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NUMERICAL TARGET INDEX

OBJECTIVE AREA 98:2—THAILAND-BANGKOK (THAILAND)—(Continued)

Target Number and Objective Area	Name	Location	Coordinates (approx.)	General Category	Particular Category	Comment
98:2-54 Thailand-Bangkok (Thailand)	Ministry of Marine Compound	W bank of Chao Phraya River (Mae Nam Chao Phraya) (Menam River), opposite Grand Palace (Phra Borom Maha Ratchawang), Bangkok (Krung Thep).	13°45′N 100°29′E	EPI	A	Naval yard, machine shops, warehouses, barracks, graving dock and crane. Coastal guns.
98:2-56 Thailand-Bangkok (Thailand)	Royal Irrigation Dept.	E bank of Chao Phraya River (Mae Nam Chao Phraya) (Menam River), about 2 miles S Rama VI RR Bridge (98:2-45) Bangkok (Krung Thep) and NE of Samsen Steam Power Plant (98:2-27).	13°47′N 100°31′E	BEI	MMT	Warehouses and machine shops for repairs on diesel dredgers.
98:2-57 Thailand-Bangkok (Thailand)	Satahib Naval Base	N end Gulf of Thailand, 65 miles SSE mouth Chao Phraya River (Menam River).	12°40′N 100°53′E	EPI MS	A P	Main base of Thai Navy. Wharf, airfield and seaplane mooring. Oil tanks behind 2 forts and also reported on Island of Pra (Ko Phra Yai) and Pranoi (Ko Phra Noi), ½ mile S and SE in bay.
98:2-58 Thailand-Bangkok (Thailand)	Ministry of Defense and QM Stores	Heart of Bangkok to rear of Ministry Bldg., ½ mile W of Chao Phraya River (Menam River).	13°45′N 100°30′E	MS	M	Central quartermasters' stores.
98:2-59 Thailand-Bangkok (Thailand)	Thai Cement Co.	N fringe of Bangkok (Krung Thep), 1 3/5 miles ESE of Rama VI RR Bridge (98:2-45), across Northern Ry from station and yards.	13°48′N 100°33′E	BPI	C	Largest cement plant SE Asia.
98:2-60 Thailand Bangkok (Thailand)	Government Distillery	W bank Chao Phraya River (Mae Nam Chao Phraya) (Menam River), at Bangkok (Krung Thep), 2 miles W Phya Thai Palace (Phra Tamnak Phaya Thai) and radio station.	13°46′N 100°30′E	BPI	C	Main government plant producing alcohol.
98:2-61 Thailand-Bangkok (Thailand)	Memorial Bridge (Bangkok)	Across Chao Phraya River (Mae Nam Chao Phraya) (Menam River), to center of Bangkok (Krung Thep).	13°44′N 100°30′E	BSU	RRT	Only vehicular bridge across Chao Phraya River in Bangkok district.

BEI—Basic Equipment Industries; BPI—Basic Processing Industries; BSU—Basic Services & Utilities; EPI—End Product Industries; MIC—Mixed Industrial Concentrations; MS—Military Stores.

A—Armament; AC—Aircraft; C—Chemicals; CIS—Coke, Iron & Steel; EP—Electric Power; LM—Light Manufacturing; MMT—Machinery & Machine Tools; M—Munitions; NFM—Non-ferrous Metals; P—Petroleum; RRT—Road & Rail Transportation; S—Shipping; TE—Transportation Equipment; UIC—Urban Industrial Concentrations.

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OBJECTIVE AREA 98:2—THAILAND-BANGKOK (THAILAND)—(Continued)

Target Number and Objective Area	Name	Location	Coordinates (approx.)	General Category	Particular Category	Comment
98:2-63 Thailand-Bangkok (Thailand)	Ban Mah Arsenal	Left bank Pasak River (Mae Nam Pa Sak), 3 miles upstream from Ayuthia (Ayutthaya), at juncture of River with Ban Mah Canal.	14°21′N 100°35′E	EPI MS	A M	Only producer of explosives in Thailand. 2 large compounds. Munitions storage.
98:2-64 Thailand-Bangkok (Thailand)	Ko Si Chang Island Oil Storage	N end Gulf of Thailand, 30 miles SSE mouth Chayo Phraya River (Mae Nam Chao Phraya) (Menam River).	13°09′N 100°49′E	MS	P	At least four 12,000 ton tanks.

BEI—Basic Equipment Industries; BPI—Basic Processing Industries; BSU—Basic Services & Utilities; EPI—End Product Industries; MIC—Mixed Industrial Concentrations; MS—Military Stores. . . . . . .

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OBJECTIVE AREA 98:3—THAILAND S (THAILAND)

Target Number and Objective Area	Name	Location	Coordinates (approx.)	General Category	Particular Category	Comment
The targets in this objective area (98:3) are targets presented in an Air Objective Folder or Interim Report published 1 February 1943. They do not reflect additional research by Joint Target Group; therefore the information concerning them is not completely representative of current conditions.						
98:3-43 Thailand S (Thailand)	Tung Song Junction	At Tung Song (Thung Song) (Ban Chamai).	8°09′N 99°40′E	BSU	RRT	Controls traffic to Trang and Kan Tang (Kantang), to Nokhon Sritamarat (Nakhon Si Thammarat) (Nagorn Sridharmraj) and main line S to Singapore.
98:3-44 Thailand S (Thailand)	Haad Yai Junction	About 16 miles SE of Singora (Songkhla) (Songkla).	7°01′N 100°31′E	BSU	RRT	Most important junction on Malay Peninsula. Controls E coast line through Penang; line to Singapore and spur line to naval base of Singora.
98:3-48 Thailand S (Thailand)	Prachuab Kirikhan RR Bridge	Just N of Prachuab Kirikhan (Prachuap Khiri Khan) (Prachuab Girikhan).	11°51′N 99°49′E	BSU	RRT	On main line to S. Prachuab Kirikhan is military air and naval base.

BEI—Basic Equipment Industries; BPI—Basuc Processing Industries; BSU—Basic Services & Utilities; EPI—End Product Industries; MIC—Mixed Industrial Concentrations; MS—Military Stores.

A—Armament; AC—Aircraft; C—Chemicals; CIS—Coke, Iron & Steel; EP—Electric Power; LM—Light Manufacturing; MMT—Machinery & Machine Tools; M—Munitions; NFM—Non-ferrous Metals; P—Petroleum; RRT—Road & Rail Transportation; S—Shipping; TE—Transportation Equipment; UIC—Urban Industrial Concentrations.

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ALPHABETICAL CROSS REFERENCE

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SHEET ....ACR
DATE.....20 June 1945

JOINT TARGET GROUP, WASHINGTON, D. C.
AIR TARGET INDEX—JAPANESE WAR
ALPHABETICAL CROSS REFERENCE

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NEW TARGET NUMBER INDEX

File No. 55,000

MEMORANDA

File No. 57,000

GENERAL MEMORANDA

File No. 57,009

J.T.G. No. 1 — NOTES IN CONNECTION WITH TARGET MATERIAL BEING PRODUCED

1. Joint Target Group prepares:
   - a. Air Estimates.
   - b. Analyses of Categories of Targets.
   - c. Intelligence Material Covering Principal Cities.
   - d. Intelligence Material Covering Individual Targets, Industrial Concentrations and Ports.
   - e. Weapon Recommendations.
   - f. Special Studies and Reports.
   - g. Target Indices.

2. The material is designed as a general air intelligence reference in the War against Japan. Its nature is basic rather than operational. It is distributed broadly to commands and agencies having an intelligence interest in the war.

3. Heretofore Joint Target Group has issued loose leaf binders entitled Air Target Index—Japanese War and Air Target System Folders — Japanese War which served as receptacles for the above material. With the development of intelligence, the furtherance of analysis, and the issue of estimates it has become desirable to assemble existing and forthcoming material in a different way.

4. As of 21 July therefore the above mentioned binders are to be superceded by the issuance of the following:
   - a. Air Target Intelligence Japanese War—General Analysis—Volume 1.
     1. This is a reference work for use in planning air operations.
   - b. Air Target Intelligence Japanese War—Index—Volume 1.
     1. This contains material of a general reference character.
   - c. Air Target Intelligence Japanese War—Target Analysis by Areas—Volume 1 through 9.
     1. These binders contain standard material concerning particular targets or areas arranged by objective areas.

5. Binders issued as of 21 July will include all of the material as amended contained in original binders and in J.T.G. addenda No. 1 through No. 11. The original binders and contents should be destroyed in accordance with appropriate military or naval regulations.

6. Joint Target Group has issued addenda envelopes on the 7th and 21st of each month containing material for insertion in its binders by the holders thereof. The issuance of new binders takes the place of addendum envelope No. 12 dated 21 July. Subsequent addenda will be issued at more frequent intervals as material is printed.

7. Details as to the following appear in "General Note" which is the first page of volume 1 of each of the Air Target Intelligence Japanese War binders—
   - a. Material included.
   - b. Filing additional J.T.G. material.
   - c. Expansion into additional binders.
   - d. Classification.
   - e. Disposal.
   - f. Distribution.

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JOINT TARGET GROUP, WASHINGTON, D. C.
GENERAL MEMORANDUM

SHEET M-2
DATE. 21 December 1944
PAGE 1

J.T.G. No. 2

Note in Connection with Grid References on Target Illustrations.

1. Illustrations

As and when suitable aerial cover is received in Washington, Target Illustrations on individual targets are being printed and issued.

2. Annotations

As far as possible all component parts of a target are being given separate identity numbers on the illustrations as shown on the annotated part of P3, P4 (when issued) and P5.

3. Use of Identity Numbers

By this means it is possible to discuss details of targets by cable or in correspondence by quoting the full illustration number and the identity number on that illustration of the building or part of the target to which it is desired to refer, as for example:

"Illustration 90:17-357–P3, building No. 32" or
"Illustration 90:17-2009–P3, item No. 16."

4. Further Identification Necessary

However, occasions may often arise when it is necessary (i) to be more specific about identifying a pinpoint within a general area covered by an annotated building or part of a target, or (ii) to be more general in referring to a section of the total target area containing the part or whole of several buildings, or (iii) to refer to some particular building which is not annotated.

5. Provision of Grid

To enable this to be done, all target illustrations are provided with a simple standard grid border. In earlier illustrations this border was shown only on the bottom and left-hand sides of the illustrations, but on later issues the grid is being shown on all four sides to enable a rule or straight edge to be laid across the illustration at the given reading.

6. Dimensions of Grid

The grid border is *always* the same irrespective of the type or scale of the illustration and it is a plain 1" (one inch) grid divided into 1/10" (one-tenths of an inch).

7. Nomenclature of Grid

The grid along the bottom and top edges of the illustration is known as the H grid (for Horizontal) and the grid alongside the left and right edges of the illustration is known as the V grid (for Vertical) and these letters H and V are always printed in the grid border together with an arrow to show the direction in which the reading is made.

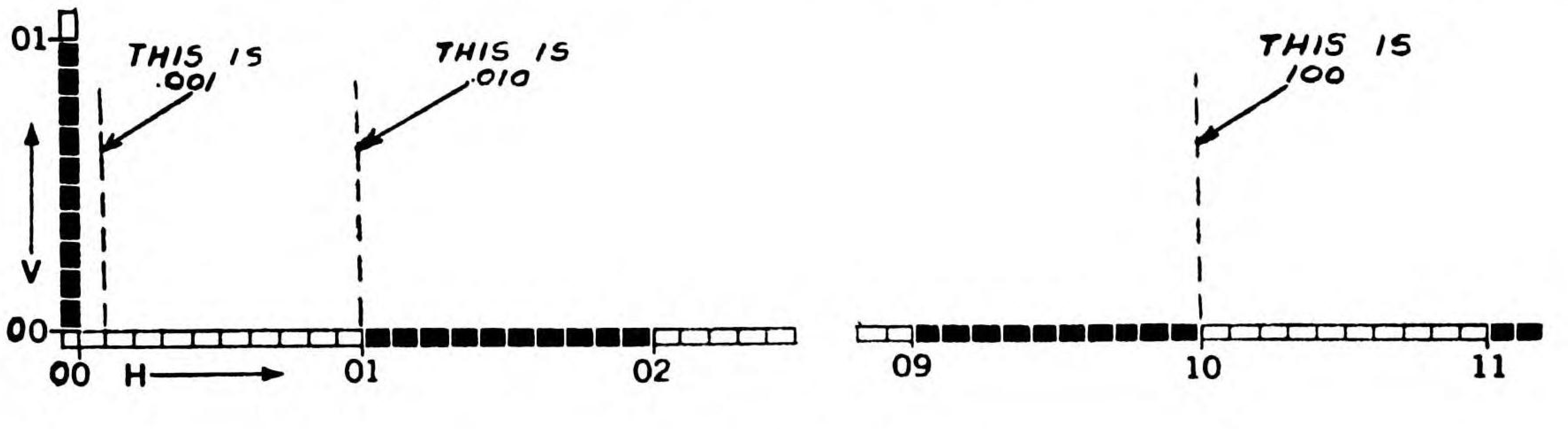
8. Method of Use of Grid

The method of expressing the grid reference for any pinpoint falling within the total area of the illustration is quite simple, the rules being as follows:

a. The horizontal (H) reading is always given first and the vertical (V) reading, second.

b. To avoid any confusion the letters H and V are put in front of the two three-digit numerals forming the two parts of the whole reference.

c. The grids themselves are always given as three-digit numerals starting from 000 in the bottom left-hand corner in both directions. Thus a point on the H grid only 1/10th of an inch from the LH side would be 001, a point one inch from the LH side would be 010 and a point 10 inches from the LH side would be 100.



In other words the figure is merely the number of one-tenths of an inch along the grid from the bottom left-hand corner, and the 0's are put in front where necessary to always make a total of three numerals. This avoids any possibility of confusion as to whether 1/10", 1" or 10", etc., is being referred to.

d. The complete grid reference is given in the form: H 012, V 134, H 123, V 056 or H 054, V 032, etc., etc.

9. Examples of Use of Grid

It is now possible to take some examples which will make the matter clear.

Referring to illustration 90:17-2009–P3 the building 16 is a very large one being approximately 1150 feet x 400 feet. Now supposing that it becomes known that a particularly important part of the plant is situated within this building a given distance to the east of the N/S axis and another given distance to the south of

(240)

the E/W axis and that it was desired to select that as the Aiming Point, in a field or operational order. By ordinary methods this might take quite a bit of explaining but, with grid system it is both simple and foolproof and would be for example: H 035, V 062.

Not only can a single pinpoint be identified in this way but an area can be given. Thus with three points a triangular area, four points a four-sided area, and so on, can be given. Thus for example, referring to illustration 90:17-356–P3 supposing that it is found from later intelligence that the group of buildings just outside the northeast corner of the annotated target outline is really part of the main target, then this information can be given with exactitude by merely quoting the grid references corresponding to the four corners, for example:

H 042, V 058; H 046, V 059; H 047, V 054; H 044, V 053.

With this information the target outline can be corrected quite simply on the illustration.

10. Usefulness of Grid

There are many ways in which this pinpointing by grids can be most useful. For example (1) in cable instructions from HQ AAF to theatre commands, regarding vital parts of targets, etc., (2) in the cable reports back from commands regarding results of a mission, concentration of bombs, parts demolished, etc., etc., (3) in interchange of intelligence between HQ AAF and theatres or P/W interrogation centres, etc,. etc.

11. Previous Use of Grid

The exact grid reference method outlined above has been used for several years in the European Theatre by American and British Air Forces and has been found to be immensely useful in intelligence planning between Air Force, Commands, and lower echelons and between coordinate units, and is especially important where units are widely separated and communications poor.

12. Application to Non-Gridded Illustrations

One other point might perhaps be mentioned and that is that the principle can be applied to illustrations even if the grid border is not printed on, although the latter is most desirable wherever possible. Thus for example the forerunner of the present type of target material was the Air Objectives Folder which has received wide distribution and which includes many photographs, plans and illustrations. Providing that a 1" ruler is available the grids can be given on any of these illustrations by following the procedure outlined in "Method of Use of Grid" above. To quote a single example refer to the AICHI AIRCRAFT WORKS, ATSUTA PLANT at NAGOYA (Target 90:20-198), and assume that it is desired to run a mission on this target before the latest form of target material is issued. In Objective Folder 90:20 on page 24 there is a plan of this target. Theatres might cable back to HQ and ask what were considered to be the most important parts of the target to select as an aiming point. Supposing that JTG analysis showed that the Wing Jig Section (say) was the most important and that they knew the location, then they could send a two-line cable giving all the information required, say as follows:

"Wing Jig Section considered most vital part, location at H 048, V 024 on plant 198 on page 24 of objective folder 90:20."

(This case is hypothetical and not factual but serves to illustrate the principle involved and reference should be made to illustration mentioned so as to check the method.)

JOINT TARGET GROUP, WASHINGTON, D. C.
GENERAL MEMORANDUM

SHEET M-5
DATE......15 July 1945
PAGE 1

J.T.G. No. 5 – NUMBERING OF AIR TARGETS

1. Joint Target Group will number new air targets in the Japanese War on its own initiative where such targets are relatively important; i.e., are generally equal in importance to those listed on index sheets in Air Target Intelligence Japanese War—Index.

2. Numbering of any targets other than those described above will be undertaken by Joint Target Group at the request of appropriate field commands. Such requests should be accompanied by photography of the target or reference to print and sortie number if photography is held in Washington.

3. Dissemination of new target numbers will be accomplished through issuance of New Target Number sheets included in the J. T. G. addendum envelopes. These sheets are designated for inclusion in the Air Target Intelligence Japanese War—Index—behind appropriate Tab.

WEAPONS MEMORANDA

File No. 65,000

JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET M-3
DATE.....21 June 1945
PAGE 1

J.T.G. No. 3 – EXPLANATION OF WEAPON RECOMMENDATIONS

A. INTRODUCTION

[In view of major changes recently made in the presentation of weapon recommendations, a revision of this memorandum is now in process and may be expected at an early date.]

The methods used by the Joint Target Group in determining the most effective combination of weapons to use against a target have been considerably simplified as a result of an analysis of attacks made to date by American Air Forces in the European and Far Eastern Theaters.

In an attempt to explain these methods so that they can be applied by technically qualified officers in field commands, the following papers have been prepared:

1. A final Part (usually Part V) of the General Analysis for each industry category entitled "Physical Vulnerability and Weapon Recommendations." Each such Part provides guidance in the selection of primary objectives, the best size, type and fuzing of HE, and the best IB; and in determining the ground densities of HE and/or IB necessary to destroy targets in the system.

2. A full technical explanation of the methods used in selecting weapons and in calculating ground densities and force requirements issued as Joint Target Group Weapons Memorandum No. 8 (M-8).

In using the technical papers referred to above for selecting weapons against a particular target, an analysis must be made of the functions of the buildings in the target (for choosing primary objectives) and of their construction. Functional and building construction analyses are made by the Photographic Division, AC/AS Intelligence, on important targets, and are summarized in Target Information Sheets (P3 or P4, P5, and paragraph on "Construction and Vulnerability"). In the absence of Target Information Sheets, functional and building construction analyses can be made by qualified photo-interpreters in field commands.

In addition to providing this type of general guidance to field commands in weapon selection, the Joint Target Group will continue to make recommendations for the attack of selected targets. These recommendations will be issued as Weapon Recommendation Sheets (WR1 and WR2) in connection with the Target Information Sheets. WR Sheets are designed to give a quick answer where a quick answer is necessary and acceptable. WR1 makes recommendations for high and medium altitude attack (primarily for heavy and very heavy bombers); WR2 for low altitude attack (primarily for carrier-based or tactical aircraft).

The *purpose of this memorandum* is to explain the use of the recommendations in WR Sheets for a specific industrial plant, and to provide a non-mathematical description of the vulnerability analysis on which the recommendations are based. Sample WR1 and WR2 Sheets, with examples of their use, are attached as Appendices.

B. VULNERABILITY ANALYSIS

In the preparation of WR Sheets, the analysis of a target for vulnerability to HE and IB weapons has two primary purposes:

1. It establishes the order of effectiveness of the principal weapons against the important elements of the target;

2. It provides data to be used in recommending best combinations of HE and IB, and in estimating force requirements for desired levels of damage.

Because of marked differences in layout, construction and occupancy between industrial targets, even within the same industry, an individual analysis of each target must be made to determine the most effective weapons and the required densities. The basic data used in these analyses are of two general types:

1. Intelligence on the target (this includes reconnaissance photos and available ground information, both of which are used in the structural and functional analysis of the target);

2. Experience data on the effectiveness of the weapons against targets of similar construction. These come partly from measured effects of comparable enemy weapons on Allied installations; partly from effects observed on post-attack cover or in ground surveys of American or Allied weapons on enemy targets; and partly from supporting experimental evidence.

1. Structural Analysis

Photo interpreters analyze each building of the target for all factors which will affect the vulnerability of the building to HE and IB or both. These factors are listed on "Building Construction Analysis" sheets, which, together with the Functional Analysis sheets, are a guide for the analysts who determine the effectiveness of HE and IB weapons against the target.

The important structural factors include type, size, and height of buildings, length of spans, and material used in walls, roofs and floors. Data is provided which permits the determination of the number, size and configuration of "fire divisions" in the target—a fire division being a building unit within which a fire is likely to be confined by air gaps or walls.

The probable contents of buildings are determined, in the absence of specific information, from the analysis of building functions and a knowledge of typical practices in the industry. The analysis of building structures and contents is continuously checked with the judgment of architects and engineers, and against target intelligence derived from many sources. Intelligence sources include P/W interrogations, captured documents, pre-war publications, and fire insurance company records.

2. Vulnerability to HE Weapons

By analysis of the weapon effectiveness data described above, it has been possible to classify major

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structural types according to their probable vulnerability to HE weapons, and to predict the *average* areas of damage to be achieved on each structural type by the available bombs and fuzings. The predicted areas of damage are calculated to reflect damage from "near-misses" as well as from direct hits. The vulnerability classifications are based solely on vulnerability to HE bombs, and the structures within a single class may include a number of architectural types. The classifications are, of course, checked continuously against new data from the bombing of Japanese targets, and revisions will be made as often as necessary.

The following are the classifications in order of increasing vulnerability to HE:

V–1: Multi-story, earthquake proof structures.
V–2: Buildings housing traveling cranes.
V–3: Ordinary steel or reinforced concrete framed, multi-story buildings.
V–3A: Multi-story buildings with load-bearing walls.
V–4: Includes most of the ordinary single story industrial building types.
V–4A: Single story, wide span, heavily braced industrial structures, generally of assembly type.
V–5: Structures susceptible to large area spreading collapse if a vital structural member is destroyed. Example: Large, long-span, arched hangars.

A full description of the architectural types included in each classification, and of the average areas of damage to each by different HE bombs, is given in M-8.

Special structural units such as coke ovens and engine test cells are not included in these major groupings and are treated as special cases, requiring more detailed application of data.

The Target Information Sheets for each target carry a listing of the primary and secondary buildings with their appropriate vulnerability classifications, together with a summary classification for the whole target.

3. Vulnerability to IB

Assessment of the vulnerability of the buildings of a target to fire begins with a classification of each building according to its combustibility. The combustibility classifications are: C (combustible buildings); N (non-combustible structures, which may be damaged structurally by fire in the contents); and R (fire resistant structures).

An assessment is also made of the relative vulnerability of the contents of the buildings to incendiaries. The vulnerability of each building to fire damage and the susceptibility of its contents to incendiaries are indicated on a Fire Susceptibility Plan (P5) for the target.

C. WR1 SHEETS – HIGH AND MEDIUM ALTITUDE ATTACK

The WR1 sheet has three functions: (1) the recommendation of most effective weapons; (2) the recommendation of best combinations of HE and IB; and (3) the estimation of force requirements for desired levels of damage to the target.

1. Weapon and Fuze Selection

On the basis of their relative effectiveness against the principal elements of the target, bombs are listed in WR1 Sheets as "preferred," "alternative," or "not recommended." "Preferred" weapons are those which are expected to do the most serious damage to the target, compared with equal weights of other available weapons. "Alternative" choices are those which are somewhat less effective than those recommended, but which may be employed if availability or stowage dictates, with reasonable expectation of damage. Classification as "not recommended" indicates that the weapons so designated are not suitable for use against this target. An IB which is "not recommended" is believed to be less effective than an equal weight of HE.

The proper fuzing for the various "preferred" or "alternative" HE weapons is given in WR sheets. The fuzing which is recommended depends basically on the vulnerability classifications of the primary or primary and secondary buildings in the plant. The selected fuzing is that which will be most effective in damaging the greatest portion of the floor area of the principal buildings. (For example, if 80 percent of the total floor area of the principal buildings is V-4, then 0.01 N/ND T fuzing will be selected.)

M-8 gives a full technical explanation of the preferred fuzings against the various vulnerability classifications. These are as follows:

V–1: 0.1 N/0.025 T
V–2: 0.1 N/0.1 T
V–3: 0.1 N/0.025 T
V–3A: 0.1 N/0.025 T
V–4: 0.01 N/ND T
V–4A: 0.01 N/ND T
V–5: 0.01 N/ND T

2. The Loading Table

Recommended combinations of HE and IB, and estimated force requirements for desired levels of damage, are presented in WR1 Sheets in the form of a Loading Table.

a. *What the Loading Table Shows.* The best combination of HE and IB to dispatch against a target depends upon three factors:

(1) The relative effectiveness of the HE and IB weapons against the target.
(2) The total tonnage to be dispatched.
(3) The expected accuracy of the bombing.

The effectiveness of the HE and IB against the target (factor 1) is calculated in the Joint Target Group by the methods explained in sections C.3 and C.4 below. The tonnage to be dispatched, of course, is determined by the operational command; and the expected accuracy of the bombing to be expected in any operation can also best be estimated by the air force making the attack.

It is therefore necessary in the WR1 Sheets, to present separate recommendations covering a range of different tonnages dispatched, and several different assumptions as to bombing accuracy. The command using the table, knowing the force to be dispatched and estimating the probable accuracy of the bombing, can read the most effective combination of HE and IB.

In the Loading Table, the same box which shows the most effective combination of HE and IB also shows the approximate level of serious damage to the target which can be expected if the recommended load is dispatched and if the accuracy of bombing is as anticipated. Serious damage is defined as *structural* damage to buildings or severe fire damage to their contents. It does not include superficial or roof damage.

The aiming point indicated in WR1 is recommended as giving the best expectancy for maximum damage to the important buildings of the target, and has been used in all calculations. The aiming point used in an attack should be as near the one recommended as is operationally feasible.

b. Use of the Loading Table for Initial Attack. A sample Loading Table, with examples of use, is attached as Appendix I.

Each line on the table represents a different total load dispatched. These loads are shown in the left-hand column. They are measured in tons of actual (not nominal) weight of bombs.

Each column of the table represents a different expected efficiency and accuracy of bombing, as measured by the percentage of bombs *dispatched* expected to fall within 1,000 feet of the aiming point. This figure is calculated by multiplying the percentage of planes dispatched expected to bomb the target (i.e., after subtracting abortives and planes bombing with gross errors) by the percentage of bombs aimed at the target which fall within 1,000 feet of the aiming point. Since statistics of bombing accuracy are carefully kept in all air forces, the average percent of bombs aimed at a target which fall within 1,000 feet of an aiming point in successful attacks will be known; this value happens, as a matter of fact, to lie between 10% and 40% for most heavy bomber forces. On a particular occasion, knowing all the circumstances of weather, opposition and local factors, the command may wish to estimate some figure higher or lower than the average. In making this estimate, the possibility of an unsuccessful attack should be ignored. The percentage figures for which load recommendations are made at present are 10%, 15%, 20%, and 30%, and there is no necessity for accuracy to be estimated with greater precision.

The Loading Table may be used in two ways:

1. Given the total tonnage to be dispatched, to determine the best division of this load between the best HE and IB weapons, and the expected level of damage to the target:

a. Estimate the percent of bombs dispatched expected to fall within 1,000 feet of the aiming point by multiplying:

(1) The percent of planes dispatched expected to bomb the target, by

(2) The percent of bombs aimed at the target expected to fall within 1,000 feet of the aiming point.

Round off the product to the nearest percentage figure at the top of the table.

b. Read in the appropriate column showing bombing accuracy and opposite the total tonnage to be dispatched, the recommended HE-IB loading and (under F) the expected percent of serious damage to the target.

2. Given the level of damage to be achieved on the target, to determine the force required and the best combination of HE and IB.

a. Estimate bombing accuracy as in 1. a. above.

b. In the appropriate accuracy column find the desired percent level of serious damage (under F).

c. Read, along side the percent level of damage, the approximate tonnages of HE and IB respectively to be dispatched to cause this level of damage.

Sample calculations for both these methods of using the Loading Table are included with the Loading Table attached to this paper as Appendix I.

Stowage factors will usually make it impossible to divide the load between HE and IB in exactly the proportions indicated. Deviations up to 20% will not materially reduce the expected damage.

c. *Use of the Loading Table for Reattack.* The Loading Table has been prepared from an analysis of the target before attack. If the important buildings of the target have suffered only slight damage in an early attack, the Table will still be suitable for determining the best loading. However, after substantial damage to the important buildings has been caused, a new analysis of the target should be made and a new Loading Table prepared.

If the target has suffered considerable damage in earlier attacks and no new Loading Table is available, the following general rules can be applied:

1. If previous attacks have destroyed most of the combustible buildings (or buildings with highly combustible contents) on the site as shown in the Fire Susceptibility Plan (ref.-P5), loads carried on subsequent attacks should consist wholly of the recommended HE weapon.

2. If the proportion of combustible buildings remains about the same as in the virgin target (when, for instance, the bomb pattern has covered only a part of the site), the original Loading Table may still be used to determine the best mixture of HE and IB for a subsequent attack.

3. If it has not been possible to assess damage in the earlier attack, the Loading Table should be used to calculate the cumulative load. For example (refer to sample WR1 Sheet, Appendix I), if 200 tons have previously been dispatched, and 200 tons additional are to be dispatched in the second attack, with an estimated accuracy of 15%, the sample Loading Table shows that the cumulative load (400 tons) should be divided 270–IB and 130–HE. If 175–IB and 25–HE were dispatched in the first attack, 95–IB and 105–HE remain to be dispatched in the second attack. In any case, the weight of HE dispatched on reattack should never be less than the minimum weight shown for an estimated bombing accuracy.

