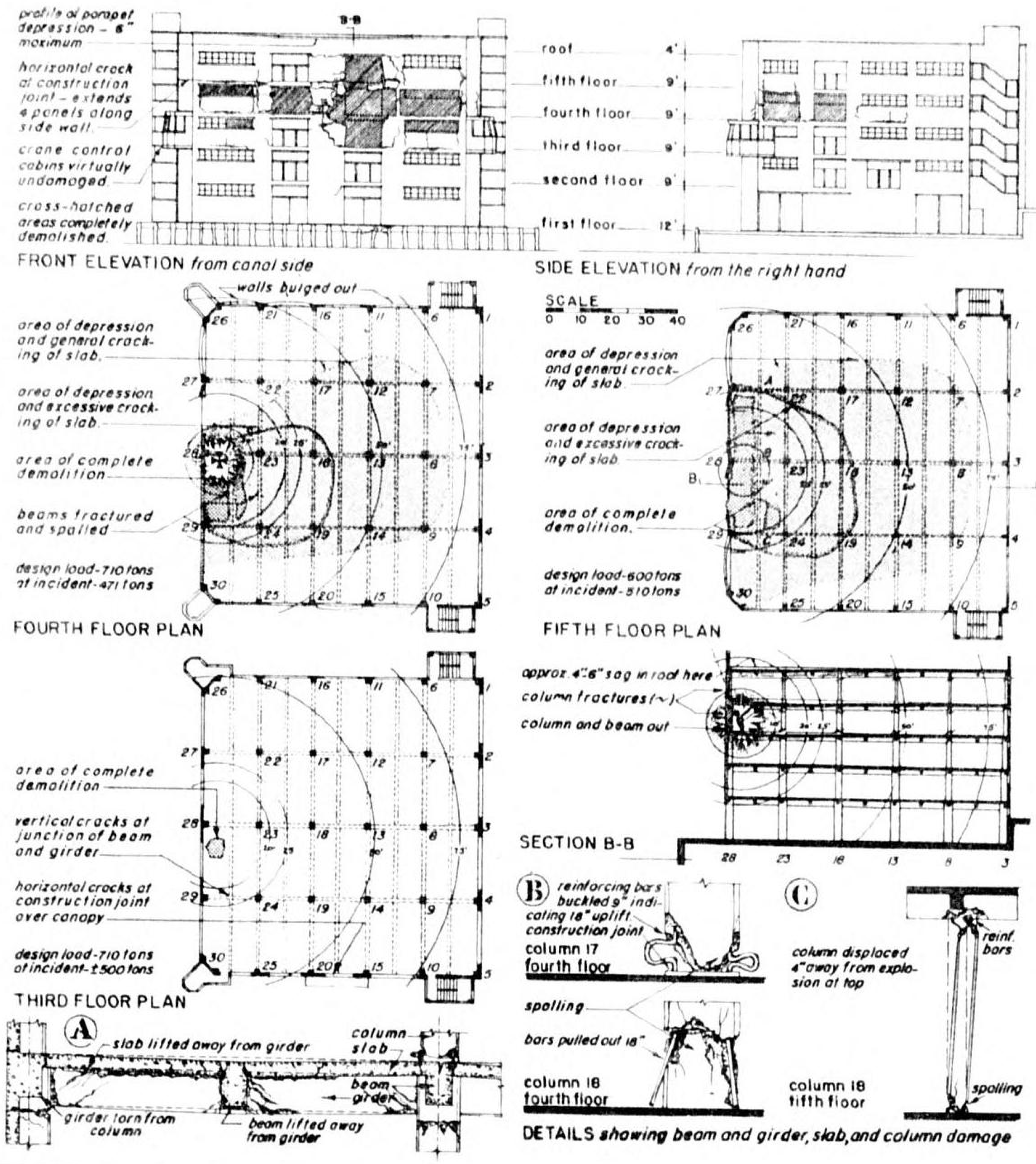
Horizontal crack in 5th floor wall at top of openings for the full length of left side of building. Fourth floor walls at front and two sides bulged dangerously at construction joints: dowel bars missing.

Window and Door Damage
Doors: 5 loading doors blown out, 5 others damaged.
Window Sash: Precast R/C - all blown out on 4th floor, some out on 3rd and 5th floors.
Glass: All broken in front elevation, approximately 50% in each side.

SUMMARY
2% of goods was destroyed. About 1/3 of building was rebuilt, remainder was continuously in service.

Note: Circles represent the intercept of sphere of designated radius with the floor in question. The center of the sphere being at the estimated position of the explosion.



NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Confidential

August 1943

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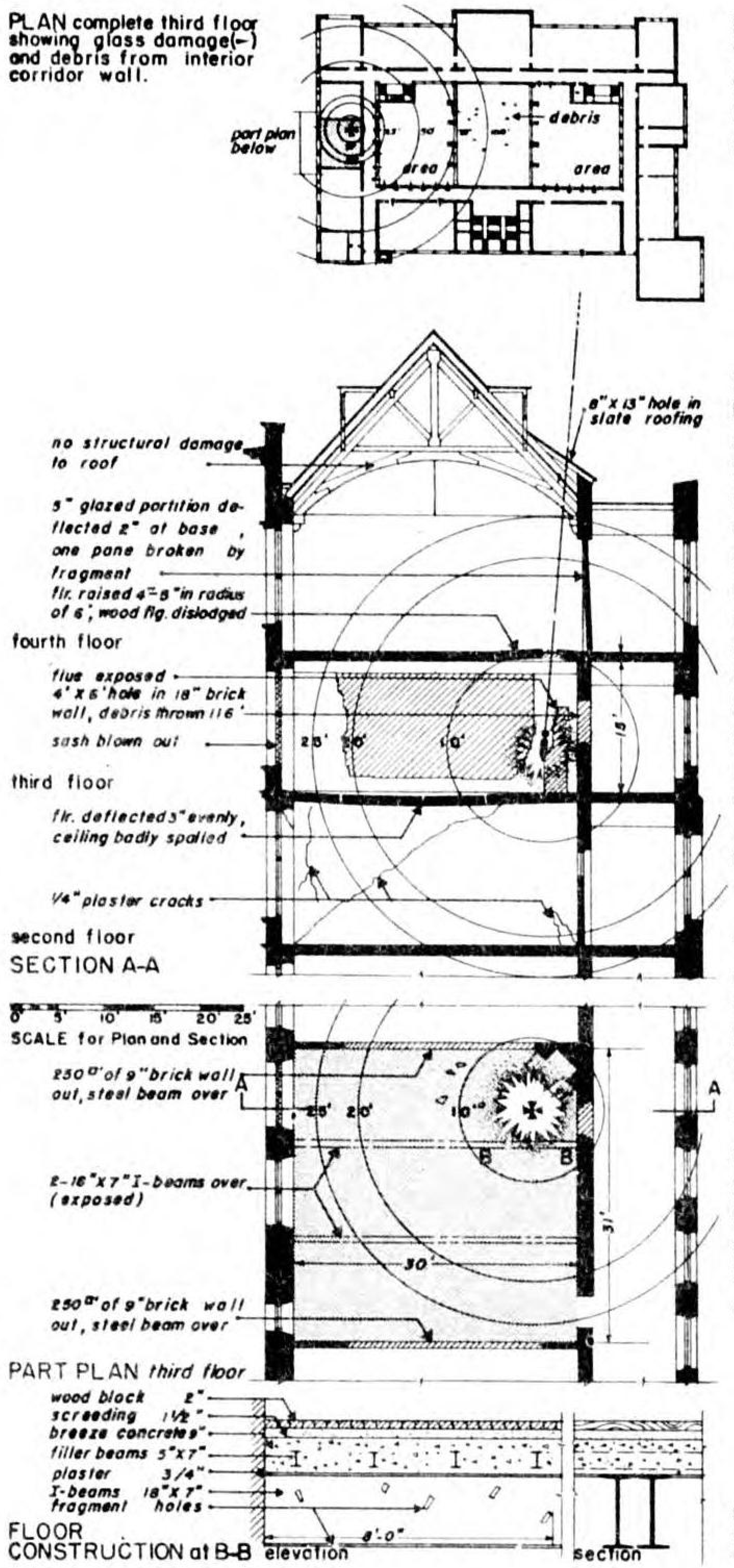
INCIDENT SUMMARY

D-110 MS-WB INCIDENT ONE

MULTI-STORY, WALL BEARING SCHOOL BUILDING STRUCK BY A 110 lb. G.P. BOMB

PF-5902/28

(GERMAN 50 Kg. S.C.? Chg. Wt. 50%)



BUILDING

Type; Six-story (basement and four upper floors; five in front). Technical College (ca. 1900)

Construction: Walls - massive, well built brick bearing walls.

Floors - 9-inch thick breeze concrete slabs on 5-inch steel filler joists, 2-inch wood block flooring. In this instance the fourth floor was reinforced with steel I-beams.

Roof - slate roofing on timber trusses.

Partitions - 9-inch brick panel walls.

DAMAGE

Bomb perforated roof and the 13½-inch fourth floor slab detonating above the third floor as shown in Section A-A. Structural damage was limited to the room (14,000 cu. ft.) in which explosion occurred and was confined to an area within 40 feet of the explosion. The bomb exploded about 5 feet from the 18-inch interior corridor wall. A hole 6'X4' was punched in this wall (probably by mass fragmentation) and the debris was thrown horizontally a distance of 116 feet into the Examination Hall in the center of the building. An area of 250□' was blown out of each end partition wall. The front exterior bearing wall was moved out about ½ inch. One window sash and the corridor door were blown out. The ceiling (4th. floor slab) within 6 feet of bomb hole was lifted and the third floor was deflected 3 inches uniformly by the blast wave.

The I-beam above the explosion was perforated in web and in flange by fragments. Maximum web perforation was 4"X1"; flange perforations were 1" and 1½ inch in diameter. (See detail of floor construction at B-B)

The brick fireplace was demolished; flue exposed for 10 feet. A small fire was started in the upholstery but was readily extinguished. The skylight in the Area suffered heavily from debris. The pattern of glass damage shows how effectively blast is baffled by the right-angled bends in corridors.

