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REPORT NO. 712

Penetration and Deceleration of 25,000-lb. Bombs in Massive Concrete Targets

W. H. BENTZ [redacted]

ABERDEEN PROVING GROUND, MARYLAND

CONFIDENTIAL

[redacted]

BALLISTIC RESEARCH LABORATORIES

REPORT NO. 712

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IN MASSIVE CONCRETE TARGETS [U], (8)

(10) William H. Bentz

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BALLISTIC RESEARCH LABORATORIES

REPORT NO. 712

Bentz/smk
Aberdeen Proving Ground, Md.
14 December 1949

PENETRATION AND DECELERATION OF 25,000-LB. BOMBS IN MASSIVE CONCRETE TARGETS

ABSTRACT

This report presents data from Project Harken, which included tests of two new American bombs, the 25,000-lb. T28E1 (Amazon II) and the 25,200-lb. T28E2 (Samson), against a massive concrete target. These tests showed that both bombs were capable of withstanding impact on such targets with striking velocities up to at least 1100 ft/sec. Those bombs recovered after penetration were intact and undeformed.

The penetration equation $P = C(d)^{0.2}(W/d^2)(V/1000)^{4/3}$ was used to estimate the penetration, perforation and scabbing limits for the above bombs. These estimates were in good agreement with the test data, thus demonstrating the ability of the equation to predict large scale bomb performance.

The average decelerations of the bombs during the early part of penetration, up to about four calibers, were obtained from film measurements and were found to be 30,300 ft/sec^2 and 37,000 ft/sec^2 for the T28E1 and T28E2 bombs respectively. The region of maximum stress concentration was taken to be the junction of the side wall and ogive. The compressive stresses at this point were calculated to be 29,000 lbs/sq.in. and 43,000 lbs/sq.in. for the T28E1 and T28E2 bombs, respectively, based on the above decelerations. These values were considerably below the ultimate compressive strength of the bomb bodies, which was estimated from the specifications to be 100,000 lbs/sq.in.

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INTRODUCTION*

Projects Ruby and Harken were joint Anglo-American Bomb tests, undertaken for the purpose of providing ballistic data and performance records of heavy concrete piercing bombs, striking reinforced concrete targets. The tests were begun in 1945 with bombs developed and used during World War II, and were continued in 1946 with newly designed bombs. The 1946 trials were known as Project Ruby and were carried out in Europe by the Air Proving Ground Command, using the Submarine Assembly Plant at Farge, Germany, as one of the targets. The 22,000-lb. SAP T28 (Amazon) bomb was dropped at Farge and its performance compared with that of the 22,000-lb. G. P. Grand Slam and 12,000-lb. G. P. Tallboy.

The results obtained with the 22,000 lb. Amazon indicated the need for redesigning the bomb to give greater case strength, without materially reducing the charge to weight ratio. Although the bomb was capable of perforating the 14'9" section of the target roof, it broke up either upon perforation of the roof, or upon secondary impact within the building. A weakness of the rear weld which joined the base ring to the bomb body was a contributing factor to break-up.

Project Harken included testing of two new bomb designs which, it was hoped, would eliminate the above difficulties. These were the 25,000 lb. SAP T28E1 (Amazon II) and the 25,200-lb. SAP T28E2 (Samson) bombs.

High speed motion pictures were taken of the bombs as they struck the target. This film was subsequently sent to the Aberdeen Proving Ground, where the Measurements Analysis Branch, Computing Laboratory of the Ballistic Reserach Laboratories made the measurements and reductions yielding decelerations, and provided the author with the resulting data. The primary purpose of this report is to present and discuss the results of the deceleration measurements.

It was hoped that examination of the deceleration data, in conjunction with the measured penetrations, both of which are given in the body of the report, would indicate whether or not present penetration equations are capable of predicting the penetration of extremely large bombs into massive concrete targets. Since these equations had been developed from relatively small caliber data, it was possible that they would not accurately account for the large change in scale involved. This report attempts to answer the above question.

DESCRIPTION OF BOMBS

The T28E1 (Amazon II) bomb is 38 inches in diameter, 154 inches long and has a main wall thickness of $4\frac{1}{2}$ inches. A cross sectional view is shown in Figure I. The charge weight is 4,200 lbs, total weight 25,000

*General information and terminal ballistic data were obtained from Part 1, Final Report, Harken Project, by U.S.A.F.