3. HE Effectiveness Calculations in WR1

In the preparation of recommendations for high level attacks, it is necessary to consider the target as a whole. To determine the most effective bomb against a particular target, the HE analyst calculates the per-

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centage of the primary and secondary objectives in the target falling in each vulnerability classification (as shown by the structural analysis). An average area of effectiveness is then computed for each bomb against primary and secondary objectives as a whole, on the basis of its predicted effectiveness against each of the vulnerability groups comprising them. A comparison of the probable areas of effectiveness of each bomb against all primary and secondary objectives, in terms of thousands of square feet per actual ton of bombs, determines the bomb or bombs to be recommended.

Using the predicted average area of effectiveness of the "preferred" bomb or bombs against the whole target, similarly estimated, it is then possible to compute the probable fraction of the target seriously damaged for each of a series of bomb densities dropped on the target.

4. IB Effectiveness Calculations in WR1

The buildings of the target are grouped into three classes of approximately equal fire vulnerability (C, N, R) as indicated by the structural analysis. If it develops that a sufficient fraction (usually 25% or more) of the target as a whole can be damaged by fire, the use of incendiaries is recommended. If incendiaries are to be used, a further analysis of the target is made to determine the preferred incendiary bomb. An average area of effectiveness is computed for each bomb suitable for use against the target as a whole, taking various factors into consideration. In selecting the preferred bomb, two factors are of primary importance, the average size of fire divisions and the character of the roofs to be penetrated. Small clustered incendiaries (M50, M69, and M74) are suitable against fire divisions of all sizes and are the only suitable incendiaries against small fire divisions. The M47 is suitable against medium or large sized fire divisions, and the M76 only against large fire divisions. The M50, M69, and M74 are suitable for penetration of light roofs and concrete roofs of very limited strength or thickness. The M47 is suitable for penetration of 5″ reinforced concrete roofs and the M76 for penetration of heavier ones.

The expected fraction of damage by fire to the whole target is then calculated for various ground densities, using the average area of effectiveness of the preferred incendiary bomb.

5. Best HE-IB Combinations

While for both HE and IB, the percentage of damage to the target increases with the density of bombs, the way in which it increases is markedly different in the two cases. In the case of HE, damage increases almost proportionately with the number of bombs on the target until it reaches a fairly high level—to cause40% damage requires only a little more than twice as many bombs as to cause 20% damage. But at high levels of damage — beyond 50% or 60% — damage increases less and less rapidly because bombs begin to fall upon buildings already destroyed by other bombs.

In the case of IB, on the other hand, a relatively low density of an effective bomb is capable of destroying almost the whole of that part of the target which will burn, and additional bombs will add little or nothing to this damage.

The efficiency of either HE or IB is measured by the additional damage which an additional tonnage of bombs delivered on the target will cause. Where the target is at all vulnerable to IB, the IB is much more efficient in this sense for low densities—i. e., a given tonnage will cause much more damage. This will be true until the point is reached at which most of the combustible part of the target has been destroyed. Beyond that point HE is more efficient in causing additional damage than IB. There is thus a maximum efficient (or optimum) density for the IB weapon, but there is no such optimum for HE short of 100% destruction of the target. In a small attack the advantage therefore lies with IB, while in heavier attacks the advantage shifts to HE (assuming that the target is not more than 30–60% combustible, as is usually the case with industrial targets). Of course, if practically the whole target can be burned, only IB need be used, because combustible buildings and contents can always be destroyed with lesser tonnages of IB than HE.

One addition to these conclusions is necessary. It is believed that it is almost always desirable to use a small amount of HE (as an auxiliary weapon to hamper and discourage firefighting) with IB. This HE is recommended not because it is more efficient in causing damage, but because it permits the IB to operate with maximum effectiveness.

D. WR2 SHEETS – LOW LEVEL ATTACKS

Low altitude attacks, as carried out by dive, glide or fighter bombers, whether land based or from carriers, are made with much greater accuracy than are those from higher levels. Consequently, instead of attempting to drop a certain density of bombs over the whole target area, it is possible to select and attack individual buildings of primary importance.

In preparing the weapon recommendations, therefore, each building is considered as a separate target.

1. Number of Hits Tables

Force requirements are presented in terms of the number of hits required on each building. No attempt is made to compute the tonnage to be dispatched, since this can readily be calculated by operational planners from a knowledge of current bombing accuracy.

The choice of weapons then depends on the relative numbers of hits required with the various bombs and upon the stowage capabilities of the available aircraft. That weapon should be chosen which will cause the damage with the minimum number of sorties, and this is best decided by the operating command.

a. Table I (HE). In this table the primary and secondary buildings are listed in the order of their importance to production. For each building there is given the number of hits with each appropriate weapon required to achieve 50% serious damage. In addition correct fuzings are listed. To obtain the number of hits required for 30% and 70% serious damage the number of hits should be multiplied by 0.5 and 1.7, respectively.

b. Table II (IB). In this table those primary and secondary buildings suitable for IB attack are listed, but not necessarily in the order of their importance to production. For each building there is given the number of hits with quick-opening clusters of incendiaries of M50 and M69 bombs, with single incendiary bombs (M47 and M76), and with the 58 gallon and 150 gallon sizes of fire bombs (belly tanks filled with napalm gel) required for 50% serious damage. "50% damage" here means a 50% probability of destroying any one fire division. When the building is a single fire division, this means a 50% probability of destroying the building. When the building includes a number of fire divisions, this means that it is to be expected that 50% of the building will be destroyed. When the building sizes and groupings are such that one incendiary cluster will cover more than one building, the appropriate buildings are grouped together in the "number of hits" column for clustered bombs. The recommendations of the table give a load which is alternative to the number of hits listed in the HE table. Either HE or IB will do the job, and the choice of which to use depends as above upon the relative numbers of hits required and the available stowage. To obtain the requirements for 30% and 70% serious damage the conversion factors listed for the HE table should be used.

2. Special Cases

In special circumstances (such as attacks on arsenals) there are no buildings of outstanding importance, virtually all buildings being primaries or secondaries. In these cases a low altitude attack should be directed against the whole target and the "number of hits" table is not applicable. In these special cases a suitable modification of the WR2 Sheet will be prepared with a full discussion of the factors involved.

3. Use of WR2 for Reattack

Where a low level attack is made on a previously damaged target, on which no new analysis is available, Tables I and II will still be a guide to the order of importance and vulnerability of those buildings which are either undamaged or only slightly damaged.

Refer to Appendix II for a sample WR2.

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JOINT TARGET GROUP, WASHINGTON, D. C.

WEAPON RECOMMENDATIONS SHEET

SHEET . . **90:17-791—WR1**
DATE. . . . **26 March 1945**
PAGE **1**

TARGET **90:17-791**
OBJ. FOLDER **90:17**
OBJ. AREA **90:17**
CATEGORY **End Prdt. Ind.—AIRCRAFT**

LAT. . . . . **35° 43′ N**
LONG. . . . . **139° 22′ E**
ALT. . . . . **360 feet**

SHOWA AIRCRAFT

TACHIKAWA JAPAN

HIGH AND MEDIUM ALTITUDE ATTACK

(See also Target Information Sheet 90:17-791—TI and associated target illustrations)

AIMING POINT

For maximum damage to primary objectives the aiming point should be building 26. (Illustration 90:17-791—P3, P5.)

WEAPON AND FUZING

	HE	Fuze	IB
Preferred. . .	1000-lb GP. . .	.01 N/ND T. . .	ANM50 4-lb (in aimable clusters).
Alternative. .	500-lb GP. . . .	.01 N/ND T. . .	AN-M69 6-lb (in aimable cluster).
	2000-lb GP. . .	.01 N/ND T. . .	AN-M47 70-lb. AN-M76 500-lb.

Note recommended: Smaller GP bombs; SAP or AP bombs; Depth bombs.

Notes: (a) Use 0.1 N fuzes, if 0.01 N fuzes are not available.
(b) The 500-lb and 2000-lb GP bombs are respectively 95 and 90 percent as effective as the 1000-lb GP bomb.

LOADING TABLE FOR INITIAL ATTACK

Loading Table for Preferred Combination of Bombs [1]

(This table is prepared for an initial attack on this target. For its applictaion to later attacks see JTG Memorandum No. 3(M-3))

Tons (actual) Dispatched	Percent of bombs dispatched falling within 1000 feet of aiming point											
	10%			15%			20%			30%		
	TONS		F[2] %	TONS		F[2] %	TONS		F[2] %	TONS		F[2] %
	HE	IB		HE	IB		HE	IB		HE	IB	
50. .	. . . . .	. . . . .	. . . .	25	25	15	20	30	20	10	40	30
100.	35	65	20	25	75	30	20	80	35	10	90	40
200.	35	165	35	25	175	45	20	180	45	50	150	50
400.	35	365	45	130	270	50	180	220	55	250	150	65
800.	380	420	55	530	270	65	. . . . .	. . . . .	. . . .	. . . . .	. . . . .	. . .
1000	580	420	60	. . . . .	. . . . .	. . . .	. . . . .	. . . . .	. . . .	. . . . .	. . . . .	. . .

[1] If the alternative bombs are used, the distribution of the load between HE and IB should be the same. The expected percent of damage will, of course, be lower.

[2] Expected percent of serious damage to the whole target.

EXAMPLES ILLUSTRATING USE OF LOADING TABLE IN WR1

1. *To find best HE-IB combination and probable percent of serious damage for a given force.*

Given:

a. Mission of 133 planes with total load of 400 tons.

b. Percent of planes expected to bomb target—70% (i. e., 30% expected abortives or bombing with gross errors).

c. Percent of bombs aimed at target expected to fall within 1,000 feet of aiming point—30%.

d. Individual A/C load=3 tons.

Solution:

a. 70%×30%=21%, which is rounded off to the nearest percentage figure at top of Loading Table,=20%. This is the percent of bombs dispatched expected to fall within 1,000 feet of aiming point.

b. Opposite 400 tons in 20% column find loading:
HE—180 tons.
IB—220 tons.

c. In the same box of Loading Table, under F, read probable level of damage to target=55%.

d. If each plane is to carry a single type bomb:
HE—180 tons=(approximately) 60 planes.
IB—220 tons=(approximately) 73 planes.

e. If eleven formations of 12 planes are to be used, each formation carrying a single type bomb, five should carry HE and six IB.

2. *To find force required to achieve a recommended level of serious damage.*

Given:

a. Recommended level of damage=40%.

b. Expected bombing accuracy as in Example 1.

c. Individual A/C load=3 tons.

Solution:

a. In 20% column find under F the percentage figures nearest to recommended level of damage=35% and 45%.

b. In same box of table interpolate required loading:
HE—20 tons.
IB—130 tons.

c. Total force required is 50 planes.

d. If 12 plane formations are used, each formation carrying a single type of bomb, four should be dispatched, one with HE and 3 with IB.

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JOINT TARGET GROUP, WASHINGTON, D. C. WEAPON RECOMMENDATIONS SHEET	SHEET . . 90:17-791—WR1 DATE. . . . 26 March 1945 PAGE 1
SHOWA AIRCRAFT	TARGET. . . . . . 90:17-791 OBJ. FOLDER . . . . . . 90:17 OBJ. AREA . . . . 90:17 CATEGORY End Prdt. Ind.—AIRCRAFT
TACHIKAWA **JAPAN**	LAT. . . . . 35° 43′ N LONG. . . . . 139° 22′ E ALT. . . . . 360 feet

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(See also Target Information Sheet 90:17-791—TI and associated target illustrations)

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	HE	IB		HE	IB		HE	IB		HE	IB	
50..	.....	.....	....	25	25	15	20	30	20	10	40	30
100.	35	65	20	25	75	30	20	80	35	10	90	40
200.	35	165	35	25	175	45	20	180	45	50	150	50
400.	35	365	45	130	270	50	180	220	55	250	150	65
800.	380	420	55	530	270	65	.....	.....	....	.....	.....	...
1000	580	420	60	.....	.....	....	.....	.....	....	.....	.....	...

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e. If eleven formations of 12 planes are to be used, each formation carrying a single type bomb, five should carry HE and six IB.

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Given:

a. Recommended level of damage=40%.

b. Expected bombing accuracy as in Example 1.

c. Individual A/C load=3 tons.

Solution:

a. In 20% column find under F the percentage figures nearest to recommended level of damage=35% and 45%.

b. In same box of table interpolate required loading:
HE—20 tons.
IB—130 tons.

c. Total force required is 50 planes.

d. If 12 plane formations are used, each formation carrying a single type of bomb, four should be dispatched, one with HE and 3 with IB.

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JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPON RECOMMENDATIONS SHEET

SHEET ..**90:17-791—WR1**
DATE....**26 March 1945**
PAGE **1**

SHOWA AIRCRAFT

TACHIKAWA **JAPAN**

TARGET......**90:17-791**
OBJ. FOLDER **90:17**
OBJ. AREA **90:17**
CATEGORY **End Prdt. Ind.—AIRCRAFT**

LAT...........**35° 43′ N**
LONG........**139° 22′ E**
ALT............**360 feet**

HIGH AND MEDIUM ALTITUDE ATTACK

(See also Target Information Sheet 90:17-791—TI and associated target illustrations)

AIMING POINT

For maximum damage to primary objectives the aiming point should be building 26. (Illustration 90:17-791—P3, P5.)

WEAPON AND FUZING

	HE	Fuze	IB
Preferred...	1000-lb GP...	.01 N/ND T...	ANM50 4-lb (in aimable clusters).
Alternative..	500-lb GP....	.01 N/ND T...	AN-M69 6-lb (in aimable cluster).
	2000-lb GP...	.01 N/ND T...	AN-M47 70-lb. AN-M76 500-lb.

Note recommended: Smaller GP bombs; SAP or AP bombs; Depth bombs.

Notes: (a) Use 0.1 N fuzes, if 0.01 N fuzes are not available.
(b) The 500-lb and 2000-lb GP bombs are respectively 95 and 90 percent as effective as the 1000-lb GP bomb.

LOADING TABLE FOR INITIAL ATTACK

Loading Table for Preferred Combination of Bombs [1]

(This table is prepared for an initial attack on this target. For its applictaion to later attacks see JTG Memorandum No. 3(M-3))

Tons (actual) Dispatched	Percent of bombs dispatched falling within 1000 feet of aiming point											
	10%			15%			20%			30%		
	TONS		F[2] %	TONS		F[2] %	TONS		F[2] %	TONS		F[2] %
	HE	IB		HE	IB		HE	IB		HE	IB	
50..	.....	.....	....	25	25	15	20	30	20	10	40	30
100.	35	65	20	25	75	30	20	80	35	10	90	40
200.	35	165	35	25	175	45	20	180	45	50	150	50
400.	35	365	45	130	270	50	180	220	55	250	150	65
800.	380	420	55	530	270	65	.....	.....	....	.....	.....	...
1000	580	420	60	.....	.....	....	.....	.....	....	.....	.....	...

[1]If the alternative bombs are used, the distribution of the load between HE and IB should be the same. The expected percent of damage will, of course, be lower.

[2]Expected percent of serious damage to the whole target.

EXAMPLES ILLUSTRATING USE OF LOADING TABLE IN WR1

1. *To find best HE-IB combination and probable percent of serious damage for a given force.*

Given:

a. Mission of 133 planes with total load of 400 tons.

b. Percent of planes expected to bomb target—70% (i. e., 30% expected abortives or bombing with gross errors).

c. Percent of bombs aimed at target expected to fall within 1,000 feet of aiming point—30%.

d. Individual A/C load=3 tons.

Solution:

a. 70%×30%=21%, which is rounded off to the nearest percentage figure at top of Loading Table,=20%. This is the percent of bombs dispatched expected to fall within 1,000 feet of aiming point.

b. Opposite 400 tons in 20% column find loading:
HE—180 tons.
IB—220 tons.

c. In the same box of Loading Table, under F, read probable level of damage to target=55%.

d. If each plane is to carry a single type bomb:
HE—180 tons=(approximately) 60 planes.
IB—220 tons=(approximately) 73 planes.

e. If eleven formations of 12 planes are to be used, each formation carrying a single type bomb, five should carry HE and six IB.

2. *To find force required to achieve a recommended level of serious damage.*

Given:

a. Recommended level of damage=40%.

b. Expected bombing accuracy as in Example 1.

c. Individual A/C load=3 tons.

Solution:

a. In 20% column find under F the percentage figures nearest to recommended level of damage=35% and 45%.

b. In same box of table interpolate required loading:
HE—20 tons.
IB—130 tons.

c. Total force required is 50 planes.

d. If 12 plane formations are used, each formation carrying a single type of bomb, four should be dispatched, one with HE and 3 with IB.

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JOINT TARGET GROUP, WASHINGTON, D. C.
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SHEET . . 90:17-791—WR2
DATE. . . . 26 March 1945
PAGE 1

TARGET 90:17-791
OBJ. FOLDER 90:17
OBJ. AREA 90:17
CATEGORY End Prdt. Ind.—AIRCRAFT

LAT. . . . . 35° 43′ N
LONG. . . . . 139° 22′ E
ALT. . . . . 360 feet

SHOWA AIRCRAFT

TACHIKAWA JAPAN

LOW ALTITUDE ATTACK

(See also Target Information Sheet 90:17-791—TI and associated target illustrations)

TYPE OF ATTACK

This sheet applies primarily to an attack by carrier based aircraft, fighter bombers, or other similar aircraft which carry out dive, glide, low level, or minimum altitude attacks.

BUILDINGS CONSIDERED

Data are given below for attack on primary and secondary buildings only (see Ill. 90:17-791—P3, P5). Other buildings are of insufficient importance to merit specific attack.

WEAPONS AND FUZING

A pure HE attack (no incendiaries) may be launched against the buildings specified in Table I; a pure IB attack (no HE) may be launched against the buildings specified in Table II. The choice of a particular HE or IB weapon for attack on a given building can be made by considering both the number of hits on that building required for the various bombs (see the tables below) and the stowage capabilities of the aircraft to be used. The proper fuzings for the HE weapons to be used against the individual buildings are given in Table I below, with the exception that for minimum altitude attacks a 4-5 sec. delay is required for safety to the aircraft. The use of SAP, AP, Smaller GP, or Depth bombs is not recommended for this target.

NUMBER OF HITS

Number of Hits Required to Achieve 50% Damage to Individual Important Buildings[1]

TABLE I (HE)

Buildings in order of importance to production (Ill. No. 90:17-791 P3, P5)	Number of Hits			Fuzing[2]
	500-lb GP	1000-lb GP	2000-lb GP	
26......................	44	22	12	.01 N/ND T
17......................	22	11	6	.01 N/ND T
27......................	17	8	5	.01 N/ND T
21......................	13	7	4	.01 N/ND T
18......................	16	8	4	.01 N/ND T
38......................	6	3	2	.01 N/ND T
40......................	8	4	2	.01 N/ND T
39......................	8	4	2	.01 N/ND T

TABLE II (IB)

Buildings (Ill. No. 90:17-791 P5)	Number of Hits							
	Clusters				Individual Bombs		Fire Bombs	
	M-50		M-69					
	M-6	M-7	M-12	M-13	M-47	M-76	58 gal.	150 gal.
38..........	7	2	5	1	5	2	1	1

[1]To obtain the number of hits required to achieve 30% damage to individual important buildings, multiply the appropriate entry in the preceding tables fo 0.5; for 70% damage, multiply by 1.7.

[2]Use 0.1 N fuzes if 0.01 N fuzes are not available.

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JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET.............M-4
DATE.....21 June 1945
PAGE...............1

J.T.G. No. 4 – BOMB DATA SHEET No. 1
Cluster, Aimable, Incendiary Bomb, 500-lb., AN-M17A1

1. Cluster, Aimable, 500-lb., M-17A1

Total weight: 460 lbs. (approx.).
Overall length: 59.25 inches.
Diameter: 14.375 inches.
Weight of cluster adapter (M10A1) and tail: 70 lbs.
Bombing table: 500–J–3
500–J–4
Number of bombs: 88 AN-M50A2
22 AN-M50XA3

Total 110
Weight of bombs: 390 pounds.
Weight of fuel: 220 pounds.
Total heat liberated: 1,450,000 Btu.

2. Fuze, Nose, Mechanical Time, T39-E1 (M-128) and (T55)

Fuze: T39-E1 or T55, Nose, Mechanical, clock actuated time delay (5 to 92 secs. after release from plane). Clock and arming vane freed simultaneously by the withdrawal of the arming wire. The fuze is armed in the usual manner by the revolving of the vanes in from 2 to 3 seconds (200 mph). The firing pin is then held solely by the trip mechanism of the clock work. At the end of the time period set on the fuze the firing pin is released and the fuze functions.

Booster: Tetryl; Primacord: Extends length of cluster; on detonation, bursts cluster holding straps, releasing individual bombs.

3. Ballistic Data

Striking velocity of unopened cluster from 25,000 ft; 960 ft/sec (approx.). Recommended altitude for cluster opening: 13,500 ft when dropped from above 20,000 ft; 8000 ft when dropped from 10,000 to 20,000 ft; 5000 ft when below 10,000 ft. Striking velocity of individual bombs, AN-M50A2 and AN-M50XA3, for altitudes of cluster opening recommended: 425-475 ft/sec. For mixed loads of HE and IB in the same plane, the combination with ballistics most suitable for aiming is the M17A1 and AN-M30, 100-lb GP bomb. At releases of 25,000 ft, plane air speed of 250 mph., cluster opening at 13,500 ft, the M17A1 will trail the M30 by approximately 36 mils. Under the same flight and dropping conditions but with the altitude of cluster opening at 8000 ft or 5000 ft, the trail difference will be approximately 16 or 10 mils respectively.

4. Plane Loadings

	B-17 or B-24 (max.)	B-29 or B-32 (max.)
No. of clusters/plane	12	40
Total load, lbs/plane	5500	18400
Weight of bombs/plane	4680	15600
Incendiary fuel/plane	2640	8800
Bombs/plane	1320	4400
Bombs/group (9 planes)	11880	49600
Bombs/group (12 planes)	15840	52800

5. Bomb Patterns

Individual cluster pattern (cluster opening at 5000 ft): 150 x 180 yds. Bomb Pattern/group (release altitude: 25,000 ft; cluster opening at 5000 ft).

12 B-17's	9–12 B-29's
1700 x 1700 ft.	2500 x 2400 ft.
2,890,000 sq. ft.	6,000,000 sq. ft.
321,000 sq. yds.	667,000 sq. yds.
66 acres	137 acres
.10 sq. miles	.22 sq. miles

6. Ground Densities

	Groups of: 12 B-17's	12 B-29's
Sq. yds./bomb	20.2	12.6
Actual tons of bombs/acre	.43	.68
Actual tons of bombs/sq. mile	271	425

7. Bomb, Incendiary, 4-lb., AN-M50A2 and AN-M50XA3

Actual weight (both types): 3 lbs. 9 oz.
Length: 21-11/32 inches.
Diameter (distance across flats): 1-11/16 in.
Weight of magnesium: 1.1 lbs.
Weight of thermate: 10 oz.
Heat liberated: 13,100 Btu.
Burning time (thermate) 1½-2 minutes.
Burning temperature: 4300° F.
Burning time (magnesium case) 5-7 min @ 2400° F.
Fragments produced by AN-M50XA3: about 250.
Certain casualty will result within 50 ft M50XA3 bombs.
Danger exists within 400 yds.
Type A—long delay (2-10 mins.) 36 grams tetryl pellets.
Type B—short delay (60-70 secs.) 40 grams tetryl pellets.

8. Penetration

Striking velocity, M50A2 and M50XA3: 475 ft/sec (approx.), cluster released at 25,000 ft, opening at 5000 ft. Will penetrate light to medium-heavy roof construction: wood, tile, slate, 4-inch reinforced concrete.

9. Performance, Probability, M-17A1 Cluster Containing AN-M50A2 and AN-M50XA3 Bombs

Malfunctions	Percentage
Clusters not opening	5
Defective fuzes, first fire mixtures	6
Flatlanders and over 20° yaw	30*

Probability of bomb functioning as expected:
(.95) (.94) (.70) = .625**

*Experimental data, trial runs, North Africa beaches:
No. of clusters dropped: 6
Ave. height release: 20,100 ft.
Ave. cluster opening: 4800 ft.
% of bombs found: 97.6
% of bombs with angle to the vertical above 20°: 36.7
% Flatlanders: 11.2

**This factor, a characteristic of the bomb; does not consider the type of target.

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10. Remarks and Recommendations as to Uses of the M-17 and M-17A1 Cluster

a. The only differences between the M-17 and M-17A1 clusters are slight structural changes; the body of the A1 cluster is olive drab, that of the M17, light gray.

b. The M-17A1 cluster used by the RAF is identical except that the nose is tapped to take the British Fuze No. 42 Mk. IV, and adapter booster.

c. There is a tendency for excessive yaw of individual bombs if the M17A1 cluster is opened below the recommended altitude. Because of the maleffect of this yaw on bomb functioning, the altitudes recommended for cluster opening have been set to allow the maximum time for bombs to stabilize in flight without lowering the aimability of the cluster.

d. In level bombing the recommended minimum altitude of operation with the M-17 is 3000 ft (opening at 1000 ft). Inability to set the T39 or T55 fuze at less than 5 secs limits the utility of the cluster at lower altitudes and for dive bombing, as the action of the cluster striking as a unit is not efficient.

e. Only the long delay (Type A) "X" bombs are being included in clusters at present. Even though the Type A bomb is designated as 2—10 minute delay, tests show that 30% of these bombs detonate in less than two minutes and only 4% are delayed longer than 5 minutes after impact. The Type A bomb therefore provides both short and long delay.

f. The effectiveness of the M-50 as an incendiary depends on its landing in a favorable position, i.e., in a location where easily ignitable material is available for propagation of the flame. Generally speaking, this weapon will be used against targets where (1) the vulnerability to fire is high, (2) there is a large number of small fire divisions, and (3) other types of incendiaries are ruled out by factors of penetration, low plane loading efficiency, and low probability of scoring hits.

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SHEET M-6
DATE . . . . 21 June 1945
PAGE 1

J.T.G. No. 6 – BOMB DATA SHEET No. 2A
Cluster, Aimable, Incendiary Bomb, 500-lb., M-19 (E46)

1. Cluster, Aimable, 500-lb., M-19 (E46)

Total Weight: 425 lbs.
Overall Length: 59.5 inches.
Diameter: 14.75 inches.
Cluster Adapter: E23.
Bombing Table: 500-Q-1.
No. of Bombs: 38 AN-M69.
Weight of Bombs: 236 lbs.
Weight of Fuel: 99 lbs.
Total Heat Liberated: 1,672,000 Btu.

2. Fuze, Tail, Mechanical Time, M-152 (T53E1)

Fuze Functioning: Aerial burst, 5 to 92 seconds after release from plane. Clock and arming vane freed simultaneously by the withdrawal of the arming wire. The fuze is armed by the revolving of the vanes in from 2 to 3 seconds (200 mph). The firing pin, then held solely by the trip mechanism of the clock work, is released at the end of the set time period, and the fuze functions.

Fuzing of the M19 (E46): With the E23 cluster adapter, *two* (2) M-152 tail fuzes are used. One acts with a 31-inch length of primacord which is channeled to the cluster tail retaining cup. On fuze functioning, the retaining cup is blown off, the tail drags in the wind stream and on separating from the cluster withdraws the cluster buckle release wires, thereby mechanically releasing the individual M69 bombs. The second fuze, insurance against failure of the first, is set to function 2 seconds after the first. This acts with a 60-inch length of primacord extending the entire length of the cluster, detonation of which explodes the holding straps and opens the cluster. A lower percentage of malfunctioning bombs due to air bursts is believed to result from the mechanical opening of the cluster.

3. Ballistic Data

Striking velocity of unopened cluster from 25,000 ft.: 900 ft/sec (approx.).

Recommended altitude for cluster opening:
2500 ft. when dropped from below 10,000 ft.
5000 ft. when dropped from above 10,000 ft.

Striking velocity of the individual bombs, AN-M69, when cluster is dropped from 25,000 ft., opening at 5,000 ft.: 200-225 ft/sec.

The ballistics of the M19 (E46) make it unsuitable for dropping with HE bombs from the same plane. The M19 will trail the AN-M30, 100-lb. GP bomb, by 64 mils when dropped from 25,000 ft., cluster opening at 5,000 ft., plane air speed 250 mph.

4. Plane Loadings

	B-17 or B-24 (max.)	B-29 or B-32 (max.)
No. of Clusters/plane	12	40
Total load, lbs/plane	4200	17000
Weight of bombs/plane	2832	9440
Incendiary fuel, lbs/plane	1190	3960
Bombs/plane	456	1520
Bombs/group (9 planes)	4104	13680
Bombs/group (12 planes)	5472	18240

5. Bomb Patterns

Individual cluster pattern (cluster opening at 5000 ft.): **120 x 150 yds.**

Bomb Pattern/group (release altitude: 20,000 ft., minimum intervalometer, cluster opening at 5000 ft.).

12 B-17's	9–12 B-29's
1700 x 1700 ft.	2500 x 2400 ft.
2,890,000 sq. ft.	6,000,000 sq. ft.
321,000 sq. yds.	667,000 sq. yds.
66 acres	137 acres
.10 sq. miles	.22 sq. miles

6. Ground Densities

	Groups of 12 B-17's	Groups of 12 B-29's
Sq. yds./bomb	58.7	36.5
Actual tons of bombs/acre	.26	.41
Actual tons of bombs/sq. mile	163	258

7. Bomb, Incendiary, 6-lb., AN-M69

Actual Weight: 6.2 pounds.
Length: 19.5 inches.
Diameter (across flats): 2⅞ inches.
Weight of Fuel (gelled gasoline): 2.6 lbs.
Heat Liberated: 44,000 Btu.
Burning Time: 4-7 minutes.
Length of Cloth Tail: 40 inches.
Delay Between Impact and Ignition: 3 seconds.
Normal Terminal Velocity: 250 ft/sec.
Burning Temperature: 1800° F.