Note Circles represent the intercept of sphere of designated radius with the floor in question the center of the sphere being at the estimated position of the explosion.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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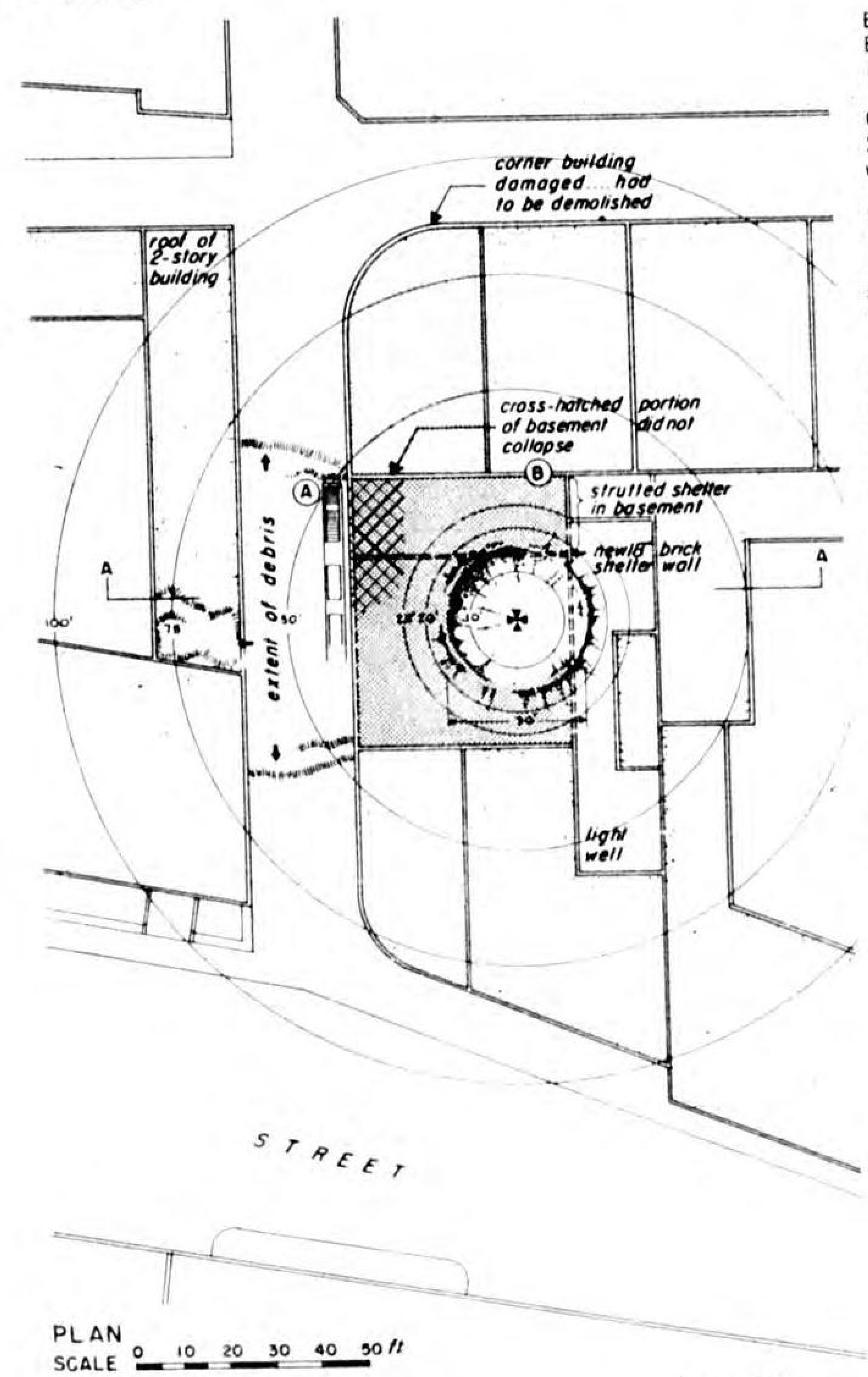
INCIDENT SUMMARY