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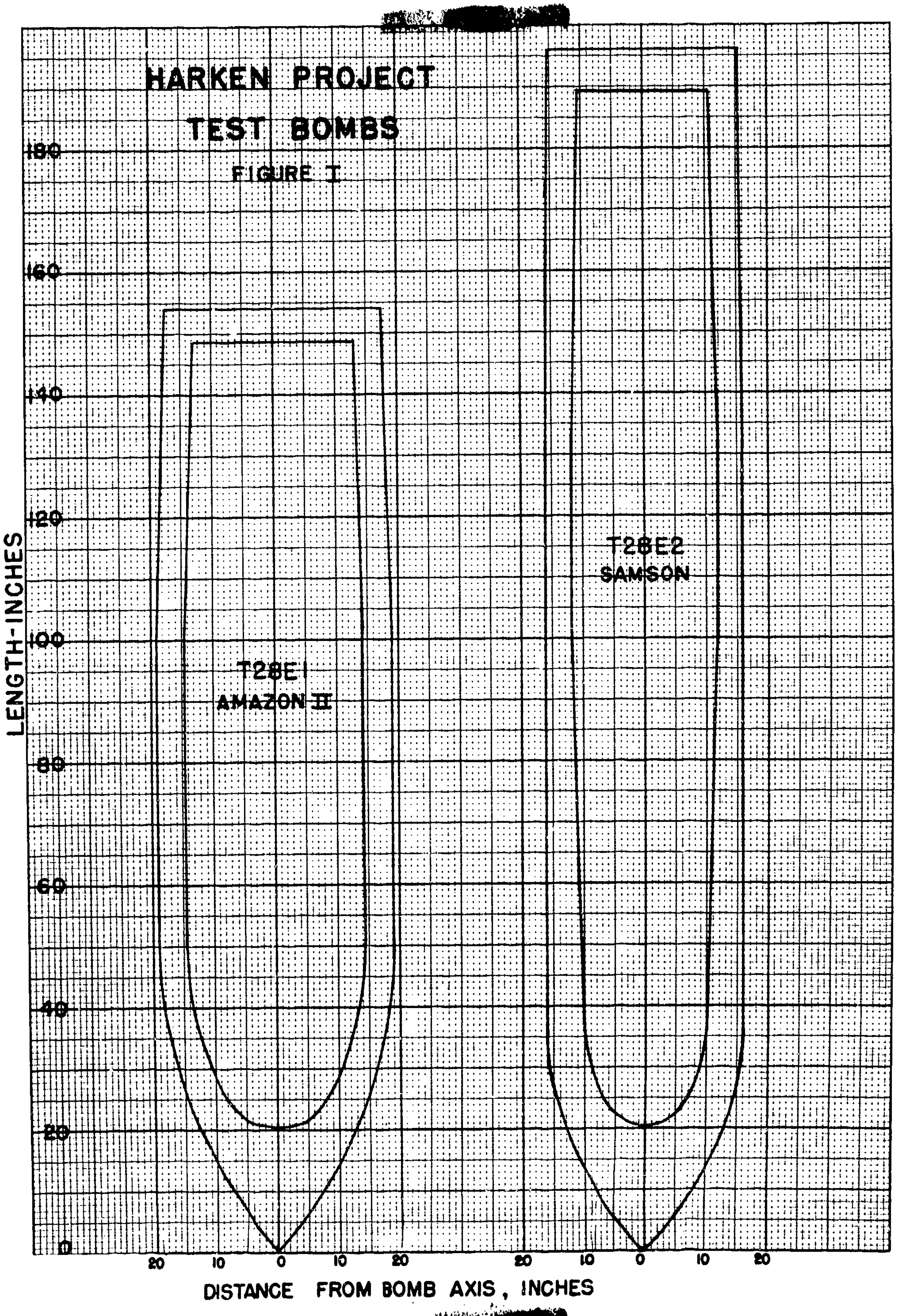

HARKEN PROJECT
TEST BOMBS
FIGURE I

[redacted]

lbs, corresponding to 16.8% explosive.

The T28E2 (Samson) bomb has approximately the same weight, 25,200 lbs, but it is longer and has a smaller outside diameter. With a 32 inch maximum outside diameter and a main body length of 196 inches, it is designed for greater penetration than is the Amazon. The main wall thickness is 4 1/8 inches with a charge weight of 3900 lbs, giving 15.5% explosive. Details are shown in Figure I.

Both the T28E1 and T28E2 bombs had the Tallboy type fin assembly consisting of a tail cone carrying four radial vanes which are set at an angle of 5° to the axis of the bomb to produce rotation in flight.