8. Penetration

Striking velocity, M69: 225 ft/sec (approx.), cluster released at 25,000 ft., opening at 5000 ft. will penetrate light to medium roof construction: 1 inch wood sheathing covered with 2 layers asphalt felt; terra cotta tile, slate, 2 to 5 inch cinder concrete, 3 inch light concrete (not reinforced).

9. Performance, Probability, M-19 Cluster Containing AN-M69 Bombs

Malfunctions	Percentage	
Clusters not opening	4	
Air Bursts	2	*Probability of
Tails torn off	2	bomb functioning
Flatlanders	3	as expected: .86
Fuze Failures	2	(.96) (.98) (.98)
Nonejection, nonignition, mechanical failures.	2	(.97) (.98) (.98) = .86.

*This factor, a characteristic of the bomb; does not consider the type of target.

10. Remarks and Recommendations as to Uses of the M-19 Cluster

a. Approved but not yet in service are two modifications of the M69: (1) The M69X, similar to the M69, but containing slightly less fuel, and an explosive charge of tetryl. (2) The M69WP, similar to the X bomb, but containing a charge of white phosphorous in place of the tetryl. Both of these modifications, designed to hinder and drive away fire fighting personnel, will be included in varying quantities with M69's in the aimable cluster.

b. Because of its low striking velocity the M69 has heretofore been regarded as suitable only for attacks on residential areas. Intelligence gained from adequate aerial cover indicates that most industrial roofs in Japan are of light construction, and recent incendiary attacks have demonstrated the ability of the M69 to penetrate and set fire to typical Japanese plants. This characteristic of the M69 makes it a good choice for use in mixed IB-HE raids where the primary target is industrial and the secondary target, for bombing through clouds, is an urban area.

c. In level bombing the recommended minimum altitude of operation with the M19 is 3000 ft. (opening at 1000 ft.). Inability to set the M-152 fuze at less than 5 secs. limits the utility of the cluster at lower altitudes and for dive bombing, as the action of the cluster striking as a unit is not efficient.

d. To be effective a small incendiary must land in a favorable location. The tail ejection feature of the M69 greatly enhances the probability that the fuel will finally come to rest adjacent to easily ignitable material.

e. The M69 and M74 are comparable in fire raising properties. Data on the use of these weapons against actual Japanese areas are not sufficient to denote a choice between the two.

f. The M19 (E46) supersedes the M18 (E6R2), 500-lb. aimable cluster containing 38 AN-M69 bombs. Better streamlining, the use of two tail fuzes, and the mechanical opening feature are significant improvements of the M19. Ballistically it has a higher trail than the M17A1 and the E48 (cluster containing 38 M74 bombs), but can be dropped satisfactorily with the present bomb sight.

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SHEET.............M-7
DATE.....21 June 1945
PAGE................1

J.T.G. No. 7—BOMB DATA SHEET No. 3
Bomb, Incendiary, 100-lb., AN-M47A2

1. Bomb, Incendiary, 100-lb, AN-M47A2:

Actual weight: 70 pounds.
Length: 48.9 inches.
Diameter: 8 inches.
Thickness of case: 1/16 inch.
Total heat liberated: 670,000 Btu (approx.).
Burning time: 10 minutes (approx.).
Bombing table: 100–G–2.
Total volume of body: 7 gals.
Void left in filling: 10 percent.
Weight of filling: 40 pounds (approx.).
Composition of Napalm filling: 88.5 percent gasoline and kerosene; 11.5 percent aluminum soaps.

2. Fuze, Bomb Nose, Mechanical Impact, AN-M126A1:

Actual weight: 1.06 pounds.
Overall length: 3-1/16 inches.
Functioning: Instantaneous.
Arming time: 340 vane revolutions, 725 feet air travel; minimum altitude to arm: 100 feet (2.5 seconds), plane air speed 200 mph.

3. Burster, AN-M12 or AN-M13:

AN-M12—actual weight: 2.4 pounds.
Length: 37⅞ inches.
Diameter: 1⅛ inches.
Contains 450 grams of a 50/50 mixture of black powder and magnesium.
AN-M13—actual weight: 5 pounds (approx.).
Length: 38¼ inches.
Diameter: 1-3/16 inches.
Contains 57.5 grams of TNT and 0.82 grams of tetryl; is used with igniter AN-M9 (WP) containing 2.2 pounds WP, or with igniter AN-M9 (Na) containing 0.7 pounds sodium for water targets.

Neither of these bursters has proved wholly superior to the other for bomb functioning.

4. Ballistic Data:

Striking velocity from 25,000 feet: 760 ft./sec. (approx.).

In the case of mixed HE-IB loads in the same plane, the AN-M47A2 will trail the AN-M30, 100-pound GP bomb by approx. 42 mils when released together at 25,000 feet.

5. Plane Loadings:

	B-17 (max.)	B-24 (max.)	B-29 (max.)
Number of bombs/plane	42	52	184
Weight of bombs/plane	2,940	3,640	12,880
Incendiary fuel/plane	1,680	2,080	7,360
Bombs/group (9 planes)	378	468	1,656
Bombs/group (12 planes)	504	624	2,208

6. Bomb Patterns:

Bomb pattern/group (release altitude: 25,000 feet, minimum intervalometer setting:

12 B-17's	9–12 B-29's
1700 x 1700 feet	2500 x 2400 feet
2,890,000 square feet	6,000,000 square feet
321,000 square yards	667,000 square yards
66 acres	137 acres
0.10 square miles	0.22 square miles

7. Ground Densities:

	Groups of—	
	12 B-17's	12 B-29's
Square yards/bomb	637	302
Actual tons of bombs/acre	.27	.56
Actual tons of bombs/square mile	176	351

8. Penetration:

Striking velocity from 25,000 feet: 760 ft./sec. (approx.). Will penetrate 5 inches of reinforced concrete.

9. Performance, Probability, AN-M47A2:

Malfunctions:	Percent
Flatlanders	10
Fuze failures	2

Probability of bomb functioning as expected: (0.90) (0.98) = 0.88.[1]

10. Remarks and Recommendations as to Uses of the AN-M47A2:

a. On functioning on hard ground or concrete, burning fuel is scattered over a radius of 50 feet. On soft ground the fuel is confined to the crater.

b. Average burning time is 10 minutes; a few large globs of gel may burn for 20 minutes or longer.

c. Cooling of the bomb to 35° F. does not affect its functioning.

d. Used extensively by the Eighth Air Force over Germany, the M47A2 has proved effective against combustible industrial targets. Its initial area of influence is considerably larger than that for small (4-10 pounds) IB's. However, where industrial targets are composed of a large number of small fire divisions (as is usually the case), the M47A2 is not considered a good choice for an IB attack because the group pattern is sparse and not enough direct hits can be expected. Near misses are completely ineffective.

e. For use by the Navy, the M47A2 is not recommended because of low plane loading efficiency. For minimum altitude or dive bombing attacks where the target is small and the bombing accuracy good, the M76 or the fire bomb (jettisonable gasoline tank) are preferred. For medium level attacks and dive bombing on large dispersed targets, clustered small bombs are recommended.

[1] This factor a characteristic of the bomb; does not consider the type of target.

JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET M-8
DATE.....23 June 1945

J. T. G. No. 8
METHODS OF WEAPONS SELECTION AND ESTIMATION OF FORCE REQUIREMENTS FOR ATTACK OF INDUSTRIAL TARGETS

FOREWORD

This memorandum is designed to explain in detail the analytic methods for choosing weapons and estimating force requirements which are used by the Joint Target Group. It is written for the benefit of technically qualified readers and should permit such persons to carry out analyses in the field on a basis comparable with those published by the Joint Target Group, provided functional and structural analyses of the target are available. The nontechnical reader is referred to JTG M-3 for a nonmathematical discussion of many of the topics discussed below.

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WEAPONS MEMORANDUM

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DATE.....23 June 1945
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PART I. METHODS OF WEAPON SELECTION

The chief problems discussed in this section are:

What is the best weapon, or combination of weapons for use against a particular target?

What fuzings should be used in HE bombs?

What ground densities, or numbers of hits (as the case may be) are required to do various levels of damage?

A. JAPANESE CONSTRUCTION

1. General Notes

In modern Japanese industrial plants single-story light-framed construction is used predominantly for production buildings although multistory buildings are occasionally used for production of small parts or light machine work and frequently for administration purposes. Single-story construction is characterized by complex framing of built-up members in either steel or wood, commonly with roofs and walls of either corrugated asbestos or corrugated iron, the object being to keep the weight, especially in the roof, as low as possible. Roofs are usually of moderate to steep pitch and sawtooth roofs are very common, no attention being paid to having the lights face north. In older plants masonry walls may be found.

Important multistory buildings are usually of very massive steel or reinforced concrete frame construction. Floors and roofs of these buildings are designed as horizontal beams to transmit lateral (earthquake) forces to the walls and to certain interior partitions, which acting as vertical beams transmit these forces to the foundations. Because of this earthquake-resistant design, these buildings are characterized by flat reinforced concrete roofs, usually with parapets, and reinforced concrete floors. The usual minimum thickness of floors and roofs is about five inches. In a few plants an additional story has been added to such multistory buildings by building a lightweight roof over the building, the original roof serving as a floor for the new story. Such temporary roofs may be of either combustible or noncombustible construction.

Wood-framed or masonry construction is limited by law to 3 stories or 32 feet in height to the eaves, although these restrictions may have been eased during the war. Wood-framed construction is quite common, especially in barracks, storage and administration buildings. Masonry construction in Japan proper has been placed under so many restrictions, however, that it has been used very little in recent years and usually is encountered only in fairly old plants. Wall-bearing construction has been very little used since about 1923. Manchuria, however, is not a seismic region and masonry construction, both panel wall and wall-bearing, is widely used.

Damage suffered by Japanese industrial plants during incendiary attacks indicates that a predominance of noncombustible construction (i.e., steel-framed with roofs and walls of noncombustible materials) is found only in the production buildings of the more important industries such as aircraft and armament and in those industries which require overhead traveling cranes. In small industrial plants, particularly in nonpriority industries such as textile or foodstuff production, a predominance of combustible construction may be expected.

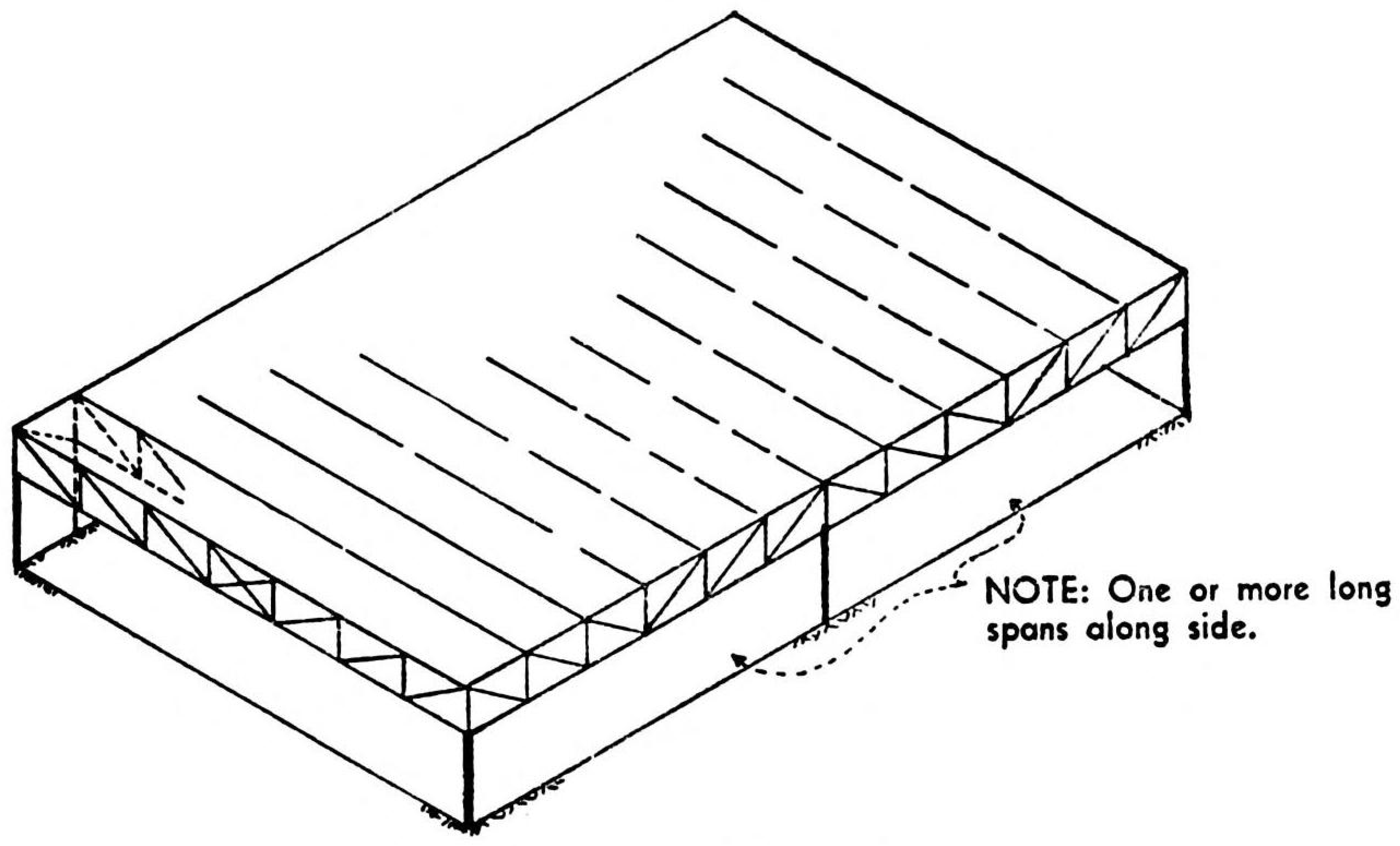
2. Structural Types

For purposes of determining the vulnerability of various buildings to damage from HE it is desirable to classify buildings according to their structural type. The following classification has been adopted:

TABLE I—Groups and Types of Industrial Buildings

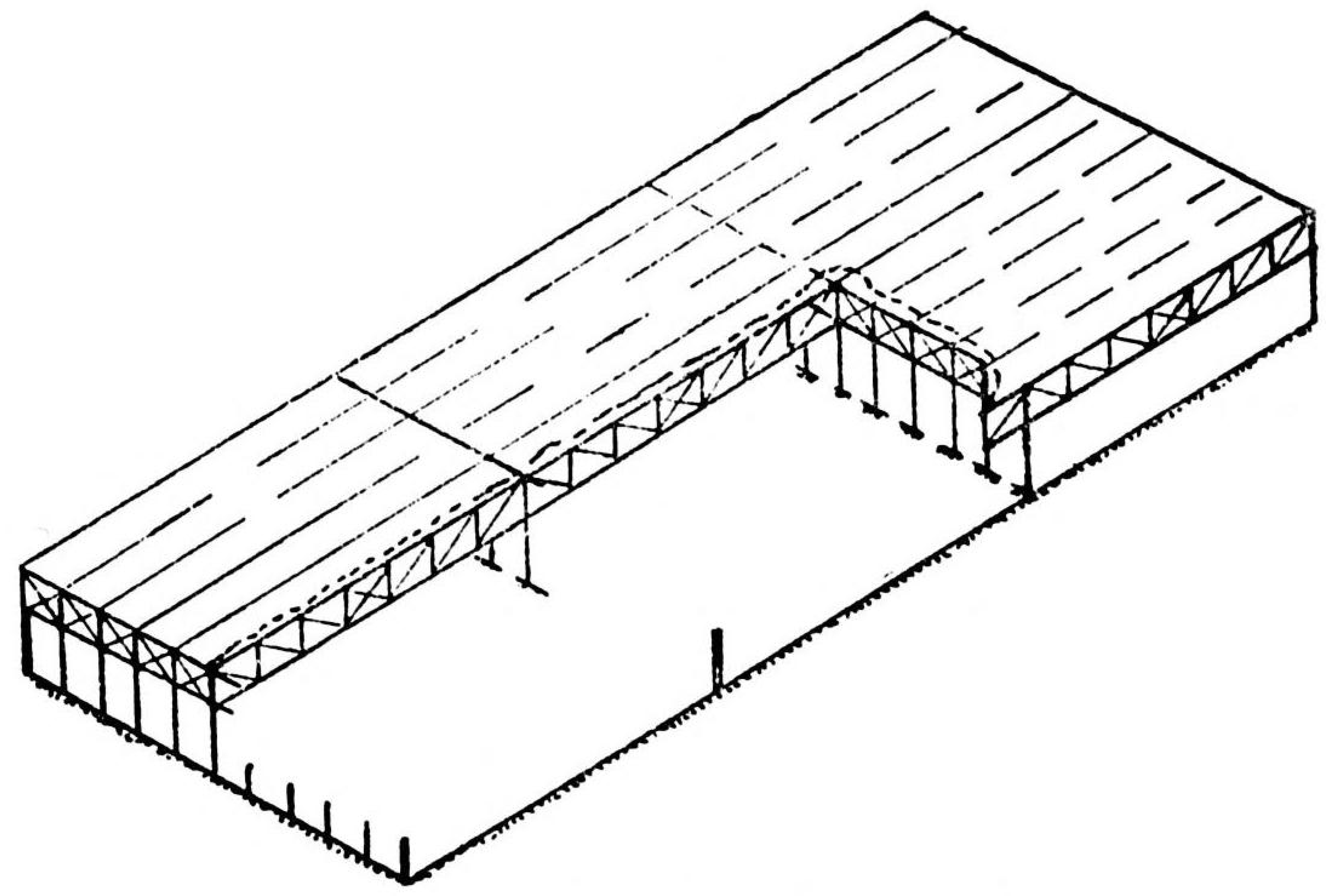
Group			Type symbol	Description
A Single story, no traveling cranes, spans generally less than 75 feet, heights at eaves generally less than 25 feet, area of 10,000 square feet or more.	1	Saw-tooth roofs	A1.1	All buildings of this group with saw-tooth roofs other than those included in types A1.2, A1.3, and A1.4.
			A1.2	Frame and roof slab monolithic reinforced concrete.
			A1.3	Exposed top chords of trusses.
			A1.4	Stressed skin type reinforced concrete (e. g. Zeiss-Dywidag).
	2	Non-saw-tooth roofs.	A2.1	Simple beam and column.
			A2.2	Arches and rigid frames.
			A2.3	Truss construction.
			A2.4	Frame and roof slab monolithic reinforced concrete.
			A2.5	Stressed skin including concrete shell.
B Single story with traveling cranes any length of span, area of 10,000 square feet or more.	1	Buildings housing heavy cranes.	B1	Buildings containing runways for heavy cranes (capacity 25 tons or more) and of height, at eaves, generally more than 30 feet.
	2	Buildings housing light cranes.	B2	All buildings in this group other than those in B1.
C Single story, no traveling crane runways. Spans greater than 75 feet. Height at eaves generally greater than 25 feet, area of 10,000 square feet or more. (See Figures 1-7 for illustration of C types.)	1	Main framed members in two directions.	C1.1	Roof trusses supported along one side of building by long span trusses and along other side by columns. Permits large door along one side, and at ends.
			C1.2	Continuous trusses in one or two directions, long span in one direction, supported by columns or exterior walls, and by internal columns.
			C1.3	Exposed chord saw-tooth roof buildings, exposed chord trusses supporting major size trusses at 90°. One or both truss systems may be of long span.
			C1.4	Diamond mesh arch.
	2	Main framed members in one direction only.	C2.1	Long span arches individually supported along sides of building. May be arranged in multiple spans joined.
			C2.2	Long span triangular or bowstring trusses individually supported by columns at sides of building. May be arranged in multiple spans joined using common columns. Roof pitch exceeds 2 in 10.
			C2.3	Long span trusses, top cord of pitch 2 in 10 or less, including exposed cord saw-tooth roofs, individually supported by columns along sides of building. May be arranged in multiple spans using common columns or may be continuous over internal columns.
	3	Shell type construction.	C3	Stressed skin including concrete shell construction.
D All single story buildings of less than 10,000 square feet plan area.	......	....	D	This type covers all single story industrial buildings, regardless of type of construction, if under 10,000 square feet in plan area.
E Multi-story framed buildings.	......	....	E1	Earthquake resistant: Extremely heavy steel or reinforced concrete, multi-story construction, designed to resist heavy lateral loads.
			E2	Structures in this group other than those in E1.
F Multi-story wall bearing buildings. (May have internal columns.)	......	....	F1	Earthquake resistant, wall bearing construction. (Walls of reinforced brick, concrete, or very massive masonry.)
			F2	Structures in this group other than those in F1.
S Special structures.	......	....	S	Coke ovens, test cells, fuel storage, boilers in power plants, etc.

(240)