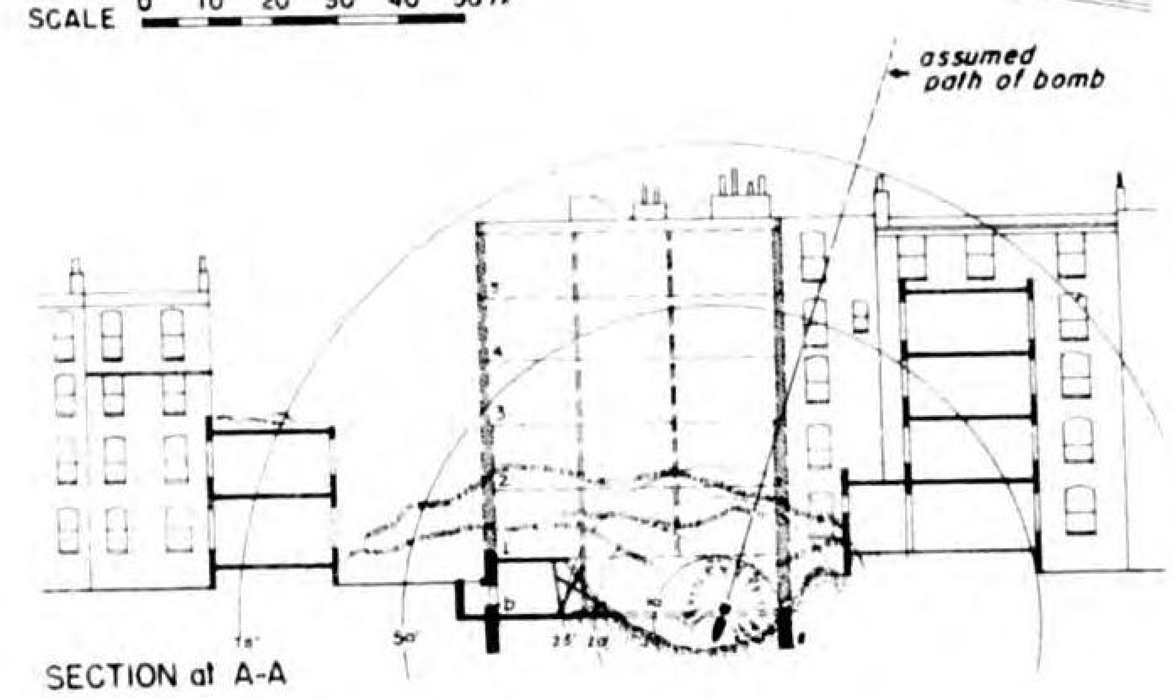
D 1100 MS-WB INCIDENT ONE

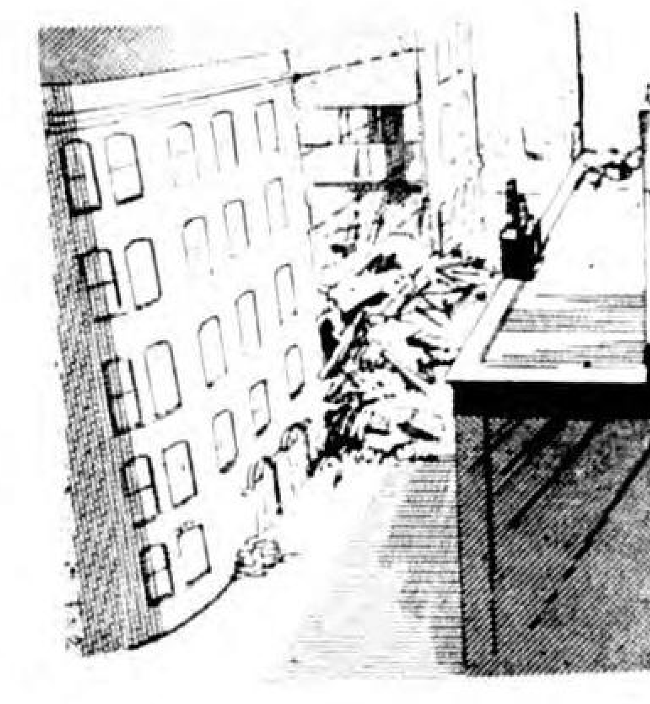
MULTI-STORY, WALL BEARING OFFICE BUILDING STRUCK BY A 1100 lb. G.P. BOMB

PF 5902/29

(GERMAN 500 kg. S.C., chg. wt. 50 %)







BUILDING

Basement and five upper floors. Over-all size approximately 50 ft. by 60 ft.

Construction: Walls - exterior brick load-bearing, 22½ inches thick for basement, first and second floor walls; 18-inch thick walls from third floor to roof. Internal steel frame.

Floors and Roof - breeze concrete and filler joists.

Shelter - basement room reinforced with 7"x6" timber struts and beams (set parallel with filler joists), some structural steel and a new 18-inch thick brick wall.

DAMAGE

The bomb apparently fell down the light well between the buildings and perforated the rear exterior wall and basement floor before detonating. A crater, 30 ft. in diameter and 8 ft. deep, was formed in the sandy-clay soil by the explosion. The entire building collapsed filling the basement and pavement at the front of the building with debris. A small part of the shelter (shown cross-hatched on the plan) did not collapse, however, thereby saving the lives of three women. They were rescued, though injured, by means of the emergency exit in the pavement light which was forced through at (A). Others in the shelter were killed when thrown by the blast against the basement wall at (B). The new 18-inch brick shelter wall was demolished. Incendiaries later started fires in the debris.

The corner building, adjacent to the one struck and of similar construction, suffered so severely from the effects of the blast and the shock that it had to be demolished later. However, other adjacent buildings did not even suffer glass damage. There was no fragmentation damage.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Confidential December 1943