DESCRIPTION OF TARGET

The target was the uncompleted Submarine Assembly Plant at Farge, Germany, near the city of Bremen. The structure was 1400 feet in length, 74 to 82 feet in height, with width varying in steps from 318 feet at one end to 220 feet at the other. The length of the widest portion was 586 feet, and over this length the roof was 14.76 ft. thick. Over the narrow section and part of the midsection the roof had been built up to a thickness of 23 ft. by pouring a layer of concrete over the original 14.76 ft. of reinforced concrete. The reinforcement was of two types. One was prefabricated, prestressed, reinforced concrete arched trusses 14.76 ft. high and 98.42 ft. long. The other type consisted of rolled steel I-beams, 24 inches in height and 8 inches in width, with a web and flange thickness of 1 inch.

CAMERAS

Two different types of cameras were used to record each bomb strike. The first type consisted of a high speed, 16mm modified Kodak HSC-3000 camera, operating at 2000 frames per second, 2½ inch focal length lens, timing marks 1000 per second. There were four of these cameras used.

The second type of camera was a 35mm Vinton HS-300, running at 200 frames per second. The time base was impressed every 1/50th of a second. There were also four of these cameras.

Assessment of film from the above cameras made it possible to determine deceleration and angle of yaw. To make these measurements possible, the bombs were painted with calibrated markings stripe on the body.

TERMINAL BALLISTIC DATA

Fifteen 25,000 T28E1 (Amazon II) bombs were dropped from 17,000 ft., producing a striking velocity of approximately 1100 f/s. Of these fifteen bombs, two were fair hits on the 14.76 feet thick roof section, two struck over a wall, and one penetrated a short distance and then broke out the edge.

Nine 25,200-lb. T28E2 (Samson) bombs were dropped from 17,000 ft. Two good hits were scored on both the 14.76 feet and the 23 feet roof sections.

TABLE I

Summary of Terminal Ballistic Data

Rd. No.	Alt. Ft.	Roof Thick.	Crater Data*		Vert. Pen.	Strik. Data**		Bomb Condition	Bomb Behavior	Remarks
			Length	Width		Vel. f/s	Angle Deg.			
T28E1 (Amazon II)										
152	17,000	14.76'	20.25'	18.5'	Perf.	1068	17.0°	Intact, Undeformed	Perf. roof and struck floor	Came to rest in horizontal position
153	17,000	14.76'	20.25'	21.0'	Perf.	1069	17.2°	Intact, Undeformed	Perf. roof and Pen. concrete floor	Came to rest at 22.5° to the vertical
157	17,010	Over Wall	Edge	Hit	---	1078	19.3°	Broke up	Struck edge of Bldg Glanced off	Only base plate and frag. from rear section found.
161	17,000	Over Wall	Edge	Hit	---	1081	19.5°	Broke up	Struck edge of Bldg Glanced off	Base plate & frag. from front and rear sections found
164	17,000	23.0'	24.0'	19.0'	9.5'	1080	19.3°	Intact Undeformed	Struck roof, broke out edge, ricocheted 1325'	Bomb came to rest horizontally on ground
T28E2 (Samson)										
183	17,000	14.76'	19.5'	17.5'	Perf.	1097	20.6°	Intact	Perf. roof and 6' floor of bldg.	Bomb disappeared below bldg. floor
184	17,030	24.0'	19.5'	17.5'	13.5'	1090	19.7°	Intact Undeformed	Came to rest in crater	No scabbing. Bomb at 49° to vert.
186	16,990	16.75'	19.5'	19.0'	Perf.	1090	19.7°	Intact	Perf. roof and floor	Bomb deflected to left in Perf. roof
189	17,000	23.0'	33.5'	33.0'	19.33'	1059	13.4°	Intact Undeformed	Came to rest in crater	Ceiling scabbed. Bomb at 43.5° to vertical

* Measured at surface of target

**Angle of bomb axis, measured from the vertical.

Details of the impacts of the bombs which hit the target are given below, while a summary of the terminal ballistic data appears in Table I.

T28E1 AMAZON II BOMBS
Altitude of Release 17,000 ft.

Round 152

This bomb perforated the 14.8 ft. roof section, severing the upper chord of one concrete arched truss and the lower chord of one ahead of it. It hit the edge of a concrete pit, and then penetrated the reinforced concrete flooring of the pit at a shallow angle, turned 90° and ripped out the reinforcing bars. The body was intact and undeformed. At the point of secondary impact, the bomb struck and broke a steel guide rail riveted to a steel channel. At the bottom of the pit a 12" I-beam with 3/4" web and flanges was flattened and the top flange of a similar I-beam was bent upward. A number of 3/4" and 1½" steel reinforcing bars were cut or distorted. The only sign of damage to the bomb, however, was a slight flattening at one point of the mild steel fin-securing ring. This bomb was recovered, shipped back to Giebelstadt and redropped.