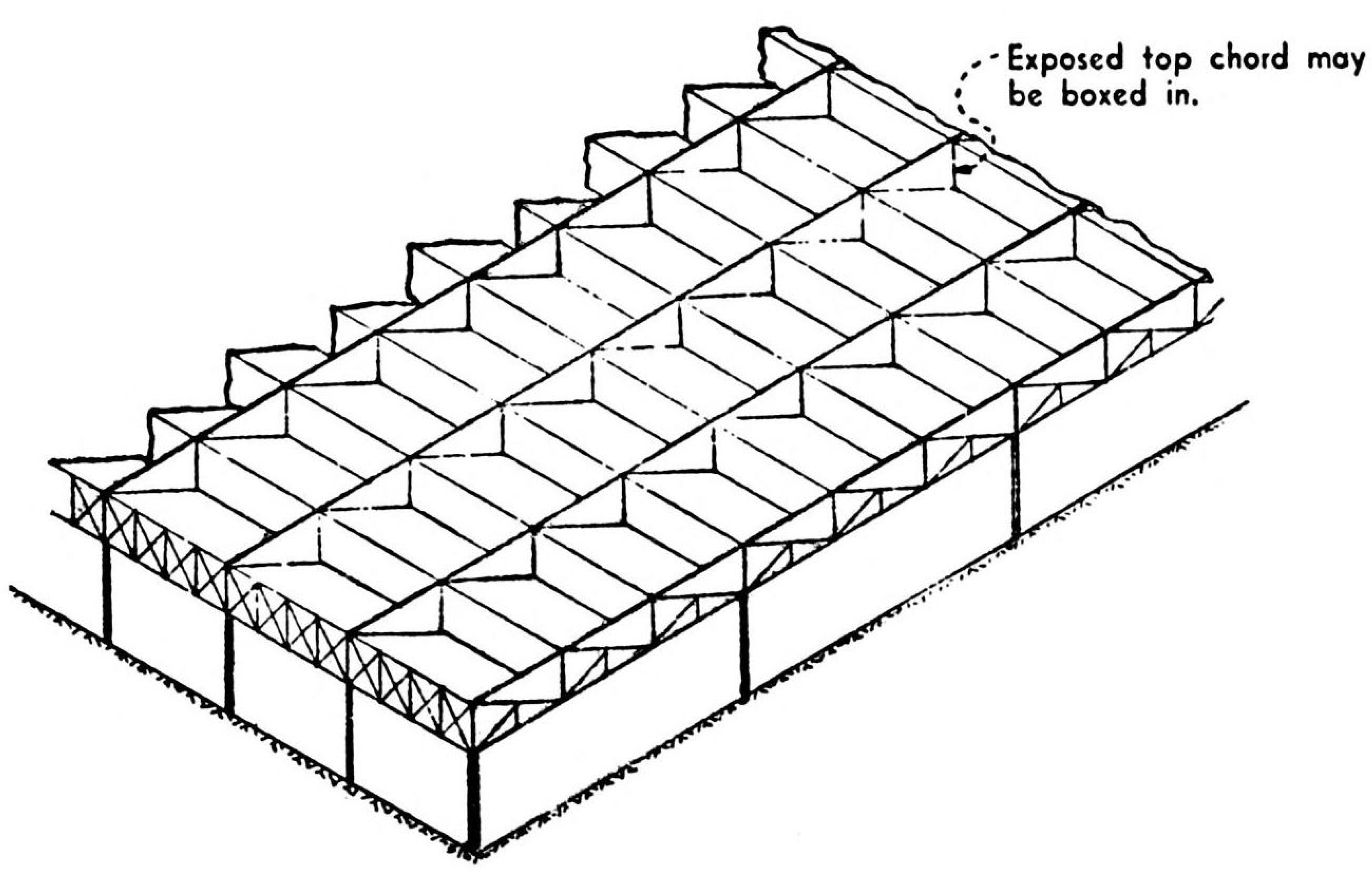
Typical Building Type C1.1

FIGURE 1



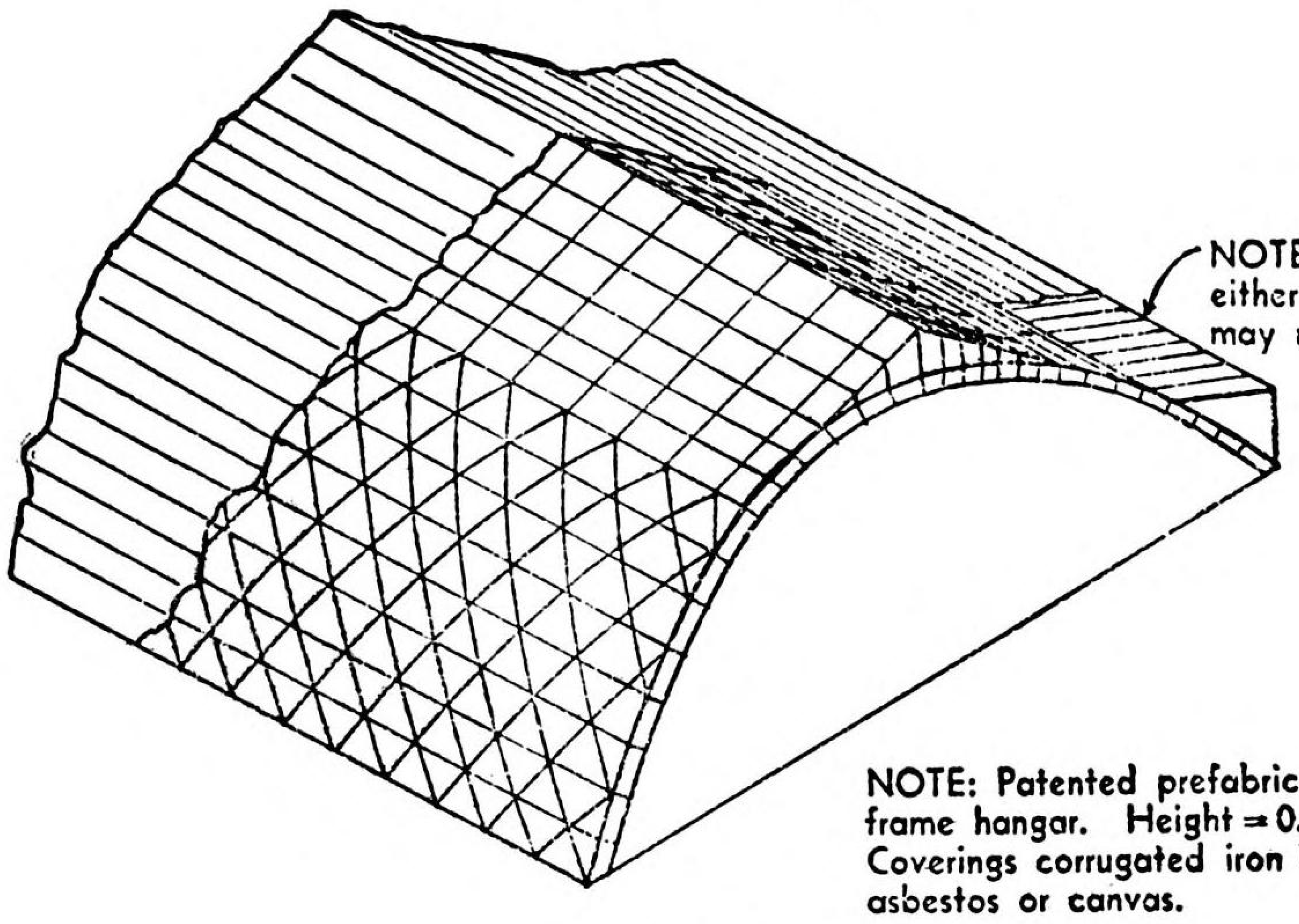
Typical Building Type C1.2

FIGURE 2



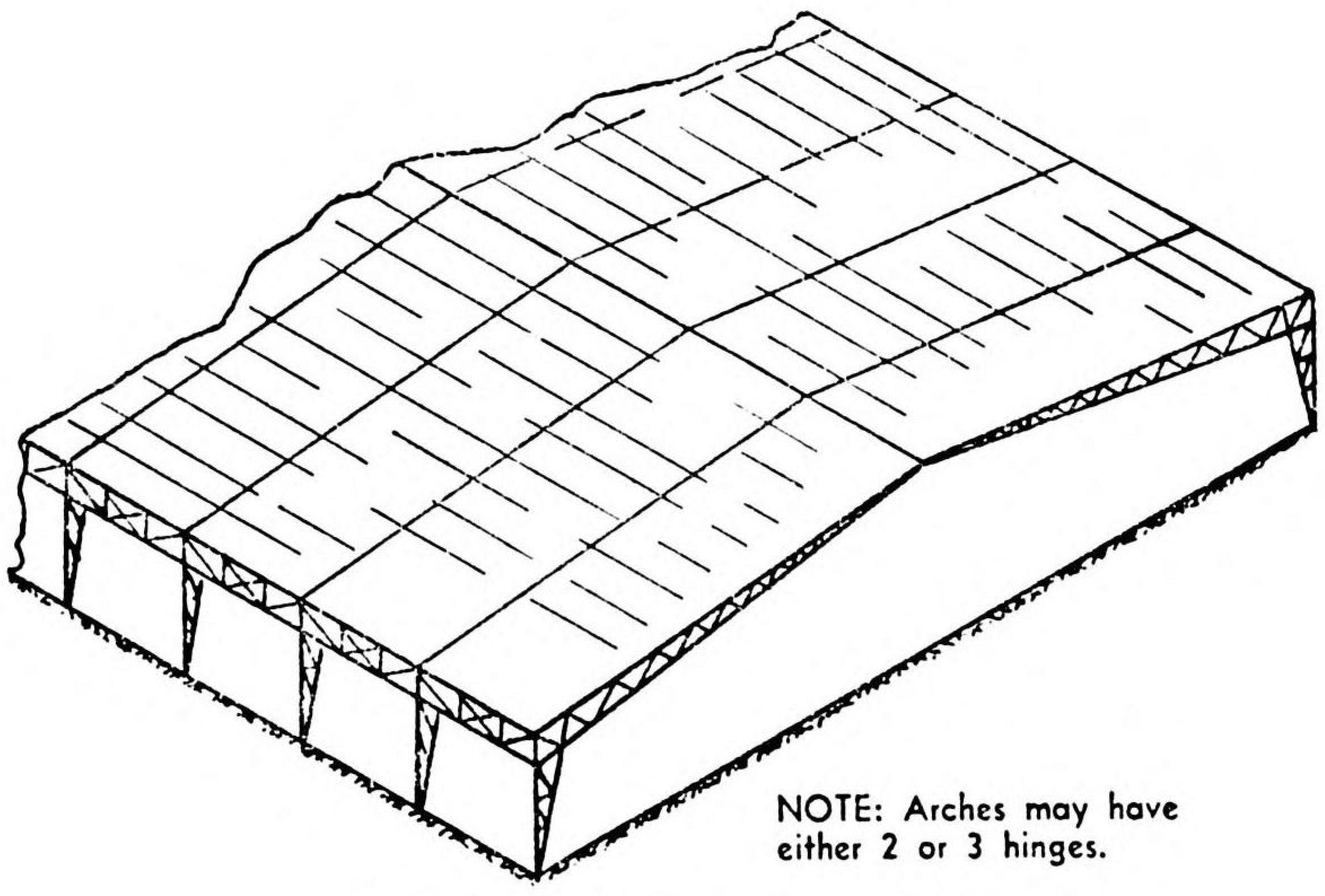
Typical Building Type C1.3

FIGURE 3



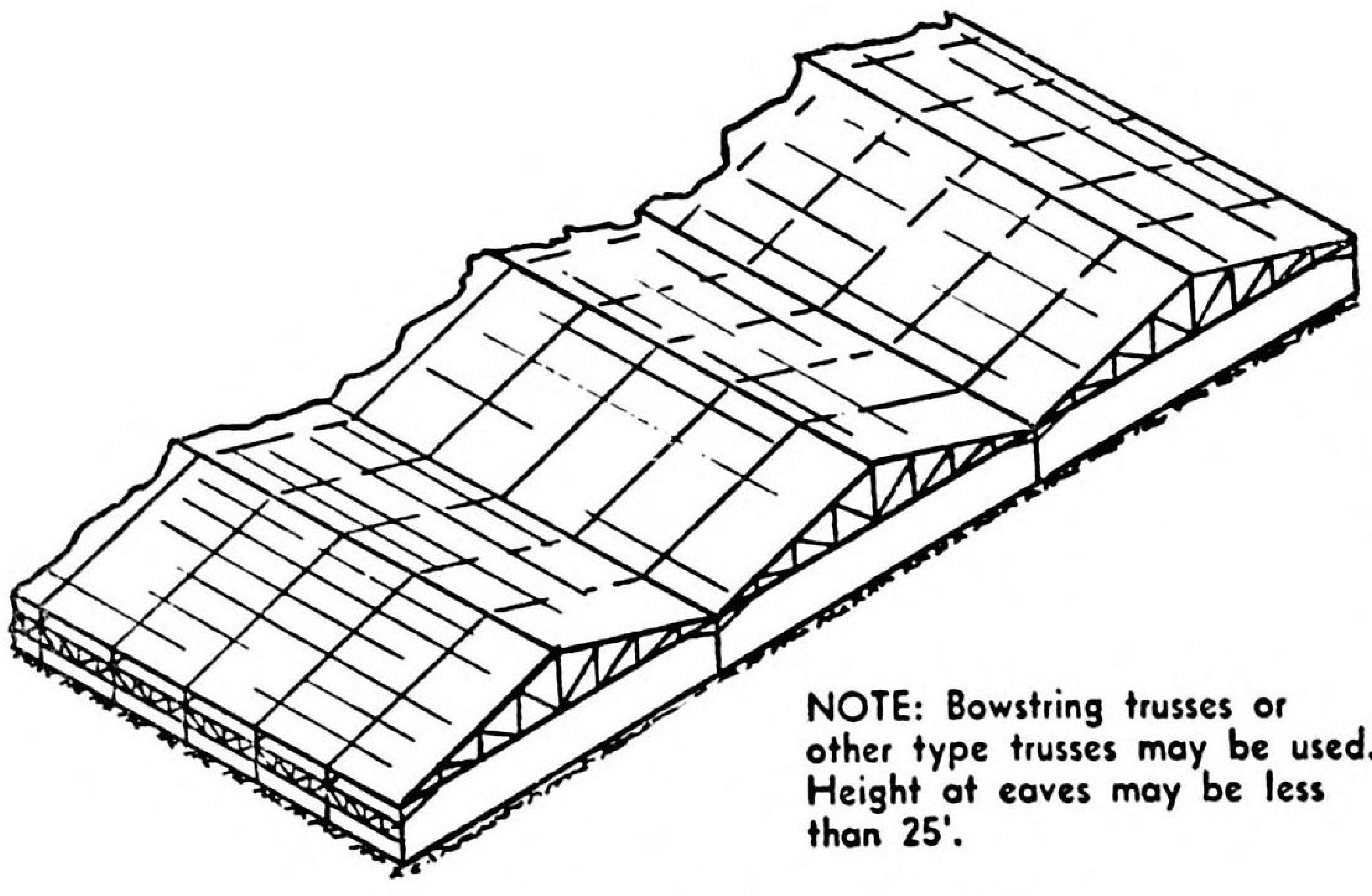
Typical Building Type C1.4

FIGURE 4



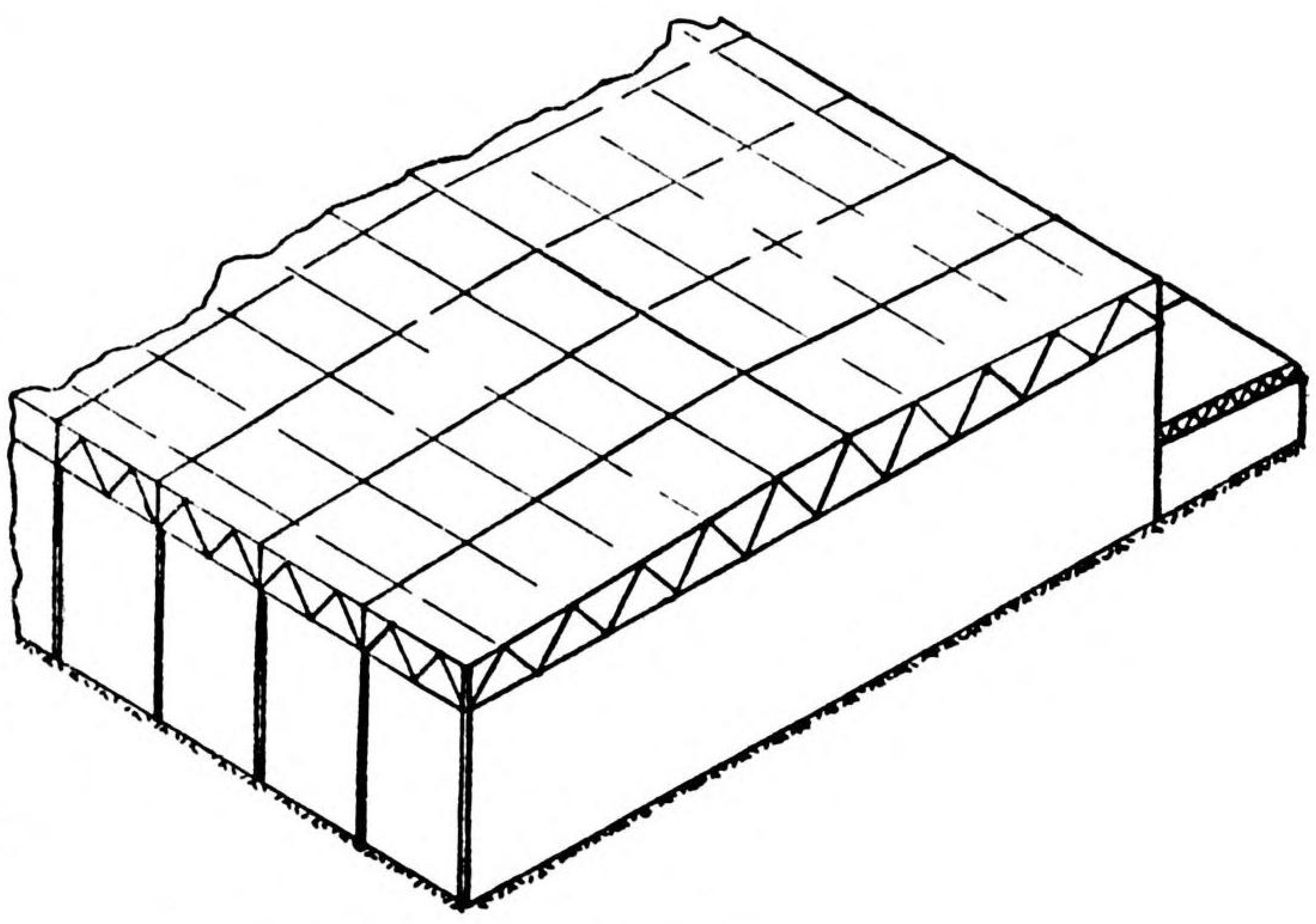
Typical Building Type C2.1

FIGURE 5



Typical Building Type C2.2

FIGURE 6



Typical Building Type C2.3

FIGURE 7

3. Recognition of Single and Multistory Buildings

a. Single-story buildings.

Single-story buildings predominate in Japanese industrial construction. Characteristic features aiding recognition from air cover include the following:

Height to eaves is too small for a multistory building.

Height to eaves is great enough for a multistory building, but type of occupancy makes multistory construction illogical. For example, aircraft assembly and heavy manufacturing processes invariably take place in one-story buildings. A one-story industrial building may be 40 to 50 feet high to eaves, or even higher, where type of occupancy demands.

Sawtooth roofs usually indicate one-story construction.

Reinforced concrete (flat) roofs occur only rarely on Japanese one-story buildings.

Height, occupancy and other factors being considered, the presence of railroad tracks entering a building or a markedly irregular plan frequently indicate one-story construction.

Special buildings having one main operating floor with partial mezzanines or platforms are generally listed as one-story. A basement usually is not considered as an additional floor unless there is evidence of its use for production purposes.

b. Multistory buildings.

Multistory buildings are largely confined to light manufacturing, offices and administration, and barracks or the like. Characteristic recognition features include the following:

Height to eaves is great enough, and type of occupancy makes more than one story logical. Number of floors is estimated on the basis of an average floor-to-floor height of 10 to 12 feet, possibly less in office and barracks buildings.

Air cover shows stair or elevator wells or penthouses, skylights over probable stair wells, air and light wells and courts, outside stairs, ramps, elevated walkways or passageways between buildings (see figure 13), or as a less dependable indication, a large number of small vents irregularly spaced over the roof.

4. Combustibility Categories and Definitions of Terms

Since incendiary bombs can destroy only the portion of a target which will burn, it is necessary to make the following classification of buildings based on their susceptibility to damage from fire:

C—Combustible: Buildings whose roof and/or walls are constructed of combustible material. The floors (except the ground floor) are required to be of similar construction. Wood-framed buildings with noncombustible sheeting on roof and/or walls are also included in "combustible" class.

N—Noncombustible: Buildings which have no significant amount of combustible material in the structure, but whose structure is susceptible to damage by fire in the contents. An example of this type is a building with exposed steel members—which may be warped irreparably by the heat of a fire. Roofs of this type are: Corrugated asbestos, corrugated iron, precast or pour-in-place cement or gypsum on exposed steel, and reinforced concrete 2½ inches thick or less.

R—Fire-resistive: Buildings which have no significant amount of combustible material in the structure and which will withstand all but the most intense fire without structural damage. Roofs and floors (other than ground) should be of concrete more than 2½ inches thick, and the steel frame should be protected and not subject to ordinary fire damage.

In case of a combination of the above types of construction, the building is classified as "Mixed."

Other definitions are as follows:

Fire Wall

A brick, concrete, or concrete-covered tile wall (minimum thickness 8 inches for brick and 6 inches for reinforced concrete) with protected openings, and with a parapet extending above the roof in those cases where the roof is of combustible material. It may be detected by parapets on photo cover or by ground intelligence. Probable fire walls are treated in the same manner as positive ones in fire calculations, and are established from photo interpretation on the bases of: change in eave height, change in roof pitch, change in design or line, change in roof composition, change in occupancy or an occupancy such as to make the presence of fire walls likely. Fire walls are expected to stop the spread of fire. Fire walls and probable fire walls are shown in the Fire Susceptibility Plan (P5) issued as standard target material.

Fire Gap

An air gap, e. g. between buildings, which stops the spread of fire. The effective air distance is extremely variable (from 10 feet to over 50 feet), depending on the presence of combustible walls, the presence of highly combustible occupancy, and the existence of multistory construction. Judgment is required to determine whether or not an air gap is of sufficient width to stop the spread of fire.

Fire Division

An area cut off by fire walls or air gaps within which fire is expected to be retained. Such an area may encompass more than one building, one building, or only a part of a building.

Partitions

A partition is an internal wall of brick, tile or other non-combustible material of lesser thickness than a fire wall, not parapetted and with or without protected openings. Partitions are assumed to have a 50 percent chance of stopping the fire.

They are commonly located between occupancies that are normally separated, between buildings and small additions and in certain specific types of occupancies such as offices, laboratories, etc.

5. Methods of Recognizing C, N, and R Buildings

Recognition from air cover of combustibility classifications is primarily dependent on recognition of the degree of combustibility of the roof and/or its framing.

For one-story construction the character of the roof normally determines the combustibility of the building. Combustibility of multistory buildings depends on roof, walls and floors. The following recognition features and characteristics of Japanese industrial construction may be of value in such determination.

a. Combustible construction.

Roof Materials:

Flat roof (not common): roofing of wood plank with tar and felt finish, over framing of wood or steel.

Pitched roofs including sawtooth roofs (very common): roofing of corrugated steel or asbestos over framing of wood, or roofing of wood plank with tar and felt finish (rare) or of wood shingles, clay tile or asbestos shingles (frequently called "slate") applied to wood sheathing or battens, over framing of either wood or steel.

Recognition Features:

Hipped or semi-hipped roof (buildings A, B, C, in figures 8, 10 and 14): roofs are frequently of tile, asbestos shingles or wood shingles over wood framing, although corrugated steel or asbestos may be used.

Relatively narrow (usually 25 to 60 feet wide) "barracks" type buildings with gable roofs; may be either single- or multistory (buildings D and E in figures 8, 10 and 12): frequently arranged in groups, sometimes with connecting passageways, and may have any of the combustible roofs listed above. Single-story buildings more than 25 or 30 feet high at eaves are usually of noncombustible construction.

Gabled, hipped or single-pitched roofs with parapet walls (building F in figures 8 and 14): may be any of the combustible types listed above; frequently found on wood-framed buildings with walls finished in stucco in close imitation of concrete.

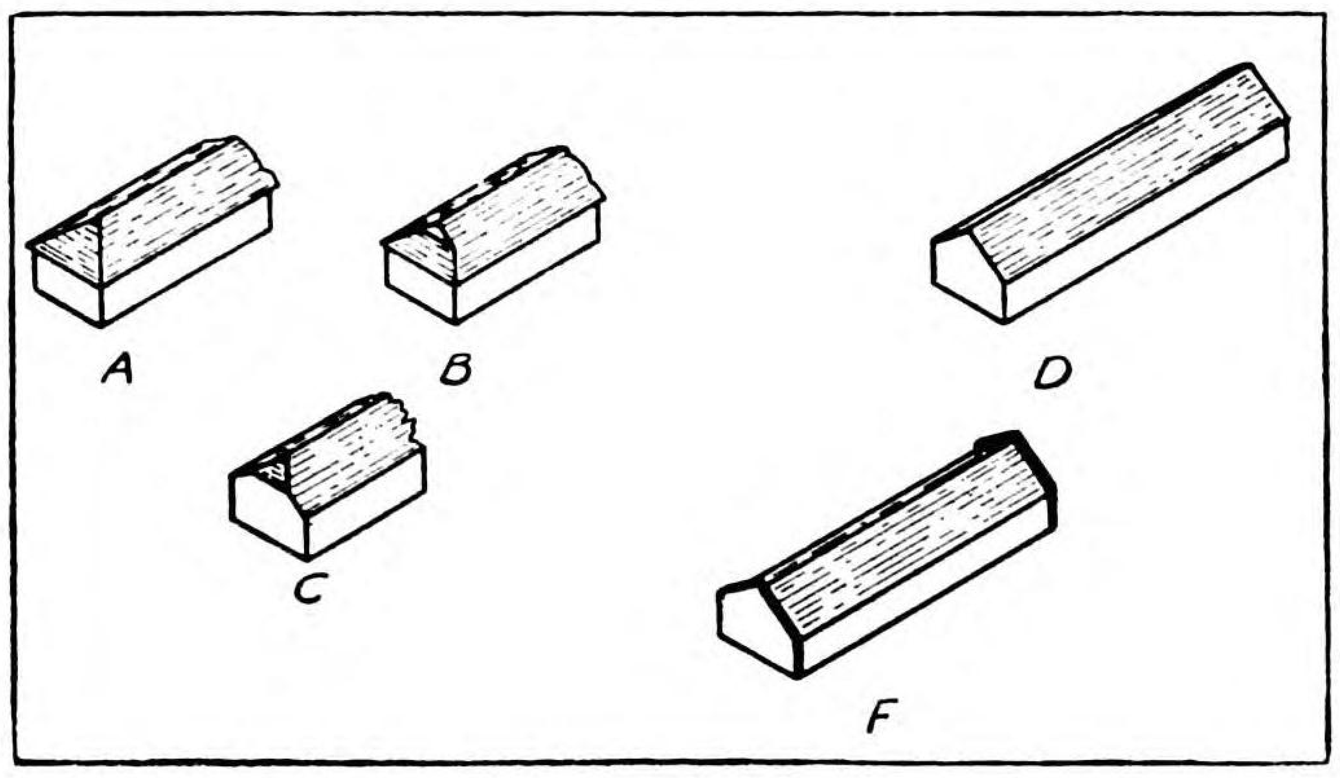


FIGURE 8

Multiple-span gable roofs, usually on single-story buildings (building G in figures 9 and 14): roofing of corrugated steel or asbestos over wood frame probably is the most common construction.

Extension of one slope of a gable roof beyond the ridge, beginning several feet inside gable ends, or alternating extensions of both slopes to form small roof lights (buildings H and I in figures 9, 12 and 14): corrugated steel or asbestos roofing over wood frame probably is the most common construction.

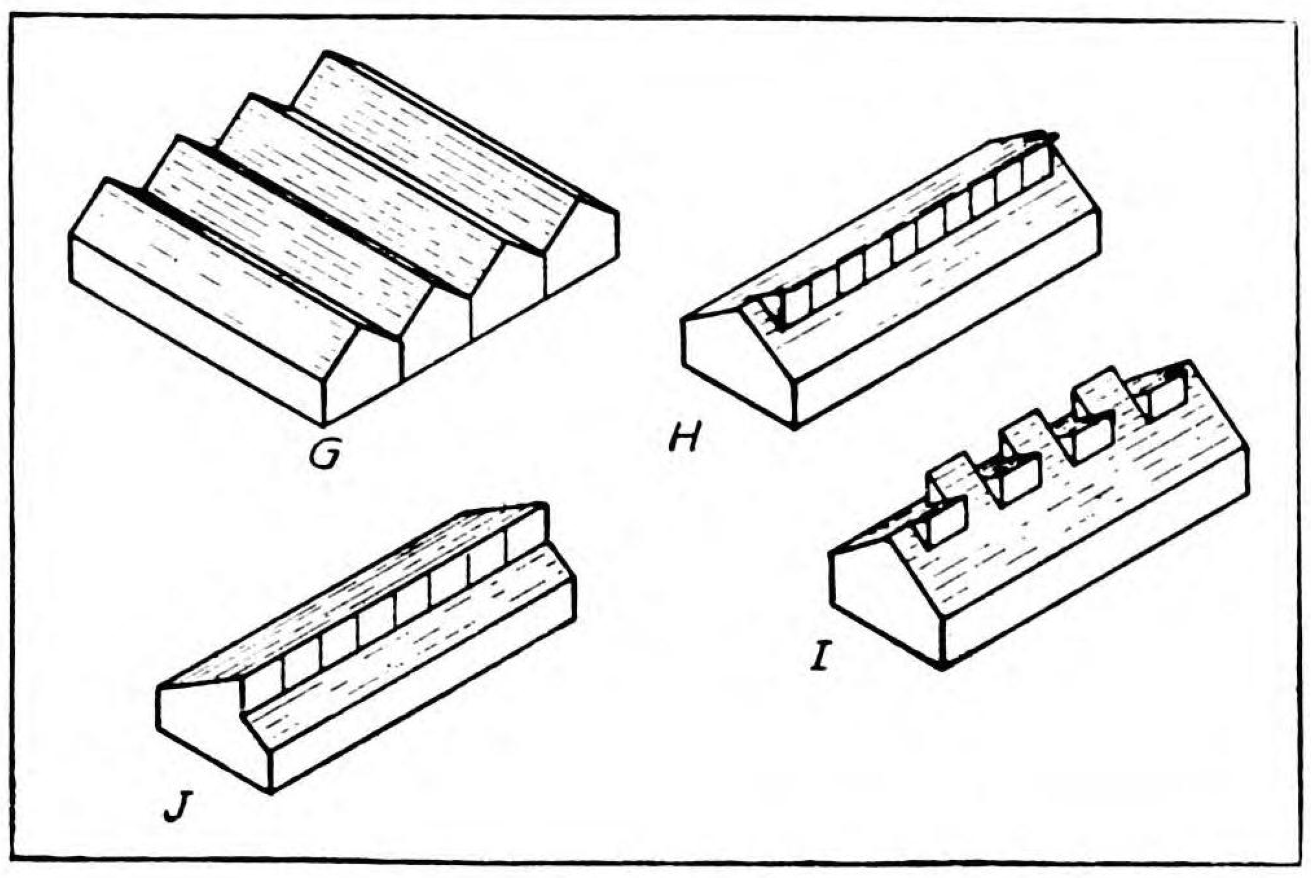


FIGURE 9

Extension of one slope of a gable roof beyond the ridge to form a small sawtooth roof light as above described except that the extension runs full length of the ridge (building J in figure 9); usual construction is corrugated steel or asbestos over wood frame. Where span exceeds about 50 feet this type is probably steel-framed and noncombustible.

Sawtooth-roofed buildings having roof spans of less than about 25 feet are frequently combustible, the usual construction being corrugated steel or asbestos over wood frame. This criterion is not dependable and must be used with judgment, considering age, type of occupancy, and general plant construction.

Parapetted fire walls breaking building up into fire divisions of 2000 to 12,000 square feet in area almost invariably indicate combustible construction and may occur with any of the combustible roofs listed; see figures 10, 11, 12, 13 and 14. Care must be taken that the upper chords, frequently boxed in, of exposed-top-chord sawtooth roofs are not mistaken for fire walls. Figure 11 shows typical combustible sawtooth roofs with parapetted fire walls; figures 12 and 14 show typical exposed-chord construction, both boxed-in and not boxed-in.

b. Noncombustible construction.

Roof Materials:

Flat or very low pitched roofs (not common): roofing of concrete slab or other slab covered with tar and felt, over framing of exposed steel.

Pitched roofs including sawtooth roofs (very common): roofing of corrugated steel or asbestos (concrete slab rarely), over framing of exposed steel.

Recognition features: there are very few reliable criteria, the noncombustible classification usually being assigned if the building does not fit into other categories. However long-span buildings, particularly of exposed-chord sawtooth construction, are usually framed in steel with corrugated steel or asbestos roofing, therefore noncombustible.

c. Fire resistant construction.

Roof Materials:

Flat roofs (very common): roofing of reinforced concrete slab with tar and felt finish, over framing of reinforced concrete or fire-protected steel.

Pitched roofs (not common): same construction as above.

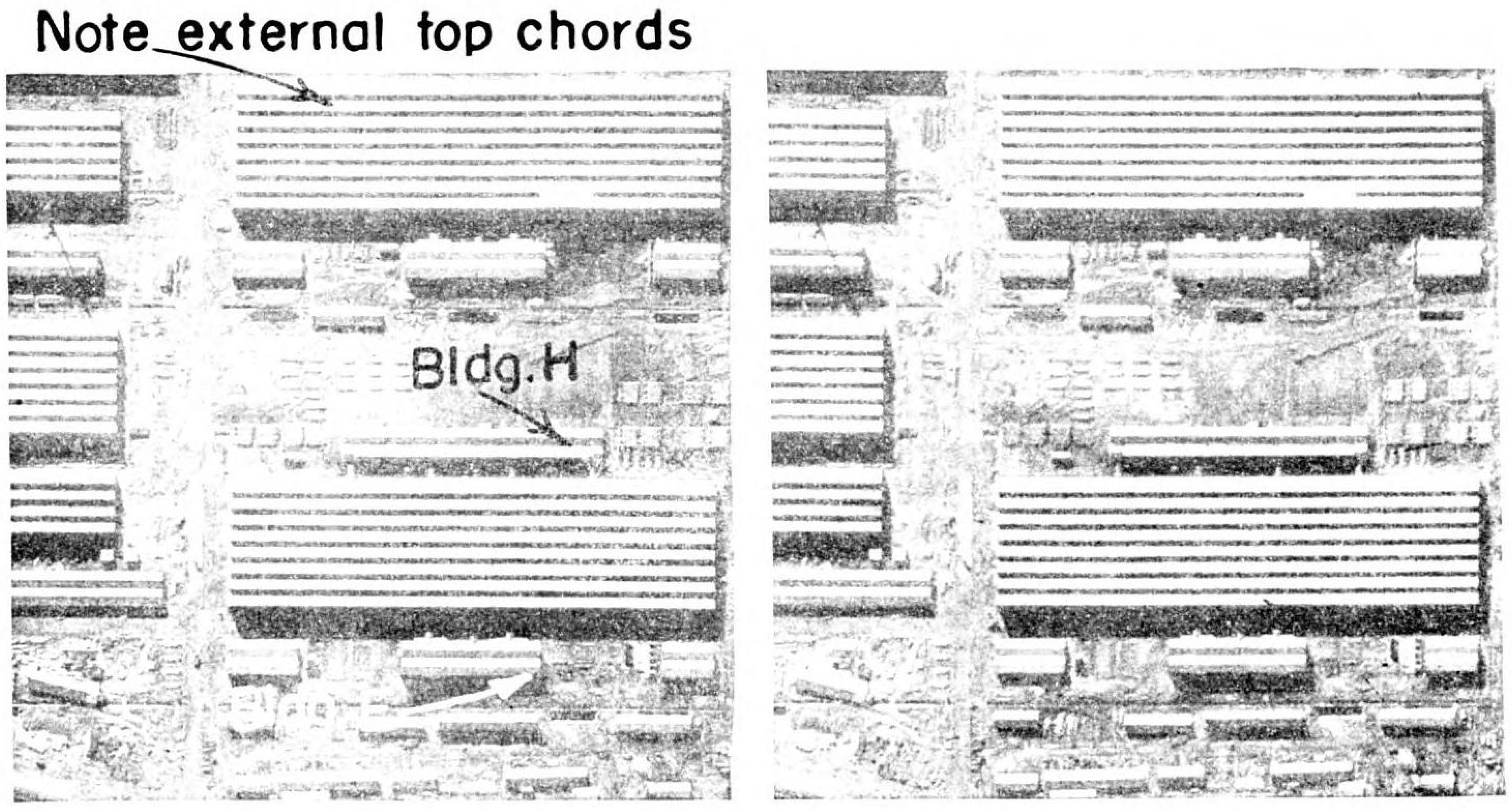


FIG. No. 10

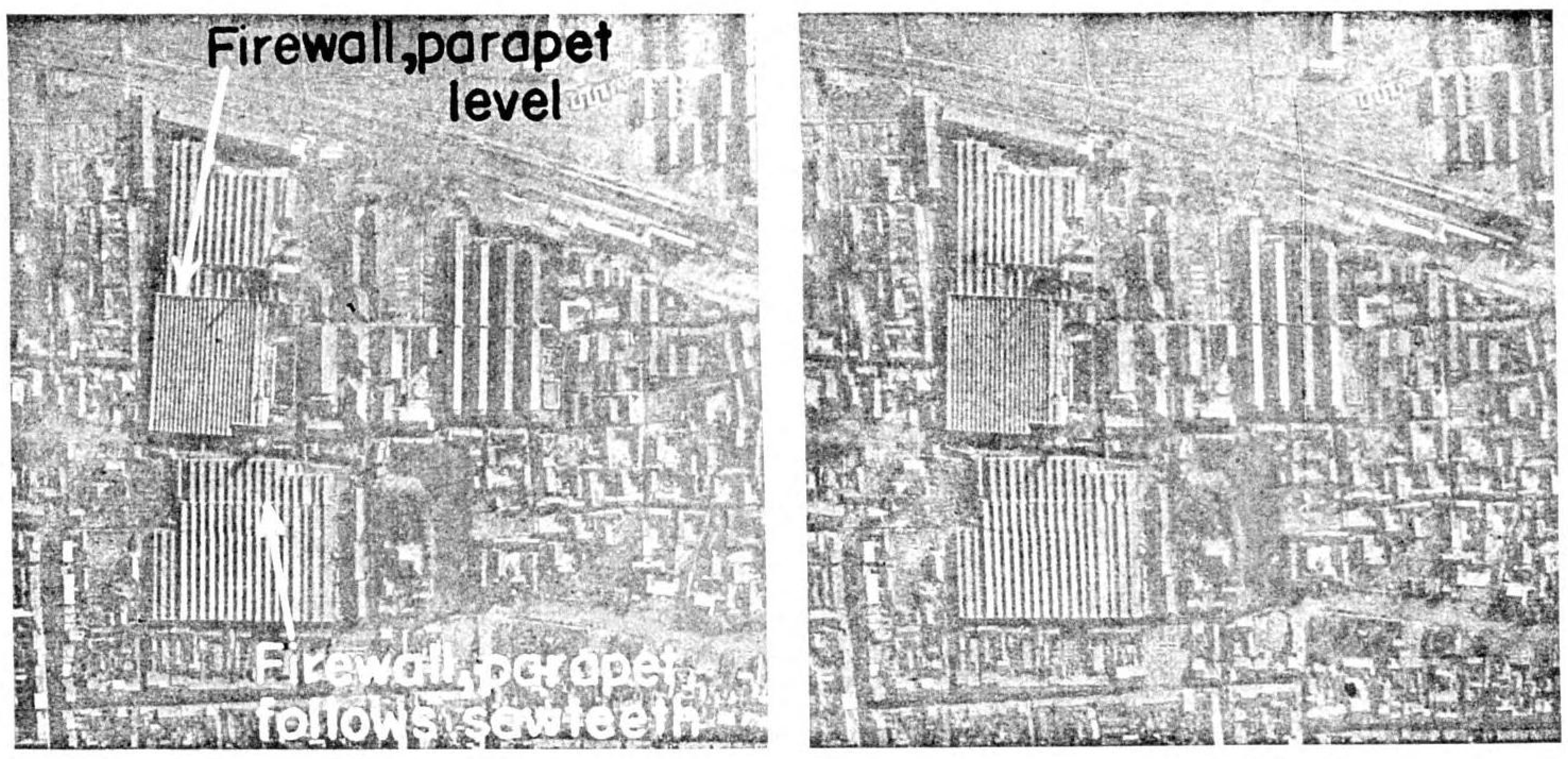


FIG. No. 11

Typical combustible sawtooth roof construction.