copy no: 1083

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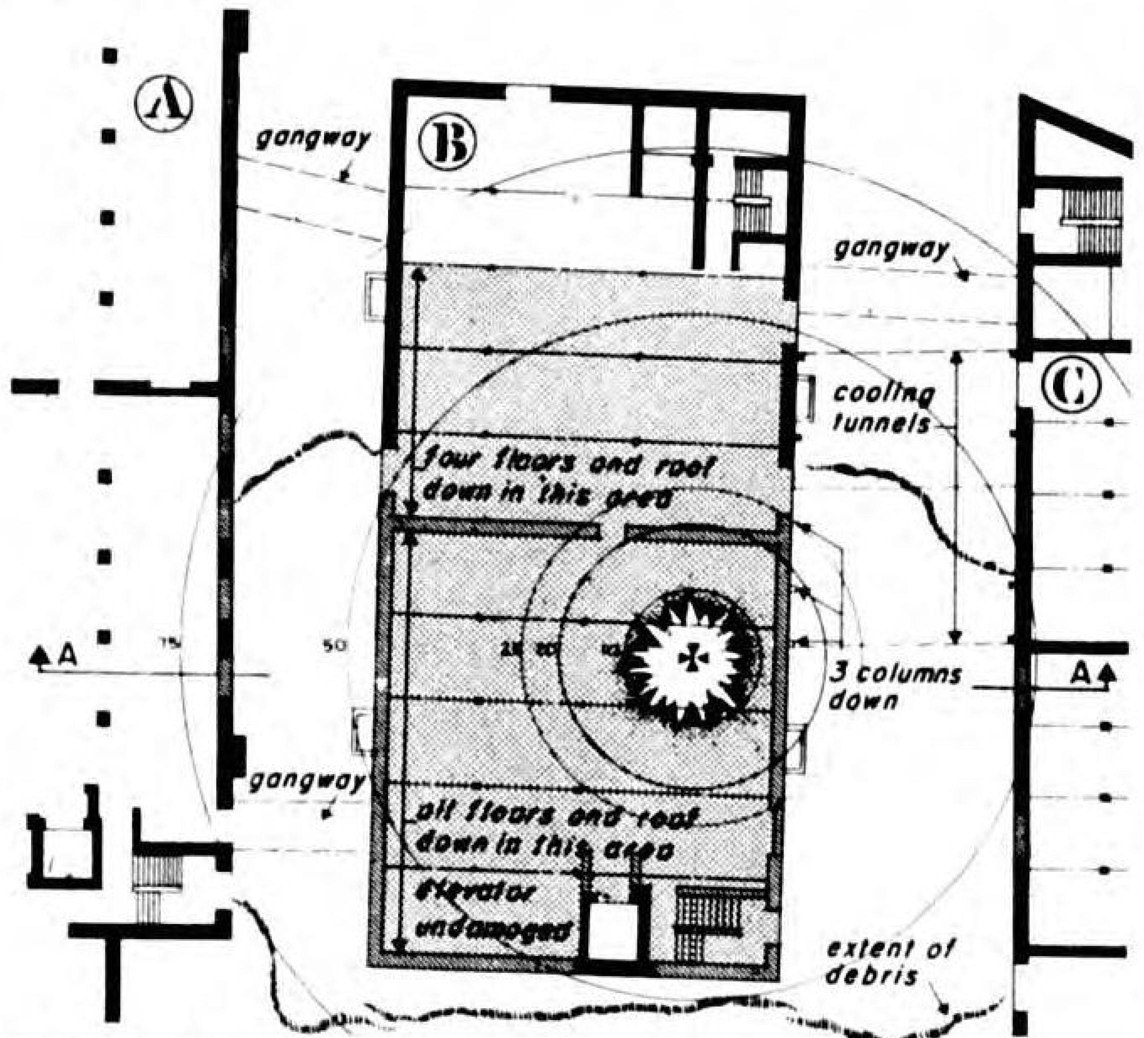
INCIDENT SUMMARY