The roof crater measured 21'0" in length and 18'6" in width. Several chords in the vicinity of the severed one had been deformed. The ceiling beneath the impact was considerably scabbed to the rear of the exit hole. The angle of penetration through the roof started at 17° to the vertical and increased to 25°. There was practically no azimuth deflection.

Round 153

This bomb perforated the 14.8 ft. roof section over the central aisle of the building where the reinforcing consists of 23.62 inch rolled steel I-beams, 8" wide with 1" thick web and flanges. It penetrated 9.6' into the floor of the building. One of the damaged I-beam sections, 19 ft. in length, was bent 3 ft. out of line where the bomb struck it. The bomb was intact and undeformed.

The angle of penetration through the roof increased from 17° to 28°, while the bomb swerved 40° to the left of its trajectory. The roof crater measured 20'3" in length and 21'0" in width.

Round 157

This bomb hit on the edge of the 14.8 ft. ledge, glanced off and fell to the ground, cutting a railroad track running into the building at this point. An oval shaped crater, 40 ft. in length, was formed indicating that the bomb hit flat. Examination of three fragments, 4½" thick, supported the belief that the rear portion of the bomb broke as the result of side impact against the edge of the roof. Excavation was impractical because of the high water level.

Round 161

This bomb struck near the edge of the roof and made a crater 15'8" by 11'6" before breaking out the side wall. The ground crater, 40 ft. long and 20 ft. wide, was similar to that for Round 157. None of the recovered body fragments showed any sign of weld failure.

Round 164

This bomb, struck on the 23 ft. roof, 10 ft. from the edge of the alcove section and 18 ft. from the wall, the last 8 ft. being 14.8 ft. thick. The bomb broke away the 8.2 ft. layer of unreinforced concrete between the point of strike and the north end of the slab, turned 45° to the right and ricocheted off the roof. In ricocheting, the bomb made a groove about 15" deep in the surface of the 14.8 ft. slab. The total penetration was 9'6". The bomb was recovered intact and undeformed in a field 1325 ft. from the point of strike. It was shipped to Giebelstadt to be redropped. (Round 190) This time the bomb struck the south wall and ruptured upon impact.

Round 183

This bomb made a clean perforation, 3 ft. in diameter, of the 14.8 ft. roof section, leaving a crater 19'6" long and 17'6" wide. Two of the reinforcing I-beams were severed by the impact. Scabbing on the underneath side of the roof was confined to an area about 10' in width and 17' in length. The bomb then perforated the 6 ft. thick reinforced concrete floor, shed its fin assembly in the floor crater, and disappeared beyond probing depth into the sand beneath the floor. The floor crater was excavated to a depth of 10 ft. and probed in all directions to a depth of 18 ft. without striking the bomb.

The perforation hole in the floor slab measured 13'6" by 11'6". In passing through the roof, the bomb was deflected 18° to the left of its original trajectory, probably because of the I-beam reinforcing. The striking angle was 21° and the bomb turned up only about 5° in perforating the roof.

Round 184

This bomb struck on a 23 ft. thick roof section and penetrated to a depth of 13'6", including 8.2 ft. of unreinforced concrete, coming to rest at an angle of 49° to the vertical. The I-beam reinforced ceiling underneath the impact was not scabbed except for one crack. The bomb was recovered intact and undeformed. The crater was 19'6" by 17'6" and extended on one side to a construction joint.

Round 186

This bomb struck the 23 ft. roof section and penetrated into the second layer of concrete, with arched truss reinforcing, to a total depth of 19'4". It came to rest at an angle of $43\frac{1}{2}^\circ$ to the vertical and was recovered intact, undamaged and undeformed.

The point of strike was directly along a construction joint running across the roof. The crater, which was 33'6" by 33'0", extended into the sections to both the right and left of the joint. Behind the crater the construction joint opened up to a width of 2 ft.

The bomb was not immediately located, but a bulge in the arched truss ceiling, amounting to as much as 2 ft., and scabbing of adjacent trusses under the end section, indicated that the bomb had nearly perforated the 23 ft. roof.

Analysis of Data

The problem of concrete penetration is a difficult one for several reasons. The cost of full scale experimentation is rather prohibitive and the extrapolation of results of small scale model tests is complicated by the uncertainty of the scale effect, by the fact that concrete is not a homogeneous material, and because an adequate theory of concrete penetration has not as yet been developed. Considerable work of this nature has been done by both the United States and Great Britain. Since 1940, work in this country was carried out first at Princeton University, by the Committee on Passive Protection Against Bombing, of the National Academy of Sciences, followed by the Committee on Fortification Design, of the National Research Council. It has been closely integrated with the program in terminal ballistics of Division 2, National Defense Research Committee.