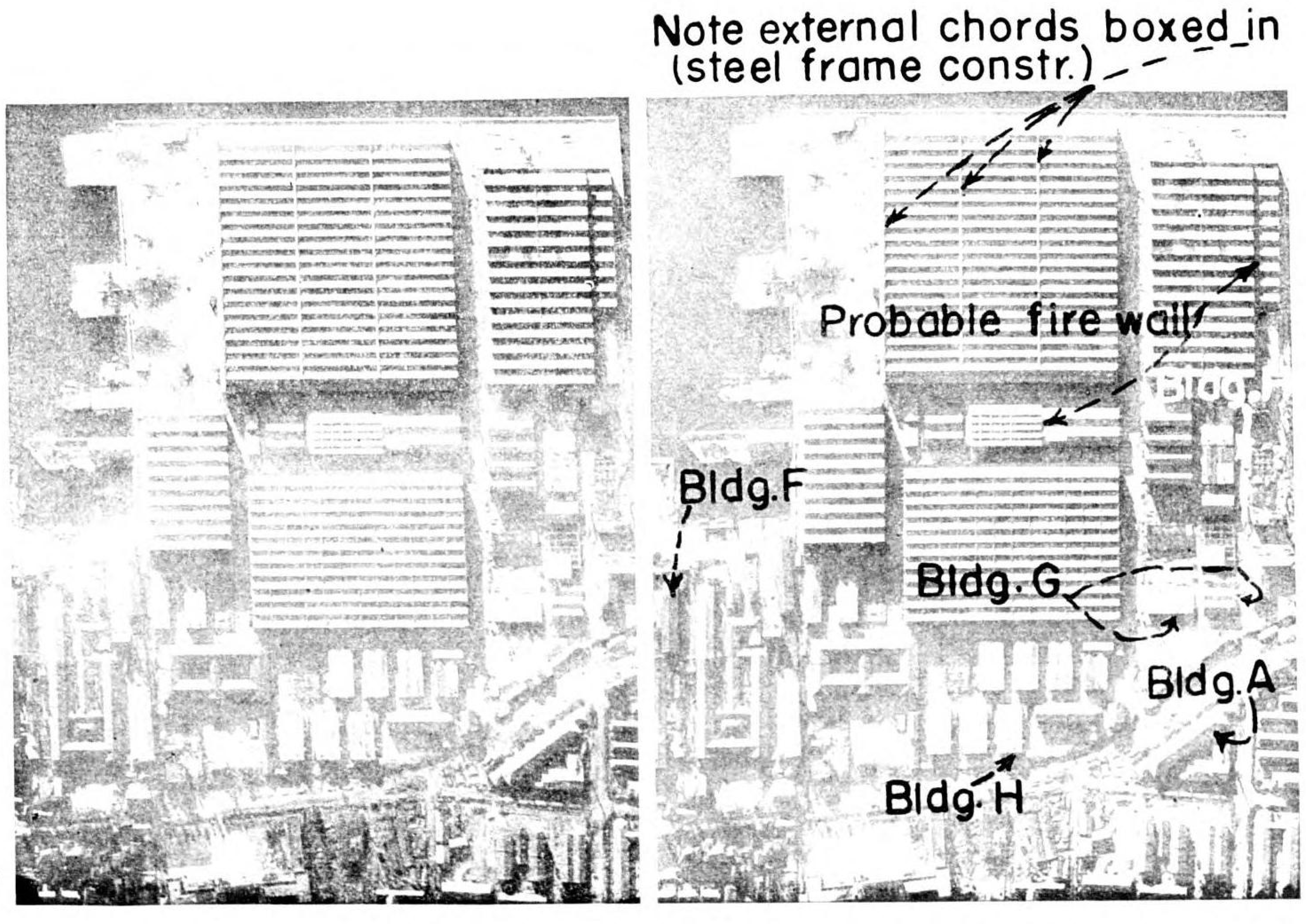


FIG. No. 12

Typical external chord sawtooth roofs, construction steel frame covered with corrugated asbestos.

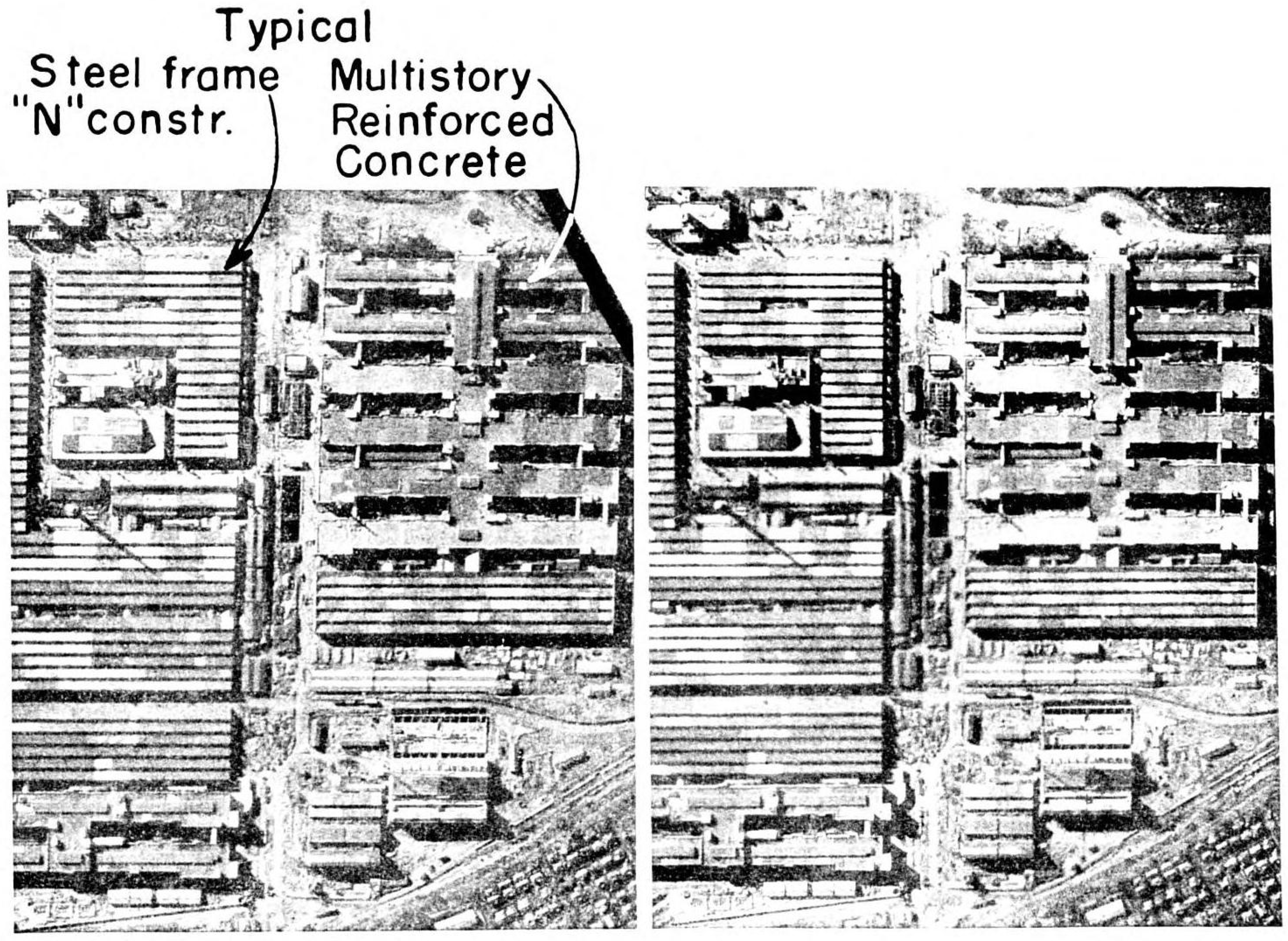
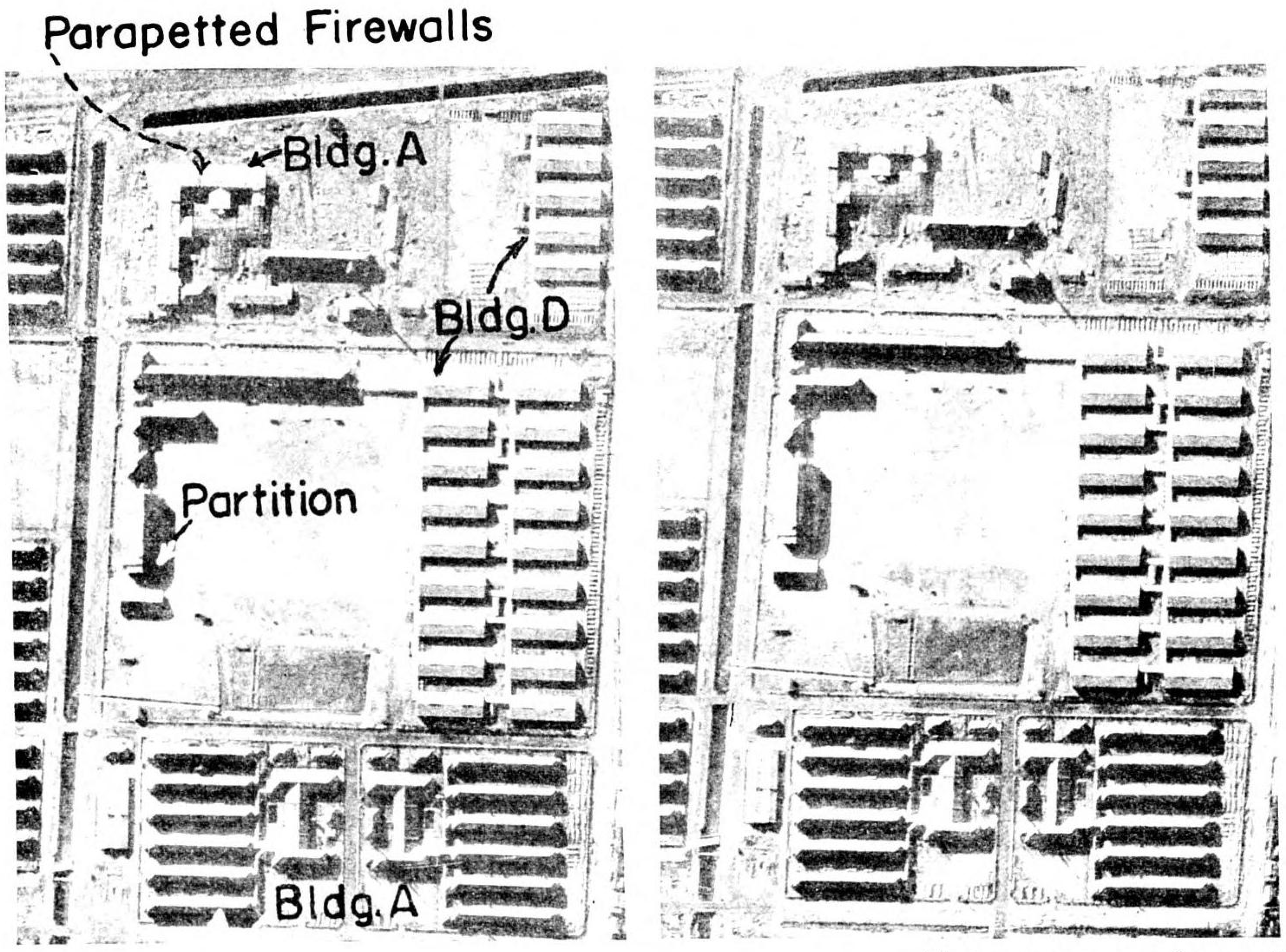


FIG. No. 13

Note numerous firewalls in minor buildings.



Note numerous firewalls.

FIG. No. 14

Recognition Features:

Flat roof, usually with parapet walls (figure 13).
Building of light color, particularly the walls.

d. Mixed construction (multistory buildings only).

In "mixed" construction (multistory) the combustibility of the roof differs from that of floors and wall framing; for example, a building having a combustible roof but fire resistant floors and framing is indicated by the symbol *C/R*.

Framing and floor materials for multistory buildings are usually determined from consideration of the general building construction and to some extent the type of occupancy. Thus wood-framed buildings usually have combustible floors while steel and reinforced concrete structures usually have floors of reinforced concrete, which are termed noncombustible if supported by exposed steel or fire resistant if supported by protected steel or concrete framing.

B. HIGH EXPLOSIVE BOMBS

1. General Remarks

The effectiveness of an HE bomb against a particular structural class of buildings is measured by the "Mean Area of Effectiveness," or MAE. This is defined as the average area of structural damage caused per unit weight of bombs by hits and near misses of this bomb against structures of this class. A full discussion of the MAE and a table of its values (table III) is given below.

This table gives the MAE's of each size of bomb against structures of various categories. For an attack against an individual building the best bomb on a weight for weight basis, can be determined by converting these MAE's to square feet of damage per ton and then choosing the bomb for which this quantity is the largest. To determine the best bomb for use against a target consisting of a number of buildings, the MAE of each bomb against each building (in square feet per ton) is found from the table. These are then averaged over all the buildings in the target to find the average MAE. In this process of averaging, the MAE of each building is weighted with the floor area of that building. Thus:

$$\text{Average MAE (for a group of buildings)} = \frac{\Sigma(\text{MAE for each building}) \times (\text{floor area of that building})}{\text{Total floor area of buildings in the group}}$$

where the summation (denoted by Σ) is over all buildings in the group being considered.

For the purpose of choosing the best bomb against the target, *only primary and secondary buildings* are considered in the above summation. That bomb which gives the largest MAE per ton with respect to these buildings is the one recommended for use.

For the purpose of determining the required density over the target as a whole, the average MAE for the chosen bomb with respect to *all* the buildings in the target is then computed. This is the value of *M* used in the next paragraph.

To determine the ground density required to achieve a given level of damage, this value of *M* is used in the formula:

$$(1) \qquad F = 1 - e^{-MD}$$

where *F* is the fraction of floor area receiving structural damage

M is the MAE of the best bomb (thousands of sq ft/ton).

D is the required ground density (tons/thousand sq ft).

To solve for *D*, one may use the formula

$$(2) \qquad D = \frac{1}{M} \log_e \frac{1}{1-F}$$

where $\log_e \frac{1}{1-F}$ may be obtained from table A-1 of appendix A.

2. Mean Area of Effectiveness

Data concerning the values of the MAE have been collected by the Ministry of Home Security in Great Britain concerning the effects of German bombs against British structures and conversely concerning the effects of American and British bombs against Axis targets. These data have been supplemented by an analysis of damage to Japanese structures in attacks made by the Twentieth Air Force. There is substantial agreement among these various sources of data, and it is believed that the figures given in table III are reliable for use against Japan. Continuing research, however, is in progress and revisions will be published as they become necessary.

The following classification of buildings has been adopted by the Joint Target Group for the purpose of listing MAE's. Those buildings have been put into the same category which exhibit the same vulnerability to HE bombs, regardless of whether or not the buildings are of similar structural characteristics. These categories are called "HE vulnerability classes" and are given the relative symbols V1, V2, and so on. In general, the higher the number, the higher will be the vulnerability of the class.

TABLE II

HE Vulnerability Classes

HE vulnerability class:	*Substructural groups (symbols refer to table I)*
V1	E1.
V2	B1, B2.
V3	E2, F1.
V3A	F2.
V4	A1.1, A1.2, A1.3, A2.1, A2.2, A2.3, A2.4, D.
V4A	C1.2, C1.3, C1.4, C2.3.
V5	A1.4, A2.5.
	C1.1.
	C2.1, C2.2.
	C3.

(240)

The MAE's for various bombs against buildings of the above categories are given in the following table:

TABLE III

MAE's for HE Bombs (square feet per bomb)

HE vulnerability class	US 500 GP	US 1,000 GP	US 2,000 GP	US 4,000 LC
V1 [1]...........	1,100	2,300	4,700	——
V2.............	1,400	3,900	10,200	——
V3 [1]...........	1,900	3,900	7,800	——
V3A...........	3,400	11,500	26,000	——
V4.............	4,100	8,000	15,000	48,000
V4A...........	2,500	7,000	15,000	48,000
V5.............	7,300	16,700	[2] 27,000 [3] 38,500	[2] 48,000 [3] 104,000

[1] The MAE's for classes V1 and V3 are to be divided by the number of stories in the building.

[2] For buildings less than 40,000 square feet and greater than 10,000 square feet in area.

[3] For buildings greater than 40,000 square feet in area.

[4] The MAE figures quoted above are based mainly on European experience, in which fuzings were predominantly 0.1/0.01 and 0.1/0.025, but in which an uncertain number of tail fuzes were initiated by the roof. This has made it impossible to date to give MAE's for each fuzing of any bomb. The MAE's quoted are averages for various fuzings, while the recommended fuzings (Section 3 below) are based on ground information on the effect of detonation at different points. It is possible, therefore, that the MAE's given are low for the optimum fuzings; on the other hand, it is possible that they have been overestimated because of the tendency to miss bombs on photo-cover, so no correction has been made for the fuzing factor. A study of the available material on MAE's, quoting and evaluating the various references, is being made and will be distributed as a Weapons Memorandum when completed. As more data are acquired it is expected that MAE tables will be revised and that eventually MAE'S will be provided for each fuzing of each type of bomb.

To compare bombs on a weight-for-weight basis it is useful to have MAE's expressed in terms of square feet/ton. Using the actual (not nominal) weights of the bombs (for TNT filling), we get the following table. Bombs are considered to be of equal effectiveness if their MAE's per ton are within 10%. Where differences greater than this amount occur, the entry for the best bomb or bombs is underlined below.

TABLE IIIa

MAE's for HE Bombs (square feet per ton)

	US 500 GP	US 1000 GP	US 2000 GP	US 4000 LC
V1 [1]...........	4180	4650	4510	——
V2.............	5320	7880	9790	——
V3 [1]...........	7220	7880	7490	——
V3A...........	12,920	23,230	24,960	——
V4.............	15,580	16,160	14,400	22,850
V4A...........	9,500	14,140	14,400	22,850
V5.............	27,740	33,730	[2] 25,920 [3] 36,960	[2] 22,850 [3] 49,500

[1] The MAE's for classes V1 and V3 are to be divided by the number of stories in the building.

[2] For buildings less than 40,000 square feet and greater than 10,000 square feet in area.

[3] For buildings greater than 40,000 square feet in area.

For Special Targets the Following Table of MAE's Has Been Prepared

TABLE IIIb.

MAE's for HE Against SPECIAL TARGETS

Target	MAE 1,000 sq. ft./bomb						Best fuze	Remarks
	1st Choice		2nd Choice		3rd Choice			
	Bomb	MAE	Bomb	MAE	Bomb	MAE	Nose/Tail	
Coke Ovens	500 GP	4.5	1000 GP	6.0			0.1/0.1	Ref.: J.T.G. Category—Basic Processing Industries, Coke, Iron, Steel: Part V
Boilers in Steam Power Plants	500 GP	3.0	1000 GP	5.0	2000 GP	7.5	0.1/0.025	Ref.: J.T.G. Category:—Basic Services and Utilities, Electric Power, Part V
Transformers in Open	500 GP	10.0	1000 GP	15.0	260 F AN-M81	3.0	Inst/N.D.	
Transformers (Protected By Blast Walls)	500 GP	Enclosed Area					0.01/N.D.	
Penstocks	250 GP	KxDxL*	500 GP	KxDxL*			0.01/0.01	Ref.: Div. 2, NDRC Rep., EWT-2 (OSRD No. 5045) 5 May '45, Attack of Penstocks
Oil Tanks (Above Ground)	100 GP	Area of Tank					0.025/0.025	
Oil Tanks (Under Ground)	500 or Larger GP Bombs SAP Bombs						0.1/0.1	Ref.: J.T.G. Category, End Product Industries, Petroleum, Part V
Synthetic and Shale Oil Plants	500 GP	2.5	250 GP	1.0	1000 GP	4.0	0.025/0.025	
Oil Refineries	500 GP	3.8	250 GP	1.25			Inst./N.D.	For refineries without blast walls in which bldg. density is less than 30%. (80-90% of cases)
	250 GP						0.01/0.01	For refineries protected by blast walls or in which building density is more than 30%.
	250 GP						0.025/0.025	For refineries shut down prior to attack and with lines drained of oil products.
	500 GP						As Above	Dive or Glide Bombing
Rectifiers	250 GP	0.9	500 GP	1.8	1000 GP	3.5	0.1/0.025	Ref.: Internal J.T.G. Study.
Eng. Test Cells	500 GP	3.4	1000 GP	5.0	2000 GP	10.0	0.1/0.025	Ref.: Unpublished report RE 8, Min. Home Sec.

*For bombing approach parallel to line of penstocks (from bottom to top of slope).

K = 0.95 to 0.8 if slope of pipe is less than 45°
= 0.8 to 0.55 if slope of pipe is 45° to 60°
D = Diam. of pipe (ft.)
L = Length of pipe measured along slope (ft.)

Table III above gives the MAE's for structural damage, and is compiled from the results of examining many aerial photographs. From such photographs, damage to building contents (e.g., machine tools, raw-material stocks, partially or wholly finished products) cannot be seen. Investigation on the ground of damaged plants in Europe, however, has now arrived at a point where certain tentative conclusions can be reached regarding damage to machine tools and other machinery.

In considering these data, it is desirable to separate the effects on "light" machinery from those on "heavy" machinery. "Light" machinery and machine tools operate in general on stock light enough to be handled manually, and are found in such industries as the automotive, aircraft, etc.

By "heavy" machinery is meant the machinery associated with typical heavy engineering industries such as shipbuilding, locomotive building, heavy diesel engine manufacture, and large gun manufacture. The term applies only to machinery which operates on stock so heavy that power handling and hoisting equipment is necessary.

The evidence from Europe shows that the Mean Areas of Effectiveness for the 500 and 1000-lb GP bombs against light machinery are greater for non-cratering bombs (i.e., those fuzed short delay, which detonate in the air between roof and floor as a result of fuze actuation by the roof) than for cratering bombs. For serious damage to such tools, that is damage necessitating the replacement of the tool or of its major components or the removal of the machine for repair, the MAE's for non-cratering 500 and 1000-lb GP bombs are of the order of 15,000 to 20,000 sq ft/ton and are, therefore, of the same order as the MAE's for structural damage. Cratering bombs do appreciably less damage to light tools. Large, light-cased, instantaneously fuzed blast bombs damage light tools (by debris, etc.) with an effectiveness greater than that of the cratering medium sized GP bombs, but less than that of the roof initiated GP, whose fragments are responsible for much of the damage caused.

Against heavy machinery the difference between the non-cratering and the cratering GP bomb is very much smaller, though the evidence available would still favor the former. The available data appear to show that the MAE's for heavy tools are appreciably less than for light, but no numerical estimate is possible at present. No evidence is presently to hand on the effect of light-cased bombs against heavy machinery, but it is unlikely to be very great.

All data on HE damage to machinery are incomplete and tentative; as new data become available from ground surveys the conclusions of this section will be revised and made more specific.

3. Choice of Fuzing

Choice of fuzing will depend upon a number of considerations, such as the structural characteristics of the target under attack, the relative desirability of doing maximum damage to the building itself or to its contents, etc. The latter distinction will be of particular importance in single story buildings. As is indicated above, fuzing for air detonation will normally be optimal for tools, but this fuzing will be too short to produce maximum damage to the building proper, in some instances. This distinction will be of less importance in multi-story buildings, since in these tools are not normally confined to the top floor, and it is plainly impossible to fuze bombs for detonation between floors for several floors down.

Where building damage is the criterion, and the target is composed of buildings of different structural types which require different fuzings, that fuze should be selected which is best against the greatest proportion of these buildings. Unless there is reasonable assurance that bombs can be delivered against designated individual buildings, as in low level attack, it is not desirable to arm part of the bombs with one fuze and part with another, for there is no assurance that the bombs will hit the buildings on the basis of which the fuzes were chosen.

a. Class V-1

Recommended fuzing is 0.1 sec. nose/0.025 sec. tail except for low and minimum level attack or where it is necessary to destroy important contents known to be more than four floors below the roof.

The fundamental weakness of ordinary multi-story steel framed buildings to bomb detonation within the building is the bowing outwards of the steel frame caused by side thrust on the wall panels. This weakness has been removed in class V-1 buildings by making the connections between the beams and columns very strong. Therefore, damage to class V-1 buildings will be confined to floors and walls. Fuzing of 0.025 sec. for bombs traveling at a velocity of 600 f/s or greater will give the best level of explosion for maximum damage. With 0.025 fuzing, the bomb will usually detonate at or below the second floor below the roof and will do direct damage to this floor, two floors below, and the floor and roof above. Additional damage may be done by falling debris. With fuzes of longer delays the bomb may strike a heavy member causing it to deflagrate or to ricochet out of the building. Bombs fuzed 0.01 sec. or less will obviously do less floor damage since a significant portion of the force liberated by the explosion will expend itself in the open air above the roof of the building.

For very resistant multi-story buildings in this class the chances of doing serious damage with standard GP bombs are small, since little or no bonus from spreading collapse is to be expected. For this reason, there is a good expectation that the efficiency of very large bombs, of the "Tallboy" or "Grand Slam" classes, would be considerably greater than that of smaller bombs, on a weight for weight basis. This expectation is based on the assumption that the large bombs will be capable of blowing out the steel frame and thus collapsing appreciable areas of the building and this, as was explained above, cannot be expected of small bombs.

Fuzing for damage to building contents is not practical for multi-story buildings as was explained in the first paragraph, Section 3, above.

b. Class V-2

Recommended fuzing is 0.1 sec. nose/0.1 sec. tail.

Structures of this class are not subject to blast or fragmentation effects. To cause primary collapse and thus severe damage to these buildings, it is necessary to destroy at least two adjoining main columns by cratering. In most cases cratering action and thereby earthshock will do more damage to contents than will blast or fragmentation. Large bombs of the GP range are recommended, since large craters are necessary to give a reasonable expectation of involving two or more main columns. For this reason, bombs smaller than the 1000-lb GP are not recommended.

It will be realized that the fuzing recommendation given above conflicts with the non-cratering fuzing, which would be recommended for damage to machinery contained in a building of this type. It is thus plainly impossible to fuze for maximum damage both to the building and its contents, simultaneously. Where this machinery is heavy, however, as will frequently be the case, the advantage of the non-cratering bomb is small and the longer delay fuzed, large GP bomb will therefore be the best choice for the building plus contents. Furthermore, the one-tenth second delay fuzing recommended for the building will be optimal for damaging the supports of the traveling crane which such a building will not infrequently contain.

Since serious damage to V2 buildings is difficult to attain in any event, it is to remarked that, should a given target contain a fair proportion of buildings demanding a shorter fuzing, fuzing of all bombs in this way may be advisable. As explained above, mixed fuzing is not recommended when all the buildings in the target area are attacked indiscriminately.

c. Class V-3

Recommended fuzing is 0.1 sec. nose/0.025 sec. tail.

The principal risk of catastrophe with multi-story steel framed buildings is the side thrust on the walls caused by blast. When the wall panels are blown out, considerable force is applied to the steel columns. Since these columns are tied to the floor, this connection may be severed, and columns, being disconnected from beams, will bow outward. If the bowing out is great enough, the building will cave in. The 0.025 sec. fuzing gives best expectancy of this effect and also produces maximum floor damage as in case of class V-1. The probability of deflagration or ricochet is greatly lessened with this fuzing. Against steel framed buildings, bombs fuzed 0.01 sec. or less would do local damage only; bowing out of the steel frame would either not occur or would be confined to the top story thus precluding collapse of the building.

In reinforced concrete framed multi-story buildings, the connection of beam to column is very strong. However, R. C. columns are not as strong as steel. Steel has very nearly the same strength under compression as in tension. Therefore, blast may lift the top of the building thereby causing the R. C. columns to fail in tension. The building normally is rendered unsafe by this action and frequently collapses. The 0.025 sec. fuzing gives best expectancy of this effect and also produces maximum floor damage as in case of class V-1. The probability of deflagration or ricochet would be much greater with a longer fuzing.

The remarks in Section 3, first paragraph, above apply to machine tools and other contents of multi-story buildings of this type.

d. Class V-3A

Recommended fuzing is 0.1 sec. nose/0.025 sec. tail.