D 2200 MS-WB INCIDENT ONE

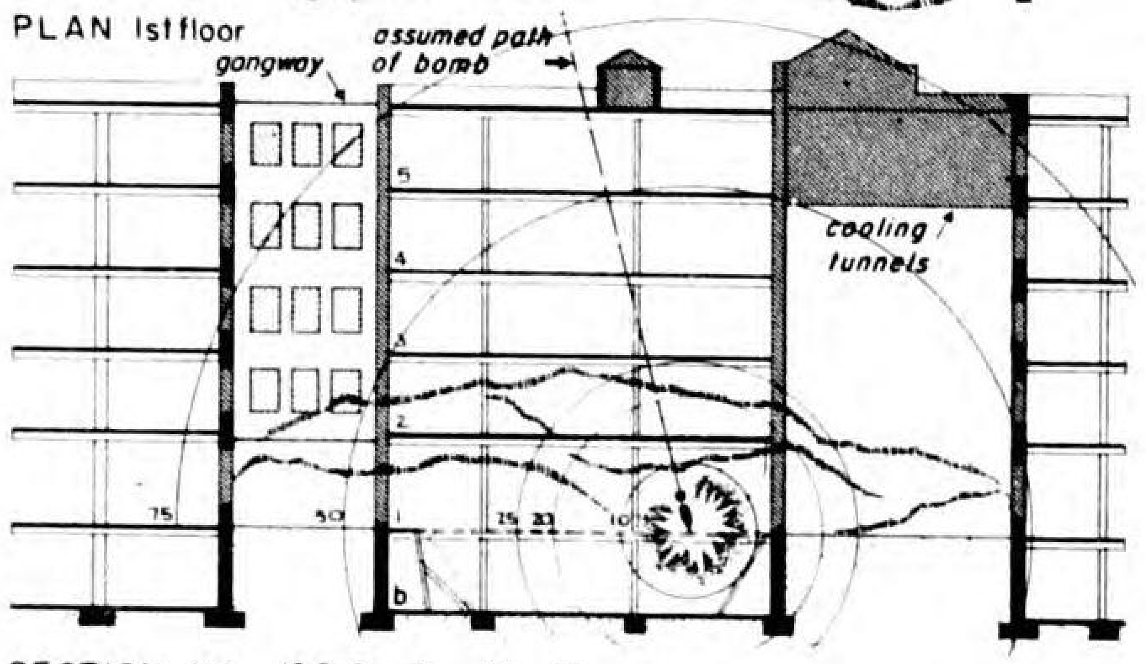
MULTI-STORY, WALL BEARING WAREHOUSE STRUCK BY A 2200 lb. A.P. BOMB

PF 5902 / 30

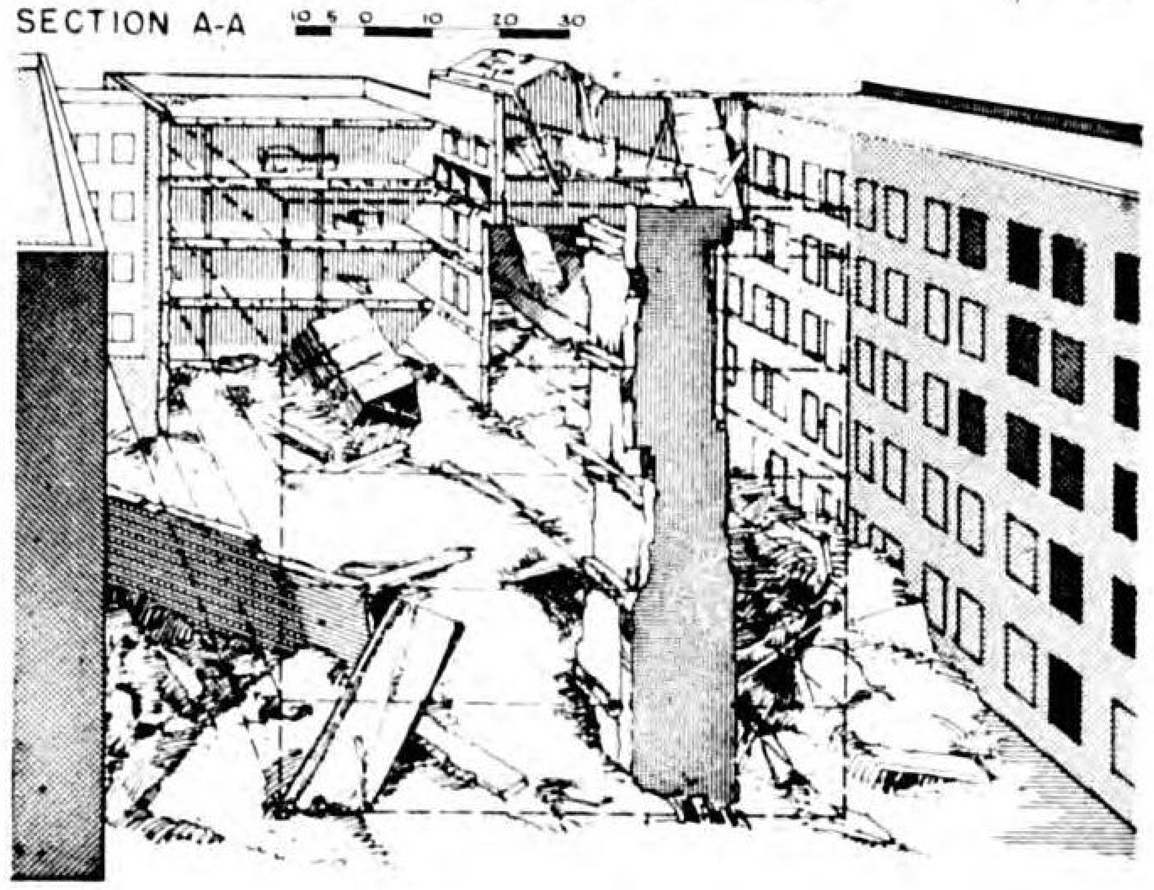
(German 1000 Kg S.D. chg. wt. 14 %)



PLAN 1st floor



SECTION A-A



BUILDING

Type: Warehouse B - one of a group of three warehouses - basement and five upper floors and flat roof. Over-all dimensions 60'x130'.

Construction of Warehouse B: brick bearing walls approximately 2' thick. Floors and roof 7" of concrete between 7" steel joists spaced at 2'x6" centers covered with 2" concrete slab. Floors and roof were supported by steel beams and intermediate cast iron columns. Basement beams and columns encased in concrete.

Warehouse Ⓒ of similar construction and warehouse Ⓐ is steel framed enclosed with brick walls.

DAMAGE

The bomb perforated the roof and 4 floors of warehouse Ⓑ and exploded on or near the first floor. The major portion of the warehouse collapsed to the first floor. The first floor collapsed into the basement in the area near to the bomb.

A four story gangway connecting warehouses Ⓐ and Ⓑ, and part of the cooling tunnels at the fifth floor between warehouses Ⓑ and Ⓒ collapsed to the ground. The cooling tunnels were used for cooling jam as it passed from warehouse Ⓒ to Ⓑ.

The elevator shaft was steel framed and remained standing altho considerably damaged.

All windows in warehouses Ⓐ and Ⓒ adjacent to Ⓑ were blown out.