The most recent compendium of concrete penetration data and formulas is that presented by Dr. R. A. Beth in Chap. 7, Vol. 1, "Effects of Impact and Explosion," Division 2 of NDRC (1946). The relation between velocity and penetration for an inert nondeforming projectile striking a massive concrete target at normal incidence, is given by Dr. Beth as follows:

$$G(Z) = KN(d)^{0.20}\, D\, V^{1.80} \qquad (1)$$

where: $G(Z) = Z^2/4$ for $0 \leqq Z \leqq 2.00$ calibers

$= Z - 1.00$ for $Z \geqq 2.00$ calibers

K = a constant of penetrability of the concrete

N = nose shape factor for the projectile

d = maximum diameter of the projectile (in.)

$D = W/d^3$ = caliber density of the projectile(lb/cu.in.)

V = striking velocity, in thousands of fps.

Z = penetration in calibers

The expression given above relating G(Z) and Z is an attempt to account for the entry of the pointed nose of the projectile and the escape of target material during crater formation.

The nose shape factor, N, may be computed from

$N = 0.72 + 0.25\sqrt{n - 0.25}$ where n is the radius in calibers of a tangent-ogive projectile nose. If the projectile does not have a tangent-ogive nose the above formula may still be used by estimating n from a tangent-ogive curve which most closely approximates the actual nose shape.

The older concrete penetration formula, also proposed by Dr. Beth, is as follows:

$$P = C(W/d^2)\ d^{1/5}\ (V/1000)^{4/3} \qquad (2)$$

where P = penetration in inches

C = 4.6 for concrete of 5000 lbs/sq.in. compressive strength

= 6.0 for concrete of 3400 lbs/sq.in. compressive strength

and the other symbols have the same meaning as in (1). In the opinion* of the author, the Equations (1) and (2) will yield essentially the same results over the velocity range 500 to 3000 fps.

The penetrations predicted by Equations (1) and (2) are based on normal incidence, while the actual striking angle, in this case, was approximately 18° from the vertical. Adjustment for this condition may be made, however, by using the tabulated values relating the striking angle, θ, to the ratio Z_p/Z given in the NDRC report. Here Z is the penetration that would be obtained at normal incidence and Z_p is the normal component of the oblique penetration at angle θ, for a common velocity. The values are based on A.P. projectile data with impact velocities between 1,000 and 2,000 fps. It must be noted that these values are very approximate, but at the same time, they are the only estimates of this type available. In view of this inaccuracy, it was felt that, although θ ranged from 13.4° to 20.6° for the bombs under consideration, the use of an average value of 18° would suffice. For this angle $Z_p/Z = 0.78$.

The perforation and scabbing limits may be estimated by the following equations, also from the NDRC report.

$$e/d = 1.23 + 1.07\ (Z_p) \qquad (3)$$

$$s/d = 2.28 + 1.13\ (Z_p) \qquad (4)$$

where: e/d = the thickness of a target that will be perforated in calibers

s/d = the thickness of a target that will be scabbed, in calibers

ESTIMATED PENETRATION, PERFORATION AND SCABBING LIMITS

Considering the apparent agreement of the two penetration formulas with experimental data, and the fact that an independent estimate of the penetrability constant, K, of the Farge concrete was not available, it was decided that the penetration, perforation, and scabbing limits should be computed by Equation (2). Table II gives the weight, diameter, caliber density, and average striking velocity in 1000 fps, for each bomb.

*From an analysis of previous firings with projectiles ranging from cal. 45 to 155mm, it was found that the two formulas agreed with each other within 15%.

TABLE II

	W, lbs.	d-in	W/d^3	V
T28E1	25,000	38	0.456	1.069
T28E2	25,200	32	0.769	1.084

T28E1

$$P = 4.6(0.456)(38)^{0.20}(1.069)^{4/3}$$
$$= 4.75 \text{ cal.}$$
$$= 15.0 \text{ ft.}$$
$$Z_p = 4.75 \times 0.78 = 3.71 \text{ cal} = 11.75 \text{ ft.}$$
$$e = [1.23 + 1.07\ (3.71)]\ 38/12 = 16.5 \text{ ft.}$$
$$s = [2.28 + 1.13\ (3.71)]\ 38/12 = 20.5 \text{ ft.}$$