Multi-story wall bearing industrial buildings have heavy walls and floors, increasing in weight toward the foundation. Blast will be very confined. If the blast is sufficient to push the walls out and to lift the floor immediately above the explosion, this floor will rise, sit down on and break the floor below, and thereby collapse the entire building. If the bomb were fuzed 0.1 sec. or longer, it would encounter heavier walls and floors and blast would probably not be sufficient to cause the desired effect. The probability of ricochet and/or deflagration would be considerably higher with 0.1 sec. or longer fuzing. Delay times of 0.01 sec. or less would do local damage only and collapse of the entire building would almost never occur.

As in the previous section, the remarks in Section 3, first paragraph, apply to machine tools and other contents of multi-story buildings of this type.

e. Classes V-4, V-4A and V-5

Recommended fuzing is 0.01 sec. nose/non-delay tail.

Buildings of classes V-4 and V-5 are best destroyed by blast action, with the explosion occurring 6 to 10 feet below roof level. Tail fuzes in use at present are very seldom initiated on the light roofs of these two classes. It is believed that the M139 nose fuze (0,01 delay) will initiate on these light roofs in most cases and will therefore give detonation at the proper point. If, however, this fuze fails to operate the blast will still be obtained by the initiation of the non-delay tail fuze on the floor of the building. Near misses will also be more effective with the ND tail fuze.

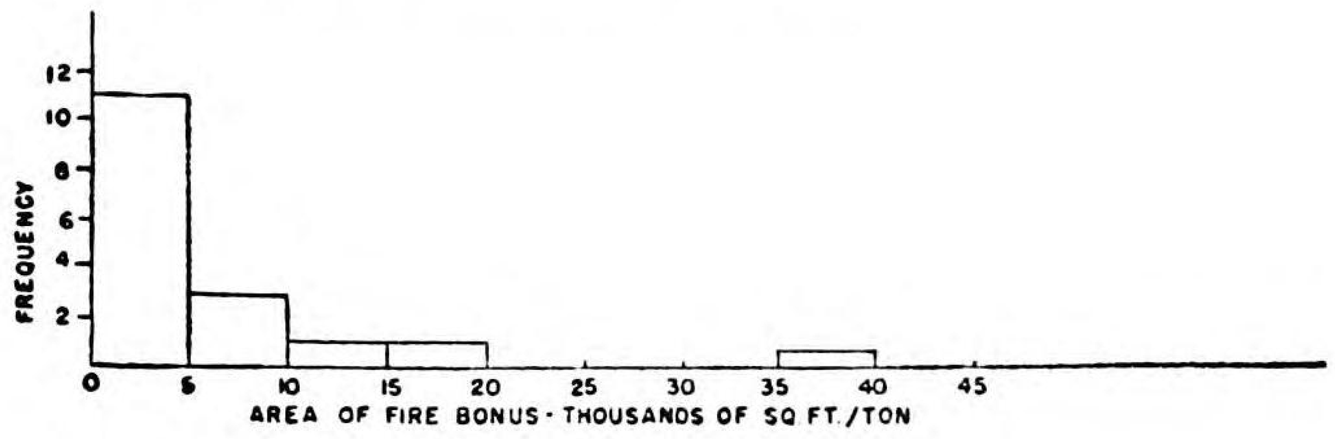
It is to be noted that the fuzing recommended for these types of buildings is identical with that which would be desirable for maximum damage to machine tools or other contents. Appreciable damage to these is to be anticipated in buildings of these types.

f. Recommended Fuzings for L. C. Bombs

Light case (L. C.) bombs must be fuzed either inst. nose/non-delay tail or airburst for all vulnerability classes.

4. Fire from HE

In addition to the normal types of damage caused by HE, there is a possibility that HE explosions will set fire to combustible buildings or to contents of non-combustible buildings. When this occurs, the area destroyed by the bomb is frequently greater than the MAE listed above. The excess of damage over the MAE is called the "fire bonus"—provided this excess is due to fire. A study has been made of the relative frequency and the magnitude of the fire bonus in the attacks on the German aircraft industry by the Eighth Air Force. The study is based on 17 pure HE attacks selected because of the relative reliability of the information available concerning them. From these data, the following graph has been plotted:



The mean fire bonus is 6,500 sq ft/ton.
The median fire bonus is 3,000 sq ft/ton.

The choice between mean and median depends on one's objective in planning. If the average fraction of damage over a long period of attacks is to be as near as possible to the predicted average fraction of damage, the mean fire bonus should be used. This however, will overpredict the damage in many cases, but will underpredict it (rather badly) in a few cases. On the other hand, if one wishes to overpredict as often as one underpredicts, it is the median fire bonus that should be used. This approach puts more emphasis on the individual attack rather than on the average of all attacks. The Joint Target Group calculations are based on the use of the median fire bonus.

It would be an error, however, to add this bonus directly to the MAE given in table III above. For fire bonus can only occur when there is something to burn, and thus it depends on the construction of the target. As explained in the next section, the combustibility of a target is measured by the quantity α. The fire bonus is now introduced in the formula:

$$(3)\quad F = 1 - (1-\alpha)e^{-MD} - \alpha e^{-M''D}$$

where F is the fraction of floor area seriously damaged. Serious damage is the sum of structural damage and severe damage to contents due to internal fire.

α is as defined in the next section.

M is the MAE as given in table III.

M'' is the sum of the MAE in table III plus 6,000 sq ft/ton.

The value of 6,000 sq. ft./ton is obtained from the 17 pure HE raids mentioned above, for which the average value of α was 0.50, by the formula:

$$6{,}000 \text{ sq. ft./ton} = \frac{\text{median fire bonus} = 3{,}000 \text{ sq. ft./ton}}{\text{average } \alpha = 0.50}$$

If it were to be decided to use the mean fire bonus instead of the median, the MAE of table III should be increase by 13,000 sq. ft./ton in order to obtain M''.

C. INCENDIARY BOMBS

1. General Remarks

Incendiary bombs can destroy only the portion of a target which will burn; and consequently it is necessary to make the following classification of buildings:

C—Combustible: Buildings whose roof and/or walls are constructed of combustible material. The floors (except the ground floor) are required to be of similar construction.

N—Noncombustible: Buildings which have no significant amount of combustible material in the structure, but whose structure is susceptible to damage by fire in the contents. An example of this type is a building with exposed steel members—which may be warped irreparably by the heat of a fire. Roofs of this type are: Corrugated asbestos, corrugated iron, precast or pour-in-place cement or gypsum on exposed steel, and reinforced concrete 2½ inches thick or less.

R—Fire-resistive: Buildings which have no significant amount of combustible material in the structure and which will withstand all but the most intense fire without structural damage. Roofs and floors (other than ground) should be of concrete more than 2½ inches thick, and the steel frame should be protected and not subject to ordinary fire damage.

In case of a combination of the above types of construction, the building is classified as "Mixed."

In addition to the classification of buildings, it is necessary to have a quantitative measure of the combustibility of the contents of the *N* and *R* buildings. In these buildings the percent of the top floor area covered by combustible material is called β. There is evidence that if these combustible contents are ignited in an *N* building the fraction of structural damage to the building will average $1.5\,\beta$. In an *R* building the possible fire damage is restricted to the contents.

The structural damage which can be expected from an incendiary attack against buildings classified as stated above can best be expressed in terms of a quantity M', the MAE of the incendiary against a building of that particular class. This quantity (M') plays a role in the incendiary theory similar to that played by the quantity M in the HE theory. Unfortunately it does not have a simple definition, but methods for calculating it will be described below. M' is best defined as a parameter in the equation:

$$(4)\quad F = \alpha(1 - e^{-M'D'})$$

where

F is the fraction of floor area seriously damaged by IB (serious damage is structural damage plus severe damage to contents from internal fire).

D' is the density of IB (tons/thousand square feet).

α is the fraction of the floor area of the target susceptible to damage by fire. (See below for precise definition.)

M' is thus given in thousands of square feet/ton.

For a pure incendiary attack, equation (4) is used for the purpose of predicting the damage to the target. For any such prediction it is clearly necessary to know the values of α and M' which apply to that particular target. M' also must be determined for each incendiary suitable for attacking the target. There are two methods for obtaining the values of these quantities, which will be called the "short" and the "long" methods respectively. These are described below.

2. Method for finding α and M′

a. To find α.

Let: c be the fraction of the floor area of the target in combustible buildings

n be the fraction of the floor area of the target in noncombustible buildings

r be the fraction of the floor area of the target in fire-resistant buildings

β_n be the average of the β values of the N buildings (weighted by the plan areas of these buildings)

β_r be the average of the β values of the R buildings (weighted by the plan areas of these buildings)

L_n be the average number of stories in the N buildings

L_n be the average number of stories in the R buildings

Then α is given by the formula:

(5)
$$\alpha = c + \left(\frac{1.5\beta_n}{L_n}\right)n + \left(\frac{\beta_r}{L_r}\right)r$$

If (as is frequently the case in practice) the buildings are largely single story, and if the total floor area of R buildings is small, this formula may be replaced by the simpler formula:

(5′)
$$\alpha = c + 1.5\beta_n(1-c)$$

If it is desired to estimate the average values of β instead of computing them in detail as described above, the following table may be used. This table refers to typical targets in the categories listed, and should be used for such targets only.

Industrial categories:	*Average Value of* β
Aero engines	0.15
Air frame	.20
Aircraft components	.20
Aircraft repair, overhaul, modification	.25
Armament:	
Ammunition storage	.30
Light ordnance	.20
Heavy ordnance	.10
Electronics	.20
Heavy electrical equipment	.15
Light electrical equipment	.25
Machine tools	.15
Marshalling Yards	.10
Shipbuilding	15
Naval bases	.10

b. To find M′

M′ is computed from the formula:

(6)
$$M' = \frac{cM'_c + n\left(\frac{1.5\beta_n}{L_n}\right)M'_n + r\left(\frac{\beta_r}{L_r}\right)M'_r}{\alpha}$$

where

M'_c is the incendiary MAE against C buildings

M'_n is the incendiary MAE against N buildings

M'_r is the incendiary MAE against R buildings

Under the same circumstances for which formula (5′) is valid, formula (6) may be replaced by the simpler

(6′)
$$M' = \frac{cM'_c + 1.5\beta(1-c)M'_n}{\alpha}$$

The average value of M′ for each of the three classes of buildings (C, N and R) depends on three quantities ($M' = TAP_f$):

(1) P_f is the probability that an incendiary bomb that hits a building will penetrate the roof and start a continuing fire whose presence can be detected from post-attack air cover.

(2) A: For C buildings this is the average floor area of the fire divisions; for N and R buildings it is the average plan area of the combustible zones.

(3) T is the number of incendiary bombs per ton (based on the total weight of the cluster for clustered incendiaries).

A detailed description of how to determine the values of P_f and A is in preparation and will be issued as Appendix C to this memorandum. Pending issuance of this appendix the following approximate method for obtaining M′ may be used.

This approximate method is dependent upon the judgment of incendiary experts and a study of the effects of incendiaries on German aircraft plants which has been carried out by NDRC Project AN-23. For these plants the following values of M′ have been obtained:

	Best of M50, M47, M69, M74[1]	M76
M′c	300,000 sq. ft./ton.	100,000 sq. ft./ton
M′n	130,000 sq. ft./ton.	43,000 sq. ft./ton.

[1]This column refers to that one of these incendiary bombs which is most suitable for the particular target under consideration. For methods of determining which bomb is the most suitable, see below.

In these plants the average size of fire divisions for C buildings, based upon floor area, was 20,000 sq ft. Although the M′ values in table above should not be applied to targets whose contents and structural characteristics are markedly different from those of German aircraft plants, approximate values for M′c and M′n for fairly similar plants may be found as follows:

(1) For C buildings in the selected target, calculate the average size of fire divisions, based upon floor area. Then multiply M'_c given in table above [2] by the ratio of the average size of fire divisions in the selected

2. Combustible buildings in the German aircraft plants had predominantly wood-sheeted roofs, whereas many Japanese combustible buildings have roofs of non-combustible sheeting on wood frame, which are less easily ignited and less likely to support fire spread within the fire division. In general *large* combustible fire divisions in Japanese targets may be assumed to have non-combustible sheeting, and where these are present in a target it is recommended that the value for M'_c in the above table be reduced from 300,000 to 250,000.

It should be remarked that the AN-23 data do not include any incendiary densities higher than 4 tons/million square feet. Thus it is not known whether or not the values for M′ in table above are reliable for higher densities. Furthermore these values assume that the density of IB used is sufficient to overwhelm the firefighters, and therefore they should not be used with very low densities.

target to the average size of fire divisions for German aircraft plants. For example, let the average size of fire divisions for C buildings in the selected target be 10,000 sq ft. Then for the selected target an approximate value of

$$M'_c = 300,000 \times \frac{10,000}{20,000} = 150,000 \text{ sq. ft./ton.}$$

and

(2) For N and R buildings in the selected target, calculate the average size of fire divisions, based upon plan area. If this is more than 10,000 sq ft the M'_n value given in table above for the M50, M47, M69 and M74 can be used for the selected target; if more than 30,000 sq ft the M'_n value given for the M76 can be used. The value of M′ given in table above for M50 and M69 can be used for the selected target regardless of the average size of fire divisions.

c. Choice of Incendiary Bombs

The decision to use the M50, M69, M74, or the M47 depends upon the contents and structural characteristics of the target to be attacked and, therefore, the selection of the preferred bomb shoud be made by an analyst who is thoroughly familiar with the target.

In general, when a detailed analysis of the target has not been made and the M′ values of the various incendiary bombs can not be compared, the analyst has the following considerations to guide him:

(1) Where the target is composed of fire divisions whose average size, based on plan area, is 12,000 sq ft or less, the M50, M69 or M74 is always preferred as the chance of obtaining multiple hits in each fire division and contacting the combustible portion of the contents is greater. (Detailed analyses of 15 Japanese targets in aircraft or armament systems have disclosed the small, clustered bombs to be superior. The M47 is 15 to 40 percent less efficient, weight for weight, than the smaller bombs against most targets. The M76 is less than 50 percent as efficient, weight for weight, as the M47.)

(2) The M47 is equally as effective as the smaller bombs where the target consists principally of large fire divisions (only in three Japanese aero-engine plants has the M47 proved equal to the M50 or M69 in effectiveness when submitted to detailed analysis).

(3) Roofs of Japanese industrial plants are unusually light and therefore penetration is seldom an important consideration. (99 percent of the primary buildings in airframe plants, and 92.5 percent in aero-engine plants have corrugated asbestos, corrugated iron, slate or wood covering. Armament plants appear to be similar.)

(4) Large single bombs (M76 and fire bombs) are preferred for accurate low altitude bombing against individual buildings.

d. Fire Damage to Machinery

In addition to damaging buildings, fires also damage machine tools and other light machinery which, though noncombustible in themselves, are adversely affected by heat. The proportion of tools destroyed or damaged in any given building will be a function of the severity of the fire in which they are involved, and this in turn will be a function of the combustibility of the building and its contents. A recent study of fire damage to machine tools yields the results given in Table IV below, from which it can be seen that the higher combustibility of wood-working shops results in a higher proportion of tools damaged than was found in relatively noncombustible metal-working installations.

TABLE IV

	Percentage of Tools Damaged Out of Total in Area of Damage		
Metal-Working Shops:	Destroyed	Heavily Damaged	Total
Single Story	23	43	66
Multi Story	55	21	76
Wood-Working Shops:			
Single Story	63	30	93
Multi Story	61	20	81

D. MIXED LOADS

Most industrial targets consist of a combustible portion (α) and a noncombustible portion (1— α). Incendiaries are much more effective against the combustible portion than HE bombs, but HE must be dropped if the noncombustible portion is to be destroyed. This leads to the recommendation of a mixed load in which enough IB are carried to burn most of the combustible portion, and enough additional HE to reach the desired level of damage to the whole target.

There exists a mathematical theory leading to the proper IB density and the best estimate of the expected damage from the mixed load. Although this theory gives the appearance of precision, it is only as reliable as the assumptions underlying it; and these have never been completely substantiated. This theory in turn may be replaced by an approximate theory which is entirely satisfactory in practice and which gives results as reliable as the more elaborate mathematical theory. We give both theories, starting with the mathematical theory.

In the mathematical theory the fundamental relation is:

$$(7) \qquad F = 1-(1-\alpha)e^{-MD} - \alpha e^{-M''D-M'D'}$$

where the following notation is used in addition to that previously introduced:

$$M = \frac{r\left(1-\frac{\beta r}{Lr}\right)M_r + n\left(1-\frac{1.5\beta n}{Ln}\right)M_n}{1-\alpha}$$

$$M'' = \frac{cM''_c + n\left(\frac{1.5\beta n}{Ln}\right)M''_n + r\left(\frac{\beta r}{Lr}\right)M''_r}{\alpha}$$

M_c, M_n, M_r are the MAE's for HE for their respective categories of buildings
M''_c, M''_n, M''_r are the corresponding MAE's for HE including fire bonus.

For most targets, however, it is unnecessary to calculate M and M″ by the relatively complicated for-

(240)

mulae just given; instead it is satisfactory to use the average values of these quantities based upon the whole target as described in Section B. In some targets, however, the values of M and M″ for the N and R buildings are markedly different than those for C buildings, and in these cases the above formulae must be used. As an example of such a case consider a target composed of fire-resistant, multistory, earthquake proof, reinforced concrete buildings as well as combustible and relatively vulnerable sheds. Such a case arises in some of the modern electronics plants which have been expanded through the construction of temporary outbuildings.

The use of formula (7) introduces certain complications in the further analysis, and it is customary to replace it by the approximate formula

$$(8) \quad F = 1-(1-\alpha)e^{-MD} - \alpha e^{-MD-M'D'}$$

where now:

α = fraction of the floor area of the target susceptible to fire damage
M = MAE for HE (not including fire bonus)
M′ = MAE for IB
D = HE ground density
D′ = IB ground density

This equation makes no allowance for fire bonus from HE, but the introduction of fire bonus in mixed attacks is not justified by the apparent gain in precision. For in the exponent in the last term of (7), namely —M′D′ —MD″, the M′D′ term is usually predominant and the sum is not significantly changed by the introduction of the fire bonus. For this reason equation (8) is used in the following discussion.

On the basis of equation (8) it is possible to prove by the standard methods of calculus that whatever the total load of HE and IB the greatest fraction of damage will be obtained if—

$$(9) \quad D' = \frac{1}{M'} \log_e \left[\frac{M'-M}{M} \times \frac{\alpha}{1-\alpha}\right]$$

(provided of course that the total load is at least as large as this value of *D′*). This value of *D′* is called the "optimum IB density." It is not necessary, however, to achieve this value of *D′* with any precision; for variations up to 20 percent of the calculated value will not appreciably affect the resulting value of *F*. The rule to be used is then:

(a) If the total load is expected to achieve a ground density less than the value of *D′* given in (10), use all IB.

(b) If the total load is expected to achieve a ground density greater than this value of *D′*, use enough IB to achieve IB ground density of approximately *D′* and put the remaining load into HE.

This mathematical theory may be approximated as follows. It is found in practice that the calculated value of the optimum of *D′* (equation (9)) is such that it will destroy a fraction of the target about equal to 0.8 α. The corresponding optimum value of *D′* may be taken to be 0.008 tons per thousand square feet for the M50, M47, and M69 and 0.020 tons per thousand square feet for the M76. The errors introduced by using this standard density rather than a variable density calculated for each target are within the range of uncertainty of the stated values of M and M′, and hence are permissible in the calculations.

(Note: The appearance of the digit 8 both in "0.8" and in "0.008 tons per thousand square feet" is of course a coincidence, resulting from the choice of units.)

To obtain the required density of HE to add to the IB to achieve a given total fraction of damage, *F*, the following formula is sufficiently accurate:

$$(10) \quad F-.8\alpha = (1-.8\alpha)(1-e^{-MD})$$

or

$$(11) \quad D = \frac{1}{M} \log_e \frac{1}{1-\frac{F-.8\alpha}{1-.8\alpha}}$$

which may be calculated using table B-1 of appendix B. The rule to follow is then:

(a) If the desired *F* is less than .8α, use all IB based on equation (4).

(b) If the desired *F* is greater than .8 α, use a loading designed to achieve ground densities as follows:

D′ = 0.008 tons/thousand square feet for the M50, M69, or M47; or
D′ = 0.020 tons/thousand square feet for the M76.
D = value obtained from equation (11).

Reservations.—The above methods are subject to three important reservations:

(1) *When not to carry IB.*—Although IB are in general the most efficient for destroying the combustible portion of a target, they should not be used if this portion is too small. For if α is small, HE may be in fact more efficient. The question of whether an HE or mixed load is preferable depends upon whether the damage expected from the recommended IB density is greater than or less than the damage expected from an equal density of HE. In terms of the formulae of the approximate theory stated above this amounts to a comparison of .8α (for IB) with $1-e^{-M(.008)}$(for HE in case the IB are M-50, M-47, or M-69) or with $1-e^{-M(.020)}$(for HE in case the IB are M-76). Thus IB may be used if:

$$(12) \quad .8\alpha > 1-e^{-M(.008)} \text{ for the M-50, M-69, M-47}$$

or

$$.8\alpha > 1-e^{-M(.020)} \text{ for the M-76}$$

But for a mixed attack to cause substantially more damage than straight HE this inequality should be more than just barely true. The policy adopted in the Joint Target Group is that IB will be recommended only if:

$$(13) \quad .8\alpha > 1.5(1-e^{-M(.008)}) \text{ for the M-50, M-69, M-47}$$

or

$$.8\alpha > 1.5(1-e^{-M(.020)}) \text{ for the M-76}$$

For example, if M has the typical value of 15,000 sq. ft./ton, the inequalities in (13) require:

$\alpha > .20$ for the M-50, M-47, M-69
$\alpha > .50$ for the M-76

(2) *Minimum HE density.*—In order for the IB to function effectively it is generally believed that they should be accompanied by a small HE density dropped for the purpose of hindering fire-fighting, breaking water mains, etc. The evidence for or against this belief is slight. It is the Joint Target Group policy to recommend a minimum HE density of 0.001 tons/thousand square feet to accompany any quantity of incendiaries. This density of course will be increased if additional HE is required to obtain the desired level of damage.

(3) *Stowage.*—The above treatment has assumed that the limiting factor in determining the loading of an aircraft is the total weight which it can carry. For this reason all tonnages stated above have been the actual weight in tons of the bombs employed. In some cases (notably IBs) these weights differ markedly from so-called "nominal" weights which in fact describe the type of bomb station required to stow this bomb. When space or number of available bomb stations becomes the limiting factor in plane loading, "stowage" factors must be taken into account in determining the composition of a mixed load.

For any bomb, the stowage factor, *K*, is defined as:

$$K = \frac{\text{nominal weight of the bomb or cluster}}{\text{actual weight of the bomb or cluster.}}$$

When space rather than weight is the limiting factor, the *M* or *M'* of each bomb should be *divided* by *K* to obtain a new *M* or *M'* which is then used in the formulae as described above. This will convert these quantities from square feet/ton of actual weight to square feet/nominal ton. This places the measures of their effectiveness of a comparable basis.

The decision to use stowage factors depends solely upon the operational circumstance of the aircraft carrying these bombs. They should be taken into account in the field if circumstances dictate.

E. SAMPLE CALCULATION

An example of the vulnerability calculations on a specimen Japanese Target is attached as Appendix B.

PART II. FORCE REQUIREMENTS

The general principles of weapon selection stated in Part I lead to the requirement of various ground densities of HE and IB in order to achieve given levels of damage. In this section, methods are developed for determining the number of bombs which should be dropped (or dispatched) to obtain these densities. These results may then be applied to determine the required numbers of sorties. Because of the different characteristics of high altitude and low altitude attack, separate treatments are given for these two cases. A final section discusses methods for deciding the number of separate aiming points which should be used in each type of attack.

A. HIGH ALTITUDE ATTACK

1. General Remarks

The fundamental question to be answered is: What fraction of the bombs dropped (or dispatched) may be expected to fall on the site area of the target. Once this fraction is known, the required number of bombs to drop (or dispatch) is obtained by multiplying the ground density by the site area of the target and dividing by this fraction. It will be noted that this procedure assumes that the bomb fall will have a density which is substantially uniform over the target. Although this is never exactly true in practice, this assumption is not likely to give results which will seriously mislead planners. Estimates of force requirements are necessarily of a very approximate character, since it is never possible to predict in advance such important factors as weather conditions, enemy opposition, and the efficiency of bombardiers. Force requirements as described below are believed to be reliable for planning an entire bombing campaign, but predictions for a particular mission are not likely to be exact.

2. Bombing Accuracy

The answer to the fundamental question just raised depends on a knowledge of the bombing accuracy and of the abortive rate of the relevant air force. The determination of these quantities is the function of agencies other than the Joint Target Group, and hence positive recommendations as to methods are not given here. Since, however, the Joint Target Group does publish force requirements, the following discussion of its methods is published as a matter of record.

Bombing accuracy is traditionally measured in terms of CEP (circular probable error). This is the radius of the circle centered on the aiming point which includes half the bomb bursts. This is a good measure of the accuracy if the bombs are individually aimed and hence may be expected to have a "normal" distribution. Current tactics of formation bombing, however, do not result in a normal distribution. And for these the CEP is not a good measure of accuracy. Various mathematical methods for measuring the accuracy of formation bombing have been advanced, but all of these depend upon a knowledge of certain quantities which are still unknown for the operations of the Twentieth Air Force.

In the absence of knowledge of these quantities, the simplest procedure is to examine actual bomb plots of the Twentieth Air Force attacks, and to compute the percent of bombs dropped which fall within circles of 1,000 feet, 2,000 feet, etc., respectively, of the aiming point. This method is particularly convenient since these figures are regularly published by the Twentieth Air Force. In order to have a single measure of accuracy, the percent of bombs dropped *which fall within 1,000 feet of the aiming point* has been chosen. It is found that the percent of bombs dropped which fall within other circles can be reliably stated in terms of the percent falling within 1,000 feet of the aiming point. On the basis of the available evidence (largely XX Bomber Command experience) table IV has been prepared. This table is tabulated for 17, 25, 33, and 50 percent, respectively, of the bombs dropped falling within 1,000 feet of the aiming point, and shows, for each of these accuracies, the percent of bombs that fall within other distances of the aiming point.

TABLE V

Percent of Bombs Dropped Which Fall Within a Distance R of the Aiming Point

R (feet)	Percent of bombs dropped falling within 1,000 feet of aiming point			
	0.17	0.25	0.33	0.50
1,000	0.17	0.25	0.33	0.50
1,100	.18	.28	.38	.57
1,200	.22	.33	.43	.62
1,300	.25	.38	.48	.67
1,400	.28	.42	.53	.72
1,500	.33	.47	.58	.75
1,600	.37	.50	.62	.78
1,700	.40	.53	.65	.82
1,800	.43	.58	.68	.85
1,900	.47	.62	.72	.87
2,000	.50	.67	.75	.92

3. Determination of Tons to Be Dropped or Dispatched

Bombs fall in patterns which are roughly circular, and target areas are in general of other shapes. In order to combine these two in a convenient manner, the target is taken to be a circle whose radius is half the greatest dimension of the site area of the target. It is the area of this circle which is multiplied by the ground density, and divided by the percentage obtained from table V for that radius, which gives the number of tons to be dropped. For convenience in calculating, table VI has been prepared. The entries in table VI are:

$$\frac{\text{Area of circle of radius } R \text{ (in millions of square feet)}}{\text{Fraction of bombs dropped falling in a circle of radius } R}$$

Then for a target of "radius *R*" the number of tons to be dropped is equal to the ground density (in tons/

(240)

million square feet) as obtained in Part I multiplied by the entry in table VI corresponding to the radius *R* and the assumed accuracy (expressed as a percent of the bombs dropped which fall within 1,000 feet of the aiming point).

TABLE VI

Area of Circle of Radius R (million of square feet)

Percent of Bombs Dropped Falling Within a Distance R of the Aiming Point

R (feet)	Percent of bombs dropped falling within 1,000 feet of aiming point			
	0.17	0.25	0.33	0.50
1,000	18	13	9	6
1,100	20	14	10	7
1,200	21	14	11	7
1,300	21	14	11	8
1,400	21	15	12	9
1,500	21	15	12	9
1,600	22	16	13	10
1,700	23	17	14	11
1,800	24	18	15	12
1,900	24	18	16	13
2,000	25	19	17	14

The number of tons to be dispatched may be calculated from the number of tons dropped by taking into account the number of planes which do not reach the target, or upon reaching it make gross bombing errors. The number of tons to dispatch is then equal to the number of tons to be dropped divided by the percent of planes dispatched which reach the target and do not make gross bombing errors.

4. Loading Tables

Force requirements for high altitude attack are published by the Joint Target Group in the form of a "Loading Table" which is included in the WR/1 sheets for each target. A description of this table and an explanation of its use are given in JTG M-3. This loading table states that if a given number of tons are dispatched, and if a given percent (namely, 10, 15, 20, or 30 percent) of the bombs dispatched fall within 1,000 feet of the aiming point, then the load should be divided in a stated fashion between HE and IB and moreover a stated fraction of serious damage may be expected. A few remarks concerning the methods of calculating these tables are pertinent here.

For a given tonnage to be dispatched and for a given percentage of this tonnage which is expected to fall within the circle enclosing the target, the average density of bombs on the target can be computed. For convenience in calculations these ground densities have been calculated in Tables A-3 to A-13 of Appendix A. These tables give the expected ground densities for a wide range of tonnages dispatched, for targets of various radii, and for the four accuracy assumptions.

In calculating these tables the accuracies given in Table V have been used, and it has been assumed that 40 percent of the planes dispatched are either abortives or make gross aiming errors. Since, however, it is the product of these quantities which appears in the loading table, the resulting densities are not sensitive to changes in the rate of abortives and gross errors; and consequently the loading tables are valid for any ordinary value of this rate.

From a knowledge of the proper division of this ground density between HE and IB (as explained in Part I) the proper division of the total load between HE and IB is determined. The expected fraction of damage is then computed from equation (8) in Part I.

To illustrate the full method of analyzing a target and preparing a loading table, a sample analysis has been prepared as Appendix B.