Shelters were provided in the basements of all three buildings and were occupied by 1500 people when the bomb struck. 5 people were killed by the collapse of the first floor of warehouse Ⓑ.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

Confidential

January 1944

copy no: 1083

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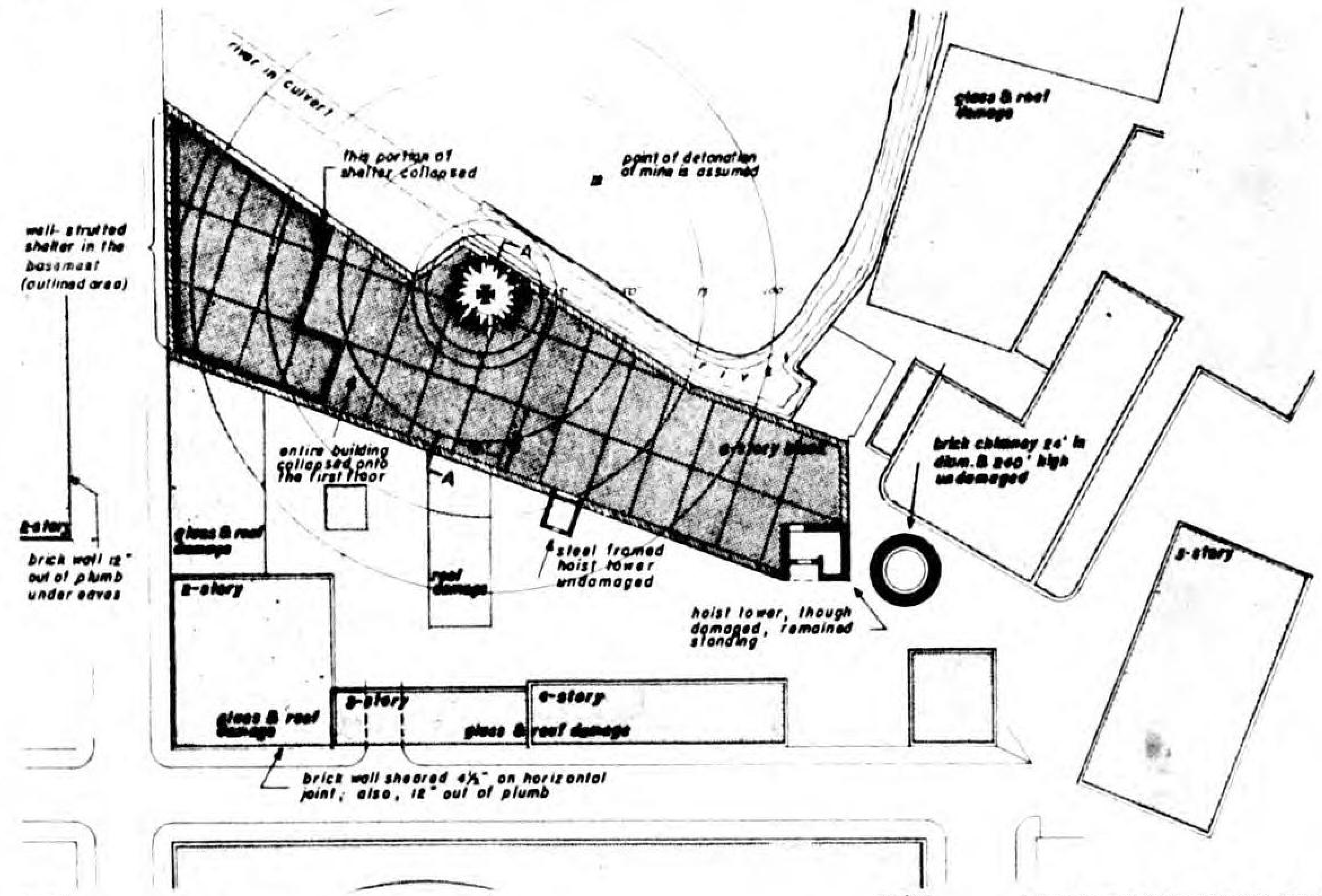
INCIDENT SUMMARY