T28E2

$$P = 4.6(0.769)(32)^{0.20}(1.084)^{4/3}$$
$$= 7.88 \text{ cal.}$$
$$= 21.0 \text{ ft.}$$
$$Z_p = 7.88 \times 0.78 = 6.15 \text{ cal.} = 16.4 \text{ ft.}$$
$$e = [1.23 + 1.07(6.15)]\ 32/12 = 20.8 \text{ ft.}$$
$$s = [2.28 + 1.13(6.15)]\ 32/12 = 24.6 \text{ ft.}$$

The above calculations indicate that both bombs could be expected to perforate the 14.76 ft. thick roof, but that neither should perforate the 23.0 ft. section. This agreed with the test data. Since there were no T28E1 hits on the thicker roof, it was not possible to check the scabbing limit estimate for this bomb. Rounds 184 and 189 indicated a scabbing limit for the T28E2 of about 23 or 24 ft. This agreed with the calculated value of 24.6 ft. The estimated penetration again could not be checked by the T28E1 data. The measured vertical components of penetration for the T28E2 bombs were 13.5 ft. and 19.33 ft. for rounds 184 and 189 respectively. The computed value and the average value were both 16.4 ft.

It appears then that there was good overall agreement between the test data and the computed values, considering the meager amount of data.

DETERMINATION OF CASING STRESSES

Since failure of a bomb casing generally takes place at the junction of the ogive and side wall, or a short distance to the rear of this point, the forces acting in this region will determine the stress most likely to cause failure of the casing. This is the stress due to inertial forces on the section immediately to the rear of the ogive.

In order to compute the inertial forces, it is necessary to know the decelerations to which the bombs were subjected during penetration. Measurements of the deceleration during penetration were supplied by the Computing Laboratory, BRL, from their analysis of the Harken films. Table III presents these data.

TABLE III

Deceleration of Bombs, Harken Project

Bomb No.	9	9	2	10
Round No.	153	153	152	184
Type Bomb	T28E1	T28E1	T28E1	T28E2
Camera	F12	G12	G11	
x		y_o		
1	18.1	21.2	32.8	5.3
2	16.2	19.2	31.2	4.5
3	14.2	18.2	30.0	3.6
4	12.0	16.2	28.2	2.9
5	9.8	14.8	26.8	2.2
6	8.2	13.3	25.4	1.5
7	6.0	11.8	24.2	1.0
8	4.3	10.6	22.7	0.2
9	2.4	9.0	21.8	-0.3
10	0.3	7.4	20.1	-1.0
11	-1.5	6.2	18.6	-1.6
12	-2.9	4.8	17.8	-2.4
13		3.7	15.9	
14			14.4	
15			14.2	
f	0.344	0.386	0.424	0.729
$t \times 10^4$(sec)	6.25	5.66	5.61	5.75
Decel.(ft/sec^2)	30,000	34,000	27,000	37,000
Stnd. Dev.	±4,000	±5,000	±10,000	±6,000

x = Serial number of observations, made at successive frames

y_o = Successive positions of bomb along path in plane of films (in measuring units)

f = Length of bomb in ft./Length of bomb in measuring units

t = Average time between observations (sec.)

Of the four T28E2 bombs which were fair hits on the roof, only Round 10 could be assessed for deceleration. Films from low speed cameras yielded too few observations while the high speed cameras, other than the one that recorded Round 10, were screened from the points of impact by intervening roof structures.

It should be noted that the above decelerations are average values of a number of measured decelerations obtained during the early part of the penetration of the bombs into the roof. The bombs were usually visible until they had penetrated about three or four calibers, after which the tail was obscured by debris. Figure 2 shows an Amazon II bomb penetrating the roof of the target.

The average decelerations of the two bombs were as follows:

$$a(T28E1) = 30{,}300 \text{ ft/sec}^2 \pm 7{,}000 \text{ (Average of 3 rounds)}$$

$$a(T28E2) = 37{,}000 \text{ ft/sec}^2 \pm 6{,}000 \text{ (One round only)}$$

These two decelerations are in the reverse order of magnitude to what might be expected from a consideration of the dimensions of the two bombs. The penetration of Round 184, on which the T28E2 deceleration was based, was 18% less than Equation (2) would predict, indicating a relatively high deceleration and thus substantiating somewhat the value obtained from the film. Further justification results from the fact that the T28E2 bomb struck the thicker roof section and was completely stopped, while the T28E1 bombs, after perforating the thinner portion of the roof, retained sufficient velocity to penetrate the floor slab inside the building.

Assuming the above decelerations to be correct then, the total force acting on the bomb is given by the following formula:

$$F_T = \frac{W_T}{g} \quad a$$

where F_T = Total retarding force on bomb, lbs.