B. LOW ALTITUDE ATTACK

1. Numbers of Hits Required

Targets for this type of attack are usually comparatively small and the requirements are stated in terms of the number of hits desired on each building of the target.

For HE bombs the number of hits required on a building is obtained from the formula:

$$N = \frac{A}{M} \log_e \frac{1}{1-F} \qquad (14)$$

where

F is the fraction of floor area to be damaged;

M is the MAE for HE expressed in square feet, *per* bomb.

A is the plan area of the building.

N is the number of hits required.

This is really formula (1) in slightly different form.

For IB the formula used is:

$$N = \frac{1}{P_f} \log_e \frac{1}{1-F} \qquad (15)$$

where

F for a single fire division is the probability of destroying that fire division; or if a number of fire divisions are involved, *F* is the expected fraction of these divisions that will be destroyed.

P_f is as defined in appendix A.

N is the number of single bomb hits required. In the case of clustered bombs this refers to the number of single bombs, not the number of clusters.

$$\text{The number of clusters required} = \frac{(\text{Area of cluster pattern}) \times (\text{Number of single hits required})}{(\text{Plan area of building}) \times (\text{Number of bombs in a cluster})}$$

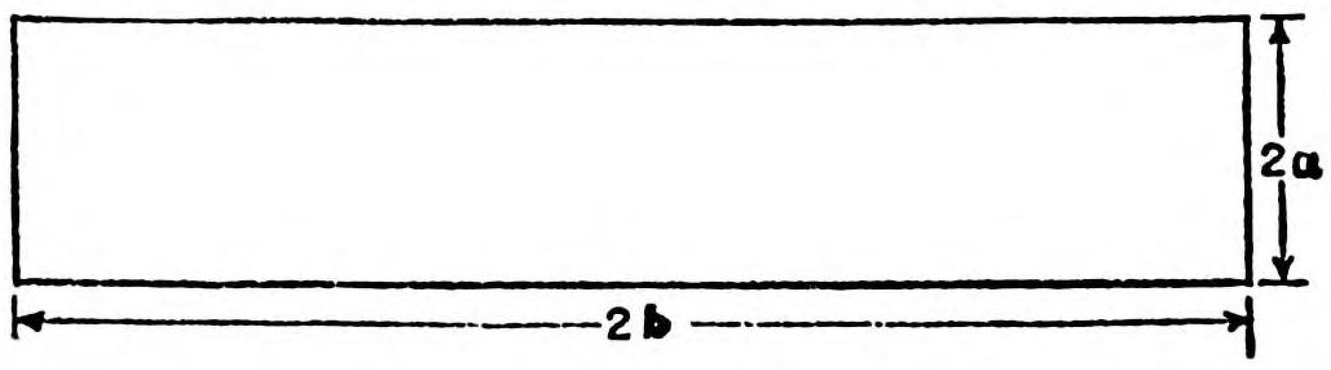
provided the cluster pattern is larger than the area of the building.

2. Number of Bombs Dropped

It is assumed for this type of attack that the bombs will have a "normal" distribution about the aiming point. The following discussion, though mainly intended for low level attack, applies equally to any altitude of attack by individual aircraft (rather than formations). For any such attack is expected to produce a normal distribution of bombs. The accuracy of bombing is then measured in terms of the CEP. The number of bombs which should be dropped depends upon the CEP, the number of hits required, and upon the degree of assurance one desires to associate with obtaining the required number of hits.

The first step in this computation is to obtain the "Single shot probability" (SSP). The following discussion of SSP will be limited to three cases: *(a)* rectangular target with the aiming point at its center; *(b)* rectangular target with aiming point displaced; *(c)* circular target. Calculations for other shapes of targets are beyond the scope of this memorandum.

a. Rectangular target—dimensions 2*a* and 2*b*. Aiming Point at the center.

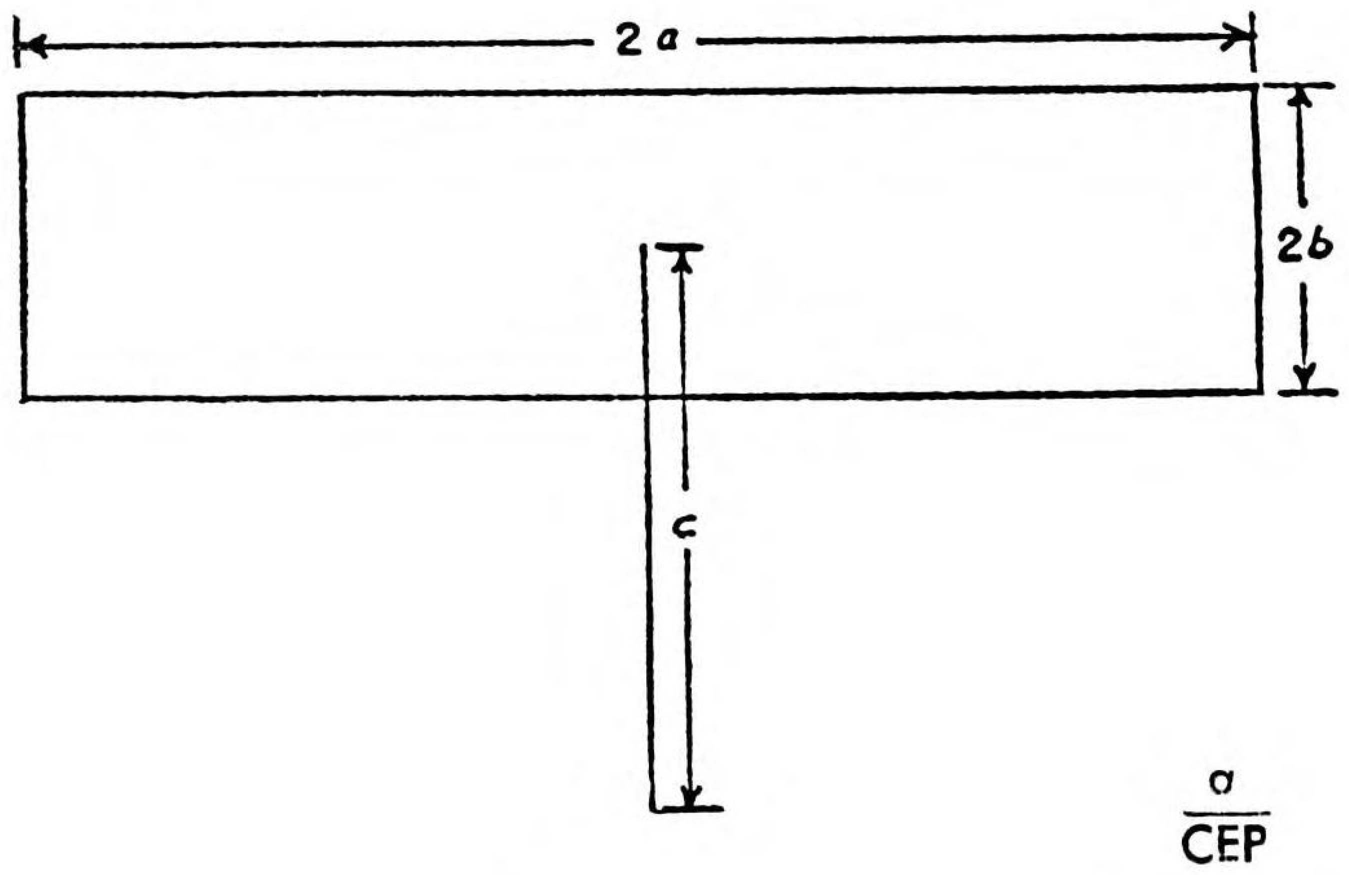


Compute *a*/CEP and *b*/CEP. Enter table A-2 of appendix A (Modified Table of the Normal Curve) with these two numbers in turn and obtain from the table respectively *P*(*a*/CEP) and *P*(*b*/CEP). The product of these two values is the SSP.

Example: *a*=200 feet; *b*=500 feet; CEP=250 feet.

$a/\text{CEP}=0.8;\ P(0.8)=0.653.$
$b/\text{CEP}=2.0;\ P(2.0)=0.981.$
$\text{SSP}=(0.981)(0.653)=0.64.$

b. Rectangular target—dimensions 2*a* and 2*b*. Aiming point offset along one axis of the rectangle a distance c from the center. (See fig. below.)



Compute $a/\text{CEP};\ \frac{c+b}{\text{CEP}};\ \frac{c-b}{\text{CEP}}$

Then from the Modified Table of the Normal Curve obtain the corresponding values of

$P(a/\text{CEP});\ P\left(\frac{c+b}{\text{CEP}}\right);$ and $P\left(\frac{c-b}{\text{CEP}}\right).$

Then:

$$\text{SSP}=P(a/\text{CEP})\times\frac{P\left(\frac{c+b}{\text{CEP}}\right)-P\left(\frac{c-b}{\text{CEP}}\right).}{2}$$

Example: $a=500$ feet; $b=100$ feet; $c=400$ feet; CEP = 250 feet.

$a/\text{CEP}=2.0;\ P(2.0)=0.981.$

$\frac{c+b}{\text{CEP}}=2.0;\ P(2.0)=0.981.$

$\frac{c-b}{\text{CEP}}=1.2;\ P(1.2)=0.841.$

$$\text{SSP}=(0.981)\left(\frac{0.981-0.841}{2}\right)=0.069.$$

c. Circular target, radius *R*.

The formula to use is:

$$\text{SSP}=1-\exp\left[-\frac{1}{2}\left(\frac{R}{0.85\ \text{CEP}}\right)^2\right]$$

If no table of the powers of e is available, the table of $\log_e \frac{1}{1-F}$ (see appendix A, table A-1) can be used to find the SSP. To do this first compute $-\frac{1}{2}\left(\frac{R}{0.85\ \text{CEP}}\right)^2$ and find the entry in the body of table B-1 nearest to this value. Then read off the corresponding value of *F*—this is the SSP.

Example: $R=100$ feet; CEP = 250 feet.

$\frac{1}{2}\left(\frac{R}{0.85\ \text{CEP}}\right)^2=0.111.$
$\text{SSP}=0.10.$

As to the "degree of assurance" desired, the usual requirement is for this to be 0.50. The systematic use of this figure will result in half the attacks obtaining at least the desired number of hits, and in half the attacks obtaining less than the required number of hits. This is the most effective policy to adopt in planning an extensive bombing campaign; but for particular vital objectives a higher degree of assurance may be required.

For a 0.50 degree of assurance, the number of bombs to be dropped is obtained from the formula:

$$\text{Number of bombs dropped}=\frac{\textit{Number of hits required}}{\text{SSP}}$$

The requirement for higher degrees of assurance usually occurs when it is desired to be quite sure of obtaining *at least one hit* or a target, for example, because the target is so vulnerable that one hit is sufficient to destroy it. In this case the formula to use is:

(16) $$P=1-(1-\text{SSP})^N$$

where

P is the degree of assurance.
N is the number of bombs to be dropped.

The solution of this equation is given by reference to the graphs in Plates I-III in the appendix A.

On occasion it is desired to find the number of bombs which must be dropped when at *least one hit* is desired on *each* of several small targets which can all be attacked with a single aiming point. This problem can be solved by using formula (17) above by replacing *P* in the formula by $\sqrt[K]{P}$ where *K* is the number of separate targets. The same procedure is followed as before except that Plates I-III are entered with $\sqrt[K]{P}$ instead of with *P*.

C. SELECTION OF AIMING POINTS

This section discusses methods for choosing the number of aiming points and for locating those which are chosen. The fundamental principle is that multiple aiming points should be chosen whenever doing so will reduce the total number of tons which must be dropped to do the desired damage, ignoring operational considerations.

For high level attack, reference should be made to table V. It will be recalled that this table gives numbers by which the ground densities should be multiplied in order to get the number of tons to be dropped. When these numbers become greater than twice the corresponding numbers for a target of half the original radius, two aiming points are recommended. Analysis of a more detailed table similar to table V gives the result:

Percent of bombs dropped falling within 1,000 feet of aiming point	Use two aiming points if greatest dimension of target is greater than—
17	7,600
25	6,000
33	3,800
50	2,800

These recommendations, though roughly correct, should be used only in conjunction with a study of the shape and other characteristics of a particular target.

For low level attack it is assumed that the bombs have a normal distribution which will be measured in terms of its σ (sigma) which is equal to 0.85 CEP. In this case the following general guides may be stated:

a. Aiming points should ordinarily be spaced uniformly over the target about 2σ apart.

b. The spacing of aiming points can be caried considerably with little reduction in the expected amount of damage.

c. For low densities, all aiming points should be kept well away from the boundaries of the target. However, for high densities the aiming points nearest the boundaries should be placed closer to the boundaries than in the low density case. This will increase the number of bombs missing the target altogether, but will more evenly distribute those hitting the target.

d. Targets less than 3σ in length require only one aiming point.

e. Targets of length 3σ to 6σ require two aiming points.

f. Targets of length 6σ to 8σ require three aiming points.

These recommendations are based on a study prepared by the Applied Mathematics Panel, which had not appeared in final form as of the date of this memorandum.

APPENDIX A

TABLES, DIAGRAMS AND ILLUSTRATIONS

TABLE A-1

$\log_e \frac{1}{1-F}$ in terms of F

[Enter left-hand border with first decimal place of F; enter top border with second decimal place of F; read $\log_e \frac{1}{1-F}$ from body of table]

	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.000	0.010	0.020	0.030	0.041	0.051	0.062	0.073	0.083	0.094
.1	.105	.117	.128	.139	.151	.163	.174	.186	.198	.211
.2	.223	.236	.248	.261	.274	.288	.301	.315	.328	.342
.3	.357	.371	.386	.400	.416	.431	.446	.462	.478	.494
.4	.511	.528	.545	.562	.580	.598	.616	.635	.654	.673
.5	.693	.713	.734	.756	.777	.798	.821	.844	.868	.892
.6	.916	.942	.968	.994	1.022	1.050	1.079	1.109	1.139	1.171
.7	1.204	1.238	1.273	1.309	1.347	1.386	1.427	1.470	1.514	1.560
.8	1.609	1.661	1.715	1.772	1.833	1.897	1.966	2.040	2.120	2.207
.9	2.303	2.408	2.526	2.659	2.813	2.996	3.219	3.507	3.912	4.605

TABLE A-2

Modified Table of the Normal Curve

$$X = \frac{\text{linear dimension}}{\text{CEP}}$$

Entries in table give $P(X) = \frac{1.18}{\sqrt{2\pi}} \int_{-x}^{x} e^{-\frac{1}{2}(1.18)^2} dx$

X	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.000	0.009	0.018	0.028	0.038	0.047	0.056	0.066	0.075	0.084
.1	.094	.103	.112	.122	.131	.140	.149	.159	.168	.177
.2	.186	.195	.204	.213	.222	.231	.240	.249	.258	.267
.3	.276	.285	.294	.302	.311	.320	.328	.337	.345	.354
.4	.362	.371	.379	.387	.396	.404	.412	.420	.428	.436
.5	.444	.452	.460	.467	.475	.483	.490	.498	.505	.513
.6	.520	.527	.535	.542	.549	.556	.563	.570	.577	.583
.7	.590	.597	.603	.610	.616	.623	.629	.635	.642	.648
.8	.654	.660	.666	.672	.677	.683	.689	.694	.700	.705
.9	.711	.716	.721	.726	.731	.737	.742	.747	.751	.756
1.0	.761	.766	.770	.775	.779	.784	.788	.792	.796	.801
1.1	.805	.809	.813	.817	.820	.824	.828	.832	.835	.839
1.2	.842	.846	.849	.852	.856	.859	.862	.865	.868	.871
1.3	.874	.877	.880	.883	.885	.888	.891	.893	.896	.898
1.4	.901	.903	.905	.908	.910	.912	.914	.916	.919	.921
1.5	.923	.925	.926	.928	.930	.932	.934	.935	.937	.939
1.6	.940	.942	.944	.945	.947	.948	.949	.951	.952	.953
1.7	.955	.956	.957	.958	.960	.961	.962	.963	.964	.965
1.8	.966	.967	.968	.969	.970	.971	.971	.972	.973	.974
1.9	.975	.975	.976	.977	.978	.978	.979	.980	.980	.981
2.0	.981	.982	.983	.983	.984	.984	.985	.985	.986	.986
2.1	.987	.987	.987	.988	.988	.989	.989	.989	.990	.990
2.2	.990	.991	.991	.991	.992	.992	.992	.992	.993	.993
2.3	.993	.993	.994	.994	.994	.995	.995	.995	.995	.995
2.4	.995	.996	.996	.996	.996	.996	.996	.996	.997	.997
2.5	.997	.997	.997	.997	.997	.997	.998	.998	.998	.998
2.6	.998	.998	.998	.998	.998	.998	.998	.998	.998	.998
2.7	.999	.999	.999	.999	.999	.999	.999	.999	.999	.999
2.8	.999	.999	.999	.999	.999	.999	.999	.999	.999	.999
2.9	.999	.999	.999	.999	.999	.999	1.000	1.000	1.000	1.000

TABLE A-3

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,000 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	3.2	4.8	6.4	9.6
200	6.4	9.6	13	19
300	9.6	14	19	29
400	13	19	26	38
500	16	24	32	48
600	19	29	38	58
700	22	34	45	67
800	26	38	51	77
900	29	43	58	86
1,000	32	48	64	96
1,100	35	53	70	106
1,200	38	58	77	115
1,300	42	62	83	125
1,400	45	67	90	134
1,500	48	72	96	144
1,600	51	77	102	154
1,700	54	82	109	163
1,800	58	86	115	173
1,900	61	91	122	182
2,000	64	96	128	192

TABLE A-4

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,100 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.9	4.5	6.0	8.9
200	5.8	8.9	12	18
300	8.7	13	18	27
400	12	18	24	36
500	14	22	30	45
600	17	27	36	54
700	20	31	42	63
800	23	36	48	72
900	26	40	54	80
1,000	29	45	60	89
1,100	32	49	67	98
1,200	35	54	73	107
1,300	38	58	79	116
1,400	40	63	85	125
1,500	43	67	91	134
1,600	46	72	97	143
1,700	49	76	100	152
1,800	52	80	109	161
1,900	55	85	115	170
2,000	58	89	121	179

TABLE A-5
Ground Densities Corresponding to Various Total Loads and to Various Accuracies
[Radius of target = 1,200 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.9	4.4	5.7	8.1
200	5.7	8.8	11	16
300	8.6	13	17	24
400	11	18	23	33
500	14	22	29	41
600	17	26	34	49
700	20	31	40	57
800	23	35	46	65
900	26	40	52	73
1,000	29	44	57	81
1,100	32	48	63	90
1,200	34	53	69	100
1,300	37	57	74	106
1,400	40	62	80	114
1,500	43	66	86	122
1,600	46	70	92	130
1,700	49	75	97	138
1,800	52	79	100	146
1,900	54	84	109	155
2,000	57	88	114	163

TABLE A-6
Ground Densities Corresponding to Various Total Loads and to Various Accuracies
[Radius of target = 1,300 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.8	4.3	5.5	7.5
200	5.6	8.7	11	15
300	8.5	13	16	23
400	11	17	22	30
500	14	22	27	38
600	17	26	33	45
700	20	30	38	53
800	23	35	44	60
900	25	39	49	68
1,000	28	43	55	75
1,100	31	48	60	83
1,200	34	52	66	90
1,300	37	56	71	98
1,400	40	61	76	105
1,500	42	65	82	113
1,600	45	69	87	120
1,700	48	74	93	128
1,800	51	78	98	136
1,900	54	82	104	143
2,000	56	87	109	151

TABLE A-7
Ground Densities Corresponding to Various Total Loads and to Various Accuracies
[Radius of target = 1,400 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.8	4.1	5.2	7.0
200	5.5	8.1	10	14
300	8.3	12	16	21
400	11	16	21	28
500	14	20	26	35
600	17	24	31	42
700	19	28	36	49
800	22	32	42	56
900	25	36	47	63
1,000	28	41	52	70
1,100	30	45	57	77
1,200	33	49	62	84
1,300	36	53	68	91
1,400	39	57	73	98
1,500	41	61	78	105
1,600	44	65	83	112
1,700	47	69	88	119
1,800	50	73	94	126
1,900	52	77	99	133
2,000	55	81	104	140

TABLE A-8
Ground Densities Corresponding to Various Total Loads and to Various Accuracies
[Radius of target = 1,500 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.8	4.0	5.0	6.4
200	5.7	7.9	9.0	13
300	8.5	12	15	19
400	11	16	20	25
500	14	20	25	32
600	17	24	30	38
700	20	28	35	44
800	23	32	40	51
900	26	36	45	57
1,000	28	40	50	64
1,100	31	44	54	70
1,200	34	48	60	76
1,300	37	52	64	83
1,400	40	55	69	89
1,500	42	59	74	95
1,600	45	63	79	102
1,700	48	67	84	108
1,800	51	71	89	114
1,900	54	75	94	121
2,000	57	79	99	127

TABLE A-9

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,600 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.7	3.7	4.6	5.8
200	5.5	7.5	9.2	12
300	8.2	11	14	18
400	11	15	18	23
500	14	19	23	29
600	16	22	28	35
700	19	26	32	41
800	22	30	37	47
900	25	34	41	53
1,000	27	37	46	58
1,100	30	41	51	64
1,200	33	45	55	70
1,300	36	48	60	76
1,400	38	52	64	82
1,500	41	56	69	88
1,600	44	60	74	93
1,700	47	63	78	99
1,800	49	67	83	105
1,900	52	71	87	111
2,000	55	75	92	117

TABLE A-10

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,700 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.6	3.5	4.3	5.4
200	5.3	7.5	8.6	11
300	7.9	11	13	16
400	11	14	17	22
500	13	18	22	27
600	16	21	26	32
700	18	25	30	38
800	21	28	34	43
900	24	32	39	49
1,000	26	35	43	54
1,100	29	39	47	59
1,200	32	42	52	65
1,300	34	46	56	70
1,400	37	49	60	76
1,500	40	53	64	81
1,600	42	56	69	86
1,700	45	60	73	92
1,800	48	63	77	97
1,900	50	67	82	103
2,000	53	70	86	109

TABLE A-11

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,800 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.6	3.4	4.0	5.0
200	5.1	6.9	8.1	10
300	7.6	10	12	15
400	10	14	16	20
500	13	17	20	25
600	15	21	24	30
700	18	24	28	35
800	20	28	32	40
900	23	31	36	45
1,000	26	34	40	50
1,100	28	38	44	55
1,200	31	41	48	60
1,300	33	45	52	65
1,400	36	48	56	70
1,500	38	52	60	75
1,600	41	55	64	80
1,700	43	58	68	85
1,800	46	62	72	90
1,900	48	65	77	95
2,000	51	69	81	100

TABLE A-12

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,000 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.5	3.3	3.8	4.6
200	4.9	6.5	7.6	9.2
300	7.4	9.8	11	14
400	9.9	13	15	18
500	12	16	19	23
600	15	20	23	28
700	17	23	26	32
800	20	26	30	37
900	22	29	34	41
1,000	25	33	38	46
1,100	27	36	42	50
1,200	30	39	46	55
1,300	32	42	49	60
1,400	35	46	53	64
1,500	37	49	57	69
1,600	40	52	61	73
1,700	42	55	64	78
1,800	44	59	68	82
1,900	47	62	70	87
2,000	49	65	76	92

TABLE A-13

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 2,000 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10 percent	15 percent	20 percent	30 percent
	Tons per million square feet			
100	2.4	3.2	3.6	4.4
200	4.8	6.4	7.2	8.8
300	7.2	9.6	11	13
400	9.6	13	14	18
500	12	16	18	22
600	14	19	22	26
700	17	22	26	31
800	19	26	29	35
900	22	29	32	39
1,000	24	32	36	44
1,100	26	35	39	48
1,200	29	38	43	53
1,300	31	41	46	57
1,400	34	45	50	61
1,500	36	48	54	66
1,600	38	51	57	70
1,700	41	54	61	74
1,800	43	57	64	79
1,900	45	60	68	83
2,000	48	64	72	88