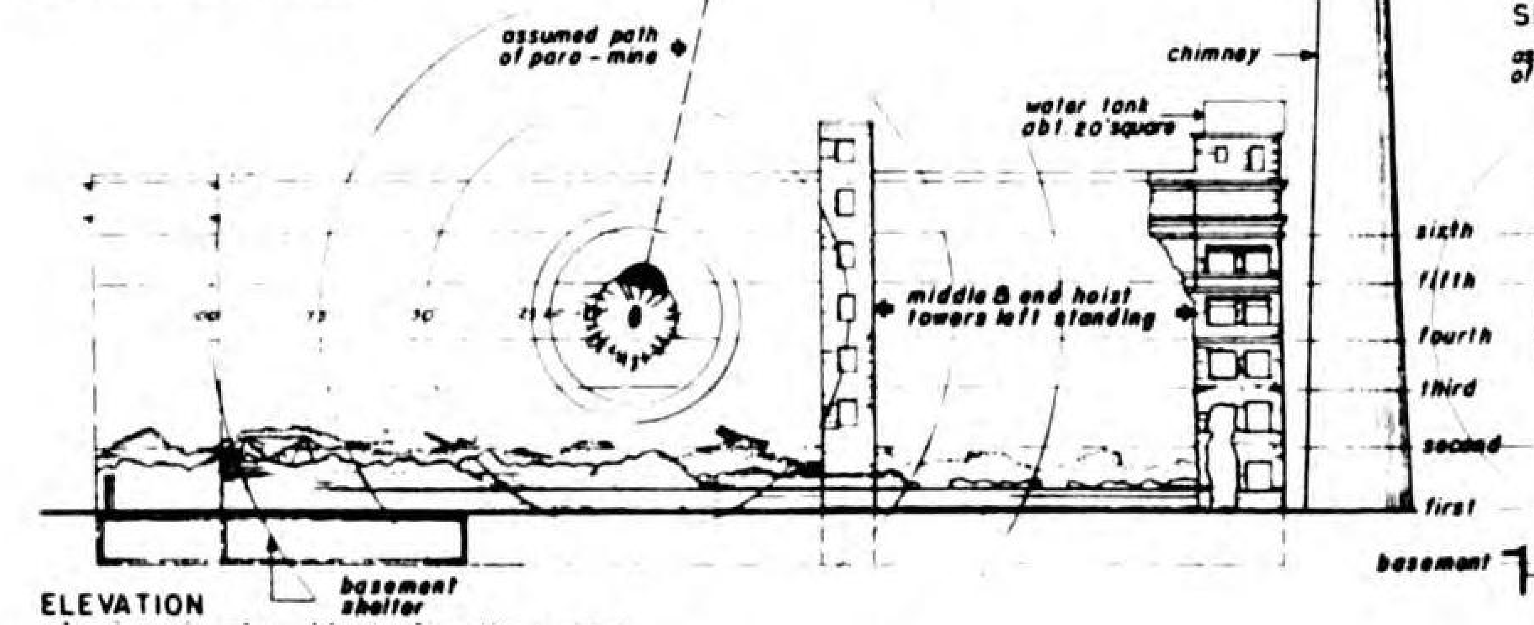
D-PARA-MINE MS-WB INCIDENT ONE

MULTI-STORY, WALL BEARING FACTORY BUILDING STRUCK BY A PARACHUTE MINE

PF - 5902 / 31



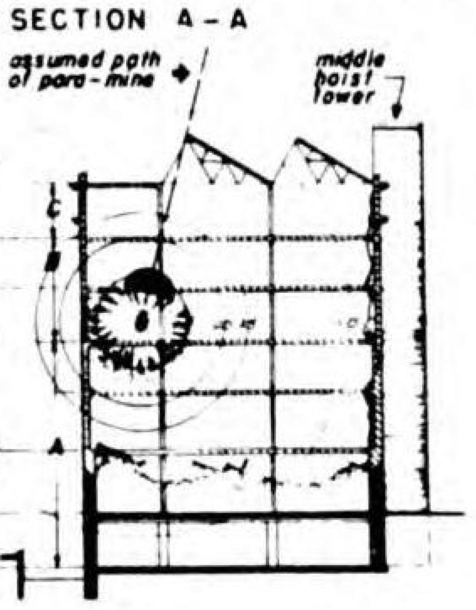
PLAN
scale
all drawings of this scale



ELEVATION
showing six-story block after the incident

A orig bldg with flat roof, built in 1896
B- first extension with flat roof.
C- second extension with N-light roof

SECTION A - A



BUILDING

Type: Six-story factory building with basement. Overall dimensions approx. 75' x 240', of irregular shape. Bays were 16' x 25'.

Construction: The building was built in three stages of brick wall bearing type construction. The original building, consisting of basement and three upper floors, was built in 1896. The second stage consisted of the addition of the fourth and fifth floors and a flat roof; the third stage consisted of the addition of the sixth floor with steel saw-tooth trusses admitting north light. Exterior brick bearing walls, 3 feet thick at the base, and interior cast iron columns supported 6-inch concrete floors with filler joists on steel beams. The 4th and 6th floor slabs, originally roof slabs, were 8-inch concrete. The middle hoist tower was built in 1931 of steel frame and brick curtain walls. A well strutted ARP shelter was built in the basemen

DAMAGE

The parachute mine was seen by roof spotters to hit the building about where shown on the drawings. Examination of the debris revealed that the fifth-floor slab was considerably scattered about, suggesting that the mine had perforated the fifth and sixth floors and probably had detonated below the fifth floor. The entire building, with the exception of the two hoist towers collapsed. The debris was piled evenly over the first floor, each floor on top of the one originally below it with the roof trusses on the top. Due to the absence of earth shock and the absorption of the blast wave by the complete collapse of building, the 240-foot chimney was undamaged. Immediately after the collapse, fire broke out and burned for three days.

Within a radius of 400 feet from the mine, roofs and windows of all other buildings were damaged. Some of this damage, however, was caused by another parachute mine which struck a building 100 yards away. It was reported, but not confirmed, that a high explosive bomb struck the end of the six-story building before the mine.

Transformers and cables, housed in the end of the building over the shelter, were destroyed, putting the entire plant out of operation until auxiliary power could be supplied.

The ARP shelter, being of excellent construction with strong exterior and compartment walls as well as sturdy overhead protection, withstood the debris load and saved the lives of 16 people. A small section, howver did collapse (shown cross hatched on plan). The remainder of the first floor collapsed after the fire.

NATIONAL DEFENSE RESEARCH COMMITTEE, DIVISION 2, PRINCETON UNIVERSITY STATION

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May 1943