W_T = Total weight of bomb, lbs.

a = Deceleration of bomb, ft/sec^2

g = 32.2 ft/sec^2

T28E1

$$F_T = \frac{25{,}200}{32.2} \times 30{,}300 = 23{,}500{,}000 \text{ lbs.}$$

T28E2

$$F_T = \frac{25{,}200}{32.2} \times 37{,}000 = 29{,}000{,}000 \text{ lbs.}$$

The compressive stresses at the junction of the side wall and ogive were computed from the equation

$$S_c = \frac{W}{g} \cdot \frac{a}{A}$$

where S_c = Compressive stress acting at assumed section lbs/sq.in.

W = Weight of bomb casing to the rear of section at which failure occurs, assumed to be total weight of bomb casing, lbs.

[redacted]

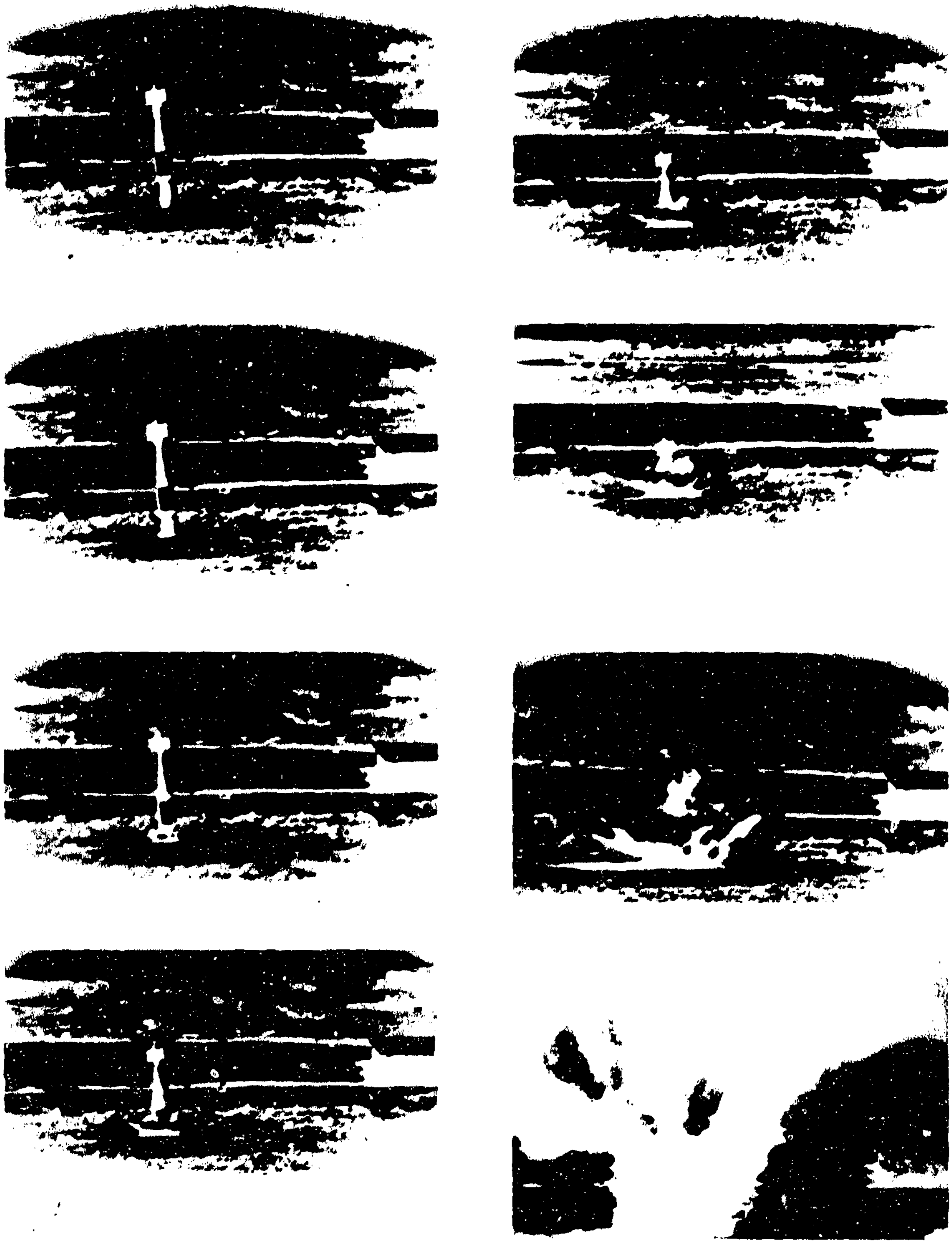

Figure 2. Amazon II bomb during various stages of penetration into concrete roof of German submarine pen at Farge, Germany.

[redacted]

A = Cross section of bomb casing at section considered, sq.in.

a = Deceleration of bomb, ft/sec^2

T28E1

$$S_c = \frac{14,600}{32.2} \times \frac{30,300}{474} = 29,000 \text{ lbs/sq. in.}$$

T28E2

$$S_c = \frac{18,200}{32.2} \times \frac{37,000}{490} = 42,700 \text{ lbs/sq.in.}$$

The specifications for manufacture of the bomb casings require a minimum tensile yield strength of 70,000 lbs/sq.in. If the minimum compressive yield strength is assumed equal to the above figure, then the compressive stresses actually developed in the bomb were 41% and 61%, respectively, of the stress necessary for permanent deformation.

MEASUREMENTS OF STRIKING YAW

The instrumentation for bomb decelerations provided data from which the yaws and yaw orientations could be determined. Table IV gives the results of the yaw measurements. It appears that the observed yaws were too small to be of appreciable effect on penetration or retardation.

TABLE IV

Bomb Type	Bomb No.	Yaw θ, Degrees	Yaw Orientation w, Degrees
T28E1	2	2.4	287
	4a	4.4	231
	4b	3.8	223
	9a	2.2	331
	9b	2.7	307
	13	3.7	313
T28E2	1	0.9	185
	10	3.9	338
	15	4.8	305

θ is the angle between the bomb axis and the bomb trajectory
w is the angle between the vertical plane containing the trajectory and the plane of the yaw, measured clockwise as viewed from the rear
The letters a and b indicate values obtained from different cameras.

SUMMARY

The Harken Project data indicate that both the T28E1 (Amazon II) and T28E2 (Samson) bombs will withstand impact on massive reinforced concrete targets with striking velocities up to about 1100 ft/sec. and possibly higher. The decelerations to which the bombs were subjected were 30,700 ft/sec^2 and 37,000 ft/sec^2, respectively, for the T28E1 and T28E2 bombs. The corresponding stresses were 29,000 lbs/sq.in. and 42,700 lbs/sq.in., at the assumed point of maximum stress concentration. The bombs that could be recovered were intact and undeformed.

The values of the penetration limits calculated by Equation (2) were in good agreement with the experimental data, indicating that the equation will probably yield accurate estimates of the performance of other large bombs.

WHBentz
William H. Bentz

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

MAY 23 2000

MEMORANDUM FOR DTIC/OCQ (ZENA ROGERS)
8725 JOHN J. KINGMAN ROAD, SUITE 0944
FORT BELVOIR VA 22060-6218

FROM: HQ AFMC/SCDP
4225 Logistics Avenue, Room A112
Wright-Patterson AFB OH 45433-5744

SUBJECT: Change in Distribution Statement for AFMC Documents

1. Distribution statements on several documents were officially changed to Distribution Statement A in accordance with AFI 61-204, 27 Jul 94, *Disseminating Scientific and Technical Information*. The documents (excluding those marked out in Atch 3) are owned by AFMC and were reviewed by the HQ AFMC History Office and HQ AFMC Public Affairs Office. The documents cleared for public release are listed on three attachments.

2. Please direct further questions to Ms. Lezora Nobles, AFMC STINFO Assistant, HQ AFMC/SCDP, DSN 787-8583.

Patricia T. McWilliams

PATRICIA T. McWILLIAMS
AFMC STINFO Program Manager
Directorate of Communications and Information

Attachments:
1. AFDTC/PA Memo, 11 Jan 95
2. HQ AFMC/PAX 1st Ind, 4 May 00
3. HQ AFMC/PAX Memo, 5 May 00

2. Attachments a through c are part of an internal AFMC/HO review; attachments d and e are requested by Mr. Morris Betry, a private researcher; attachments f through h are requested by Ms. Pat McWilliams (AFMC/SCDP); and attachment i is requested by Mr. Gregory Hughes (ASC/ENFD).

3. The AFMC/HO point of contact for these reviews is Dr. William Elliott, who may be reached at extension 77476.

JOHN D. WEBER
Command Historian

~~8~~ 6 Attachments:

a. ~~AFSC No. 150.174~~
b. ~~AFSC No. 400.490~~
c. DTIC No. AD-098 048
d. DTIC No. AD-376 934
e. DTIC No. AD-895 879
f. DTIC No. AD-094 838
g. DTIC No. AD-068 388
h. DTIC No. AD-046 931
~~i. AFLC No. R1-120-2~~

1st Ind, HQ AFMC/PAX 4 May 2000

This material has been reviewed for security and policy IAW AFI 35-101. It is cleared for public release.

JAMES A. MORROW
Security and Policy Review
Office of Public Affairs

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