PROBABILITY OF AT LEAST ONE HIT VS. NUMBER OF BOMBS DROPPED FOR VARIOUS VALUES OF THE SINGLE SHOT PROBABILITY

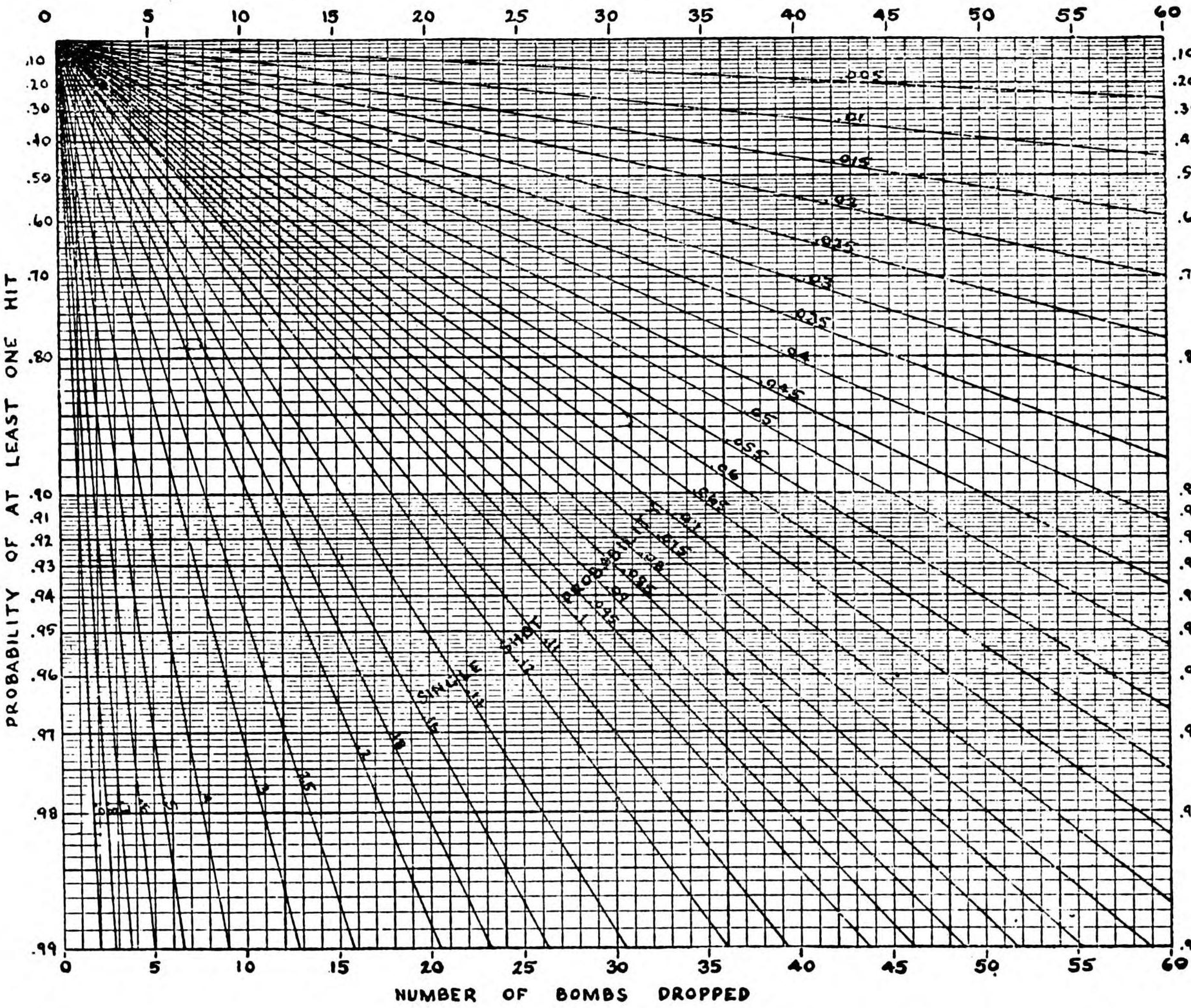


FIG. No. 15

PROBABILITY OF AT LEAST ONE HIT VS. NUMBER OF BOMBS DROPPED FOR VARIOUS VALUES OF THE SINGLE SHOT PROBABILITY

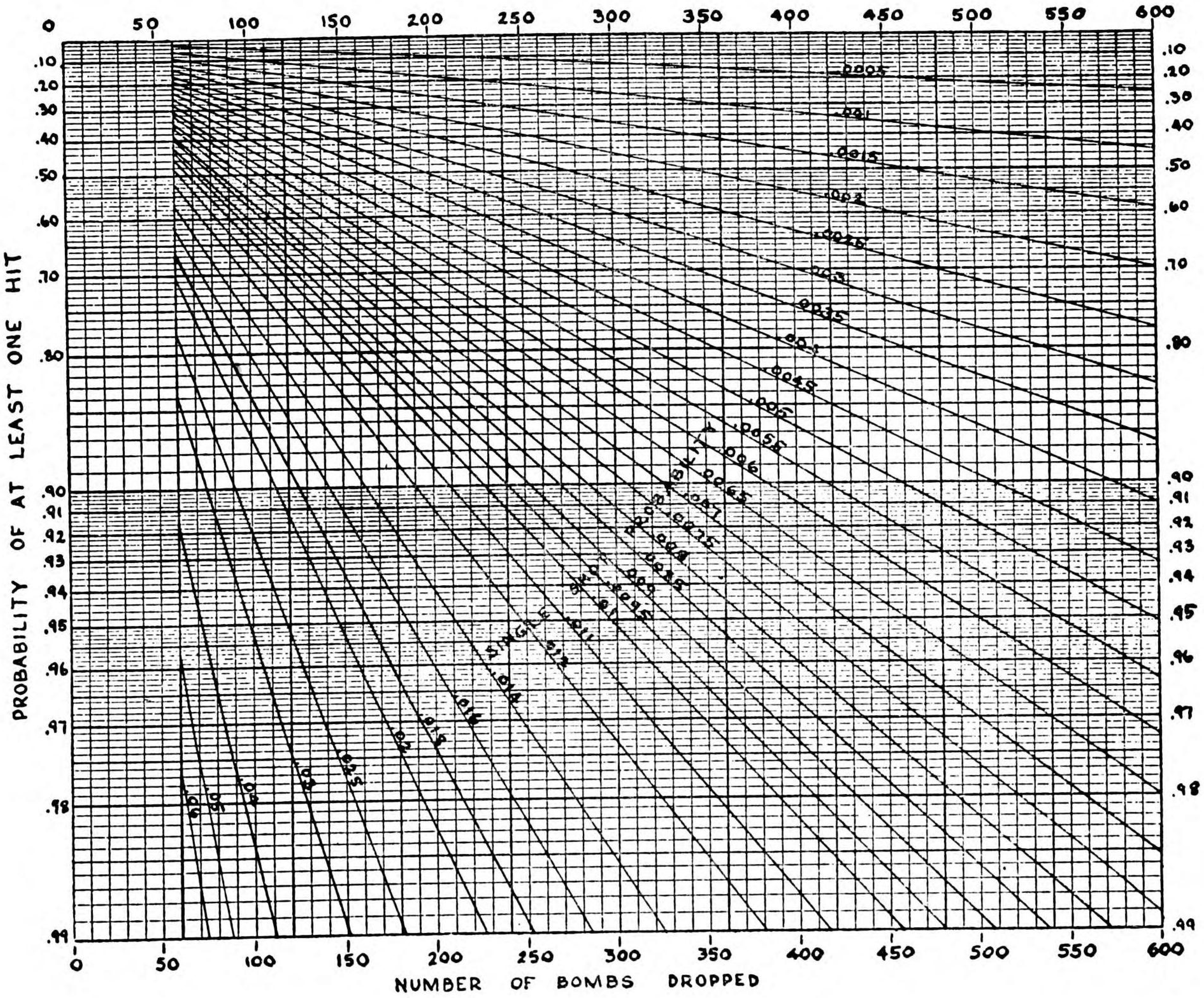


FIG. No. 16

PROBABILITY OF AT LEAST ONE HIT VS. NUMBER OF BOMBS DROPPED FOR VARIOUS VALUES OF THE SINGLE SHOT PROBABILITY

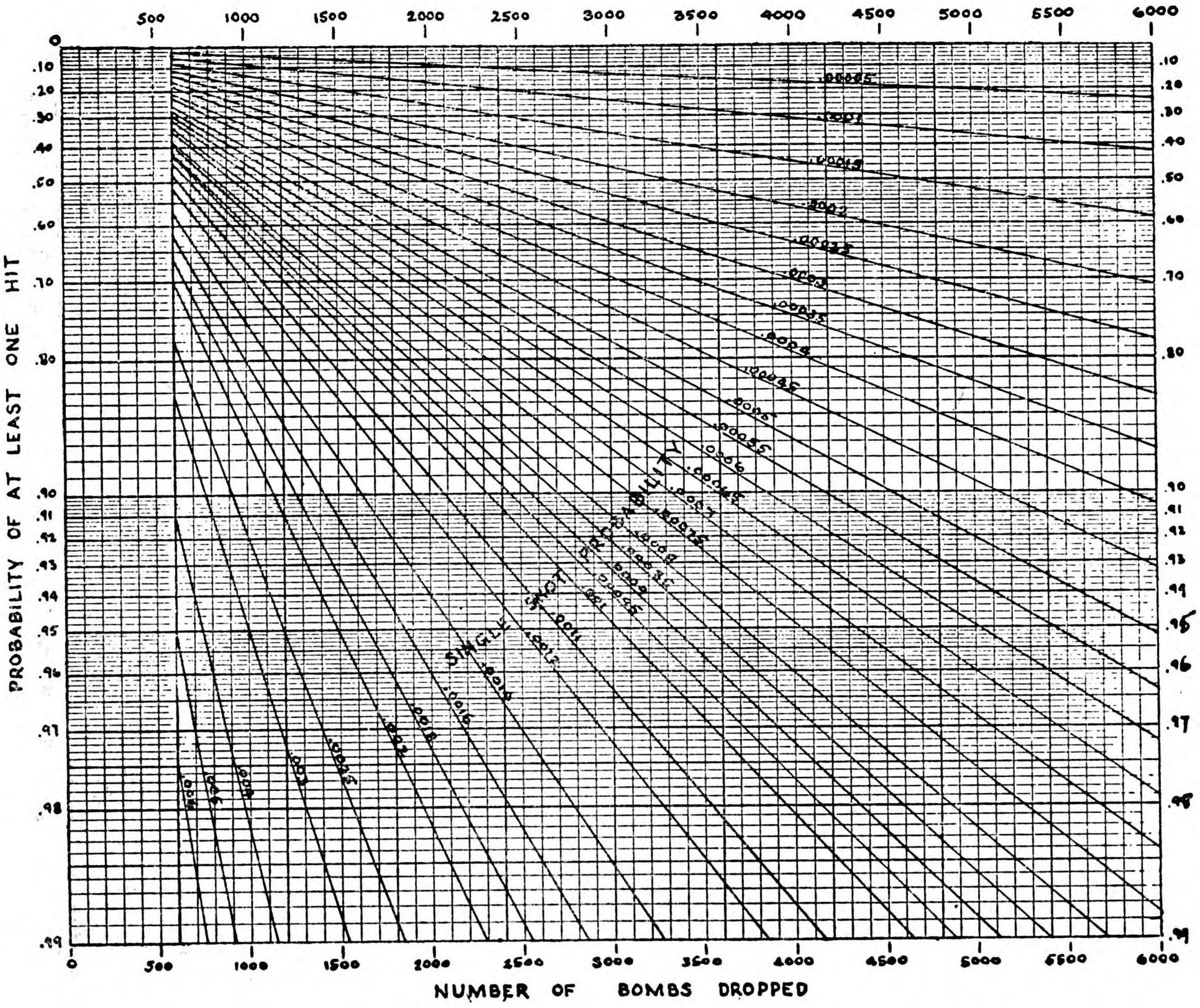


FIG. No. 17

APPENDIX B
SAMPLE TARGET VULNERABILITY ANALYSIS

A. INTRODUCTION

To illustrate the calculations required for a complete target vulnerability analysis, the following computations on the Kisarazu Aircraft Engine Plant at Kisarazu, Japan (90:14-2016) are presented in detail. Examination of the target site reveals that the plant consists of two sections, a southeast portion containing all the primary and secondary buildings, and a northwest portion which has been dropped from the analysis since it is of relatively little importance and would only serve to increase force requirements with a resultant wastage of effort. All calculations based on the southeastern portion of the plant and treated in accordance with the principles outlined in the text of JTG M-8, are shown and explained. Suggested work sheets are included.

References apply to the text of JTG M-8.

B. DATA REQUIRED

1. Functional analysis (type of occupancy of each building).

2. Structural analysis of each building. It should supply the following: building number (corresponding to that assigned in paragraph 3 below), number of fire divisions, fire susceptibility type (see JTG M-8–I), plan area, number of floors, floor area, and HE vulnerability class.

3. Plant layout. JTG uses a plan to a scale of 1:6000 (500 feet to the inch) for target Illustration P5, Fire Susceptibility Plan. Numbers assigned to buildings and sub-buildings on this sheet are used consistently for all references to the particular target buildings.

Below is a compilation of the data on the important southeast portion (buildings 21-52) of the Kisarazu Aircraft Engine Plant.

Bldg. No.	No. of fire Divisions	Type	Plan Area thsnd. sq. ft.	No. Floors	Floor Area thsnd. sq. ft.	Occupancy	HE Vuln. class
21	1	C	17.8	1	17.8	Unidentified	V4
23	1	C	5.2	1	5.2	Storage	V4
24	1	C	4.3	1	4.3	Storage	V4
25	1	C	8.0	1	8.0	Storage	V4
26	1	C	6.0	1	6.0	Storage	V4
27	1	C	5.2	2	10.4	Storage	V3
28	1	C	6.0	1	6.0	Unidentified	V4
29a	1	C	6.0	1	6.0	Unidentified	V4
29b	1	C	2.1	1	2.1	Unidentified	V4
30	1	C	6.0	1	6.0	Unidentified	V4
31	1	C	6.0	1	6.0	Unidentified	V4
32	1	C	9.9	1	9.9	Unidentified	V4
33	1	C	4.2	1	4.2	Storage	V4
34	1	C	11.0	1	11.0	Unidentified	V4
36	1	C	6.3	1	6.3	Storage	V4
37	1	N	28.4	1	28.4	Shop	V4
38	1	N	13.2	1	13.2	Small machine shop	V4
39	1	N	13.2	1	13.2	Small machine shop	V4
40a	3	C	6.0	1	6.0	Office	V4
40b	3	C	4.6	1	4.6	Office	V4
40c	3	C	6.0	1	6.0	Office	V4
40d	3	C	2.5	1	2.5	Office	V4
41	1	N	12.1	1	12.1	Small shop	V4
42	1	N	6.6	1	6.6	Small shop	V4
43	1	C	4.0	2	8.0	Unidentified	V3
44	1	C	4.2	1	4.2	Storage	V4
45	1	C	4.2	1	4.2	Storage	V4
46	1	C	4.2	1	4.2	Storage	V4
47	1	N	19.0	1	19.0	Shop	V4
49	1	N	110.9	1	110.9	Engine repair	V4
50	1	N	88.0	1	88.0	Engine repair	V4
51	1	R	30.6	1	30.6	Engine test cells	S
52	1	R	30.6	1	30.6	Engine test cells	S
			Total Plan Area = 492.3		Total Floor Area = 501.5		

Note: Buildings 22, 35, and 48 have been removed.

C. CALCULATIONS FOR , M′, M

1. Preliminary calculations

a. A fire susceptibility plan should be prepared showing C, N, R, and Mixed buildings (by color code if desired). Refer to 90:14-2016–P5.

b. Values of β (the percentage of top floor area occupied by combustible material) are assigned to each building by an experienced fire engineer.

c. Primary and secondary objectives are determined from the functional analysis. These are shown on the fire susceptibility plan also. Primaries and secondaries are recorded in the following table.

Primary and Secondary Objectives listed in order of importance.

Bldg. No.	Plan Area (thsnd. sq. ft.)	Stories	Roof*	Combustibility Type	HE Vulnerability
49	110.9	1	Light	N	V4
50	88.0	1	Light	N	V4
47	19.0	1	Light	N	V4
37	28.4	1	Light	N	V4
38	13.2	1	Light	N	V4
39	13.2	1	Light	N	V4

*Lightweight roofs are readily penetrated by all types of incendiary bombs. Initiation of HE tail fuzes by these roofs cannot be depended upon except for bombs striking structural members (30 to 40 percent of bombs striking buildings).

2. Summary of final calculations. A suggested summary sheet is shown below.

1. Target number 90:14-2016
2. Name .... Kisarazu Aircraft Engine Plant
3. Section designation .... Southeast section, Bldgs. 21-52
4. Section site area .... App. 1500 x 1900 or 2,850,000 sq. ft.
5. Radius of target circle .... 1000 feet
6. Aiming point .... Vicinity bldg. 39
7. Plan area of buildings .... 492,300 sq. ft.
8. Floor area of buildings .... 501,500 sq. ft.
9. Ratio of floor area to plan area 1.02
10. c (Fraction of floor area in C buildings) 0.30
11. n (Fraction of floor area in N buildings) 0.58
12. r (Fraction of floor area in R buildings) 0.12
13. β for N and R buildings 0.15
14. L (Average number of floors in N and R buildings) 1.00
15. α (Fraction of floor area subject to fire damage) 0.45
16. Preferred IB (incendiary bomb) .... M50, M69 or M74
17. M′c (Expected damaged to C bldgs. per ton of best IB) ...... 105 000 sq. ft.
18. M′n (Expected damage to vulnerable portion of N bldgs. per ton of best IB) .... 130,000 sq. ft.
19. 6′(Expected damage to vulnerable portion of whole target per ton) 110,000 sq. ft.

20. HE vulnerability (Fraction of total floor area in each class):

Classification	Primary and Secondary Objectives	Whole Target
V1 -story	0	0
V2 1-story	0	0
V3 2-story	0	0.02
V3A -story	0	0
V4 1-story	1.00	0.86
V5 1-story	0	0
S (Test cells)	0	0.12

21. MAEs against primaries (Mean area of effectiveness per ton of high explosives) .... 500-lb GP ...... 15,600 sq. ft.; 1000-lb GP ...... 16,100 sq. ft.; 2000-lb GP ...... 14,400 sq. ft.
22. Preferred HE bomb .... 1000-lb GP
23. MAEs against whole target (per ton) .... 500-lb GP ...... 14,800 sq. ft.; 1000-lb GP ...... 15,000 sq. ft.; 2000-lb GP ...... 13,400 sq. ft.
24. M (Expected damage to whole target per ton of preferred HE). 15,000 sq. ft.
25. RESULTS:
    α 0.45
    M′ .... 110,000 sq. ft.
    M .... 15,000 sq. ft.

3. Explanation of final calculations (Numbers correspond to item numbers of the preceding summary):

(5) Buildings 21 to 52 (the SE portion) fall within a circle whose radius is 1000′. This is known as the "target circle" upon which calculations are based.

(6) Aiming point should be in the vicinity of building 39, the approximate center of the target area. With a normal bomb pattern all primaries and secondaries may be expected to receive hits.

(9) Ratio of Floor Area to Plan Area $= \frac{501.5}{492.3} = 1.02$

(10) Floor area of C buildings is 148,900 sq. ft. $c = \frac{148.9}{501.5} = 0.30$

(11) Floor area of N buildings is 291,400 sq. ft. $n = 0.58$

(12) Floor area of R buildings is 61,200 sq. ft. $r = 0.12$

(13) β may be assigned from the table of values given on page .., paragraph ... The average β assigned to N and R buildings is computed by multiplying the assigned β of each building by its plan area, adding the products, and dividing by the sum of the plan area as follows:

β for N and R buildings			
N & R Bldgs. No.	Plan Area (thousand sq. ft.) A	β	βX Plan Area βA
37	28.4	0.20	5.68
38	13.2	0.20	2.64
39	13.2	0.20	2.64
41	12.1	0.20	2.42
42	6.6	0.20	1.32
47	19.0	0.20	3.80
49	110.9	0.15	16.60
50	88.0	0.20	17.60
51	30.6	0.01	0.306
52	30.6	0.01	0.306
	A = 352.6		βA = 53.31

$\beta = \frac{\Sigma \beta A}{\Sigma A} = \frac{53.31}{352.6} = 0.15$ (Same as estimated value in this case).

(14) All N and R buildings in this target are single story. Average number of floors is 1.00. When multistory buildings are encountered procedure is as follows. Divide the total floor area in N and R buildings by the total plan area. The quotient is the average number of floors.

(15) $\alpha = c + 1.5\beta_n(1 - c)$ (Equation 5′, page 12)
$\alpha = 0.30 + 1.5(0.15)(0.70) = 0.46$ or 0.45

(Values are rounded off to nearest 0.05)

(16) Target consists of numerous small combustible buildings and larger noncombustible buildings and fire resistant test cells. Since the average size fire division in the combustible buildings is small (less than 10,000 sq. ft.), the M50, M69 or M74 IB's are recommended. (See M-8–I, paragraph (1), page 15.)

(17-18) Paragraph 2b, page 13, in M-8–I gives an average M′c of 300,000 square feet and an average M′n of 130,000 square feet for German aircraft plants. The M′c value is based on an average size fire division of 20,000 square feet. In this Japanese plant, however, the average size combustible fire division is only 7000 square feet, but construction is similar to German aircraft plants. Therefore, 300,000 is multiplied by the fraction $\frac{7000}{20,000}$ to give an M'c for this plant of 105,000 square feet. M'n is independent of the average size of fire divisions except when the size is small (approximately 10,000 sq. ft. or less) but is dependent upon the characteristics of building contents. The contents of this Japanese plant are similar to those of German aircraft plants. Therefore, M'n is assumed to be 130,000 square feet per ton.

(19)
$$\frac{c(M'_c) + 1.5\beta_n(1-c)(M'_n)}{c + 1.5\beta_n(1-c)}$$
(Equation 6', page 13)

$$= \frac{0.30(105,000) + 1.5(0.15)(0.70)(130,000)}{0.30 + 1.5(0.15)(0.70)}$$

$= 114,000$ or 110,000 square feet

(Values of M' are rounded off to nearest 10,000)

(20) Number of stories of each V1, V3, and V3A classes are recorded from the structural analysis. Fraction of total floor area in each class is computed from the structural analysis, and recorded.

(21-24) M is calculated in the following work table.

Primaries and Secondaries							
Vuln. class	MAE			Percentage of plan area	MAE x % plan area		
	500 (1)	1000 (2)	2000 (3)		500	1000	2000
V4	4100	8000	15000	1.00	4100	8000	15000
				Totals =	4100	8000	15000
				Totals ÷ floor area / plan area of primaries (1.0) =	4100	8000	15000
				M (per ton) =	15600	16100	14400
Whole Target							
V3	1900	3900	7800	0.02	38	78	156
V4	4100	8000	15000	0.86	3520	6880	12900
S	3400	5000	10000	0.12	408	600	1200
				Totals =	3966	7558	14256
				Totals ÷ 1.02 =	3888	7410	13976
				M (per ton) =	14800	15000	13400

a. Values of MAE for columns (1), (2), and (3), from Tables III and IIIb, page 9 in M-8—I. The footnote to Table III states that MAE's for VI and V3 classes are to be divided by the number of stories in the building. Using a shortcut which gives the same result, MAE's are used *as listed* in Table III, and the multistory effect is considered by dividing the "Totals" figures by the ratio of floor area to plan area. This figure is then multiplied by the number of bombs per ton to get M. With TNT filling, use 3.8 for 500 lb., 2.02 for 1000 lb., and 0.96 for 2000 lb. GP bombs.

b. The bomb which produces the greatest M, calculated against the primaries and secondaries only, is the preferred HE bomb. M of 16100 dictates use of 1000 lb. GP.

c. For ground density calculations, M is based on the whole target, and is that of the preferred bomb. M is therefore 15000 sq ft/ton for this target.

D. FORCE REQUIREMENTS FOR HIGH LEVEL ATTACK

1. Optimum IB Density

The optimum IB density may be computed from

$D' = \frac{1}{M'} \log_e \left[\frac{M'-M}{M} \times \frac{\alpha'}{M}\right]$ (equation (9), page 15).

In the interest of expediency, when a number of targets are to be analyzed, a graphical method is preferred. Fraction of Damage, F, is plotted against Density, D, on semi-logarithmic paper, F being on the log scale *inverted,* and D on the normal scale. See Figure B-1.

The HE portion of the total damage is given by

$F = 1 - e^{-MD}$ (eauation (1), page 8.)

Since the plot of this equation is a straight line on semi-log paper, only one point other than F = 0, D = 0, need be located. For D = 35 tons/million sq. ft. and M = 15,000 sq. ft./ton, F is 0.409. The line connecting this point and (0,0) is the HE damage curve (Curve I).

IB damaae is given bv $F' = \alpha(1 - e^{-M'D'})$ (Equation 4).

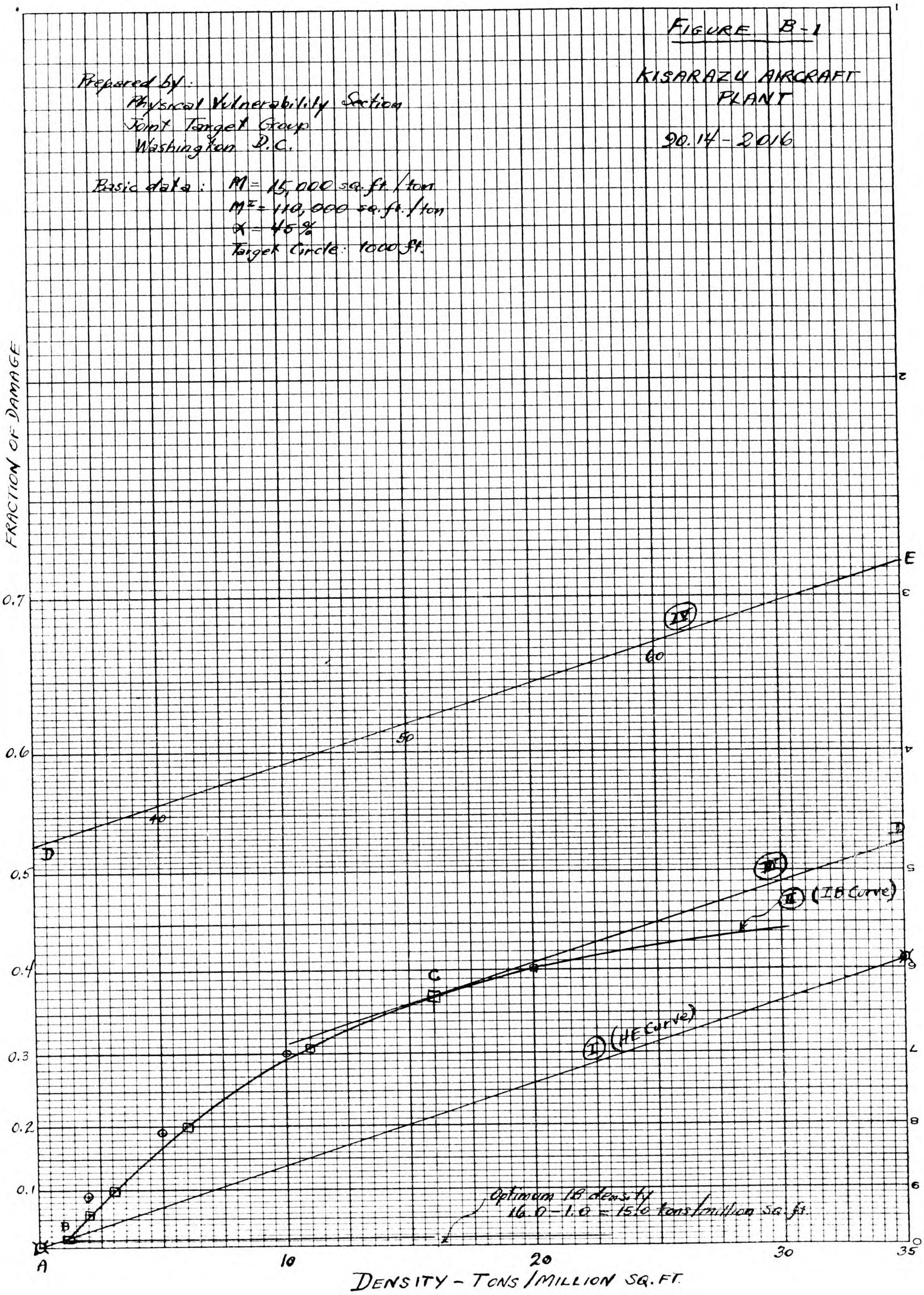


FIGURE B-1
KISARAZU AIRCRAFT PLANT
90.14-2016
Prepared by:
Physical Vulnerability Section
Joint Target Group
Washington D.C.
Basic data: M = 15,000 sq.ft./ton
M' = 110,000 sq.ft./ton
α = 45%
Target Circle: 1000 ft.
FRACTION OF DAMAGE
DENSITY - TONS/MILLION SQ.FT.
(IB Curve)
(HE Curve)
Optimum IB density
16.0 - 1.0 = 15.0 tons/million sq.ft.

Solving for values of D′ of 1, 2, 5, 10, and 20 tons/million sq. ft., F is found to be 0.047, 0.089, 0.189, 0.300, and 0.400, respectively. These points are indicated on the graph by the small circles.

A minimum HE density of 1 ton/million sq. ft. is recommended to support even a "pure" incendiary attack in order to interfere with fire fighting activities; hence the resulting expected damage should be considered. In plotting fraction of damage against IB density, then, density values are increased by 1, and the increment of damage (vertical portion of *AB*) is added graphically. This series of points is shown by the small squares, and the smooth curve joining them is the IB curve (II).

Now if a straight line (III), parallel to line (J), is drawn tangent to curve II, the point of tangency, C will be at the optimum IB density. Line IV is the continuation of III.

The working graph of F against D is then the line *ABCDE* which shows the total expected damage for densities ranging from 0 to 50 tons/million sq. ft., and with optimum IB density = 15.0 tons/million sq. ft.

2. Loading Table for High Level Attack

a. Table A-3, Appendix A, is reproduced below.

TABLE A-3

Ground Densities Corresponding to Various Total Loads and to Various Accuracies

[Radius of target = 1,000 feet]

Total load in tons	Percent of bombs dispatched expected to fall within 1,000 feet of aiming point			
	10%	15%	20%	30%
	Tons per million square feet			
100	3.2	4.8	6.4	9.6
200	6.4	9.6	13	19
300	9.6	14	19	29
400	13	19	26	38
500	16	24	32	48
600	19	29	38	58
700	22	34	45	67
800	26	38	51	77
900	29	43	58	86
1000	32	48	64	96
1100	35	53	70	106
1200	38	58	77	115
1300	42	62	83	125
1400	45	67	90	134
1500	48	72	96	144
1600	51	77	102	154
1700	54	82	109	163
1800	58	86	115	173
1900	61	91	122	182
2000	64	96	128	192

For a target whose radius is 1000 ft., a load of 100 tons and an accuracy of 10% will achieve a ground density of 3.2 tons/million sq. ft. F may be found for this load by equation (8), (where D is the minimum HE density of 1 ton/million sq. ft. and D′ is the remainder or 2.2 tons/million sq. ft.). However, the graph previously drawn proves its worth by giving a graphical solution to equation (8). Entering the curve at a density of 3.2, F is found to be on the order of 0.10 (to the nearest 0.05). Similarly, 200 tons gives D = 6.4 and F = 0.20. In a like manner we find F to be 0.35, 0.50, and 0.60 for loads 500, 1000, and 1500 tons, respectively. F of 0.60 is considered the upper limit of predictions. The method is carried out to find F corresponding to the same loads at accuracies of 15%, 20%, and 30%.

b. To find the distribution of HE and IB in the total loads, only two values must be determined for each accuracy expectation, namely, the number of tons of HE which will give the minimum ground density of 1 ton/million sq. ft., and the number of tons of IB which will produce the optimum IB density. With an accuracy of 10%, 3.2 tons/million sq. ft. will result if 100 tons are carried. Only 1 ton of HE is desired. Therefore, $\frac{1}{3.2}$ x 100 or 30 tons of the 100 should be HE. (Values here are rounded off to the nearest 5 tons.) For 15% accuracy, $\frac{1}{4.8}$ x 100 or 20 tons should be HE. For 20%, 15 tons HE; for 30%, 10 tons HE. Thus we have the minimum HE loads for the four categories of accuracy.

Examination of Table A-3 shows that, for any accuracy, loads of 400 tons or more will achieve densities in excess of the optimum for IB, 15 tons/million sq. ft. Any of these loads may be used for the calculation of IB tonnages. Using 500 tons, densities of 16, 24, 32, and 48 tons/million sq. ft. will result, according to the accuracy category. Since only 11 tons/millions sq. ft. are desired to be IB, the corresponding IB tonnages (to the nearest 5 tons) should be: $\frac{15}{16}$ x 500 or 470 tons (10%), $\frac{15}{24}$ x 500 or 310 tons (15%), $\frac{15}{32}$ x 500 or 240 tons (20%), and 155 tons (30%).

The loading table may now be completed as follows:

100 tons, 10%: IB = 100 — 30 = 70 tons
200 tons, 10%: IB = 200 — 30 = 170 tons
500 tons, 10%: HE = 500 — 470 = 30 tons
1000 tons, 10%: HE = 1000 — 470 = 530 tons
1500 tons, 10%: HE = 1500 — 470 = 1030 tons

The remainder of the table for the other three accuracy columns are determined in the same manner. The completed table is shown below.

LOADING TABLE FOR INITIAL ATTACK

Loading Table for Prefered Combination of Bombs[2]

Tons (Actual) Dis-patched	Percent of bombs dispatched falling within 1000 feet of aiming point											
	10%			15%			20%			30%		
	Tons HE	Tons IB	F[1]	Tons HE	Tons IB	F[1]	Tons HE	Tons IB	F[1]	Tons HE	Tons IB	F[1]
100	30	70	10	20	80	15	15	85	20	10	90	30
200	30	170	20	20	180	30	15	185	35	45	155	40
500	30	470	35	190	310	45	260	240	50	345	155	60
1000	530	470	50	690	310	60						
1500	1030	470	60									

[1]Expected percent of serious damage to the whole target.
[2]If alternative bombs are used, the distribution of load between HE and IB should be the same. The expected percent of damage will, of course, be lower.

E. FORCE REQUIREMENTS FOR LOW LEVEL ATTACK

The table of number of hits required in a low level attack is based on F of 0.50 for each building and may be found from equation (14), page 00. $N=\frac{A}{M}\log_e\frac{1}{1-F}$

$\log_e\frac{1}{1-0.5}=0.693$ (Table A-1, App. A).

The following work sheet may be used for computations.

Bldg. No.	Floor Area	Vuln. Class	MAE			Floor Area ÷ MAE			0.693 x A/MAE		
			500	1000	2000	500	1000	2000	500	1000	2000
49	110.9	V4	4100	8000	15000	27.0	13.9	7.4	18.7	9.6	5.1
50	88.0	V4	4100	8000	15000	21.5	11.0	5.0	14.9	7.6	3.46
47	19.0	V4	4100	8000	15000	4.6	2.4	1.3	3.2	1.7	0.9
37	28.4	V4	4100	8000	15000	6.9	3.55	1.9	4.8	2.46	1.3
38	13.2	V4	4100	8000	15000	3.2	1.65	0.9	2.2	1.1	0.6
39	13.2	V4	4100	8000	15000	3.2	1.65	0.9	2.2	1.1	0.6

When F is 0.3, $\log_e\frac{1}{1-F}=0.357$, and when F is 0.7; $\log_e\frac{1}{1-F}=1.204$.

Conversion factors for the required number of hits to achieve 30% and 70% serious damage are then

$$\frac{0.357}{0.693}=0.515 \text{ or } 0.5 \qquad \frac{1.204}{0.693}=1.74 \text{ or } 1.7$$

The table of number of hits as it appears on WR2 sheets then becomes:

NUMBER OF HITS

Number of Hits Required to Achieve 50% Serious Damage to Individual Buildings[1]

Buildings in order of importance to production	Number of Hits			Fuzing
	500 lb GP	1000 lb GP	2000 lb GP	
49	19	10	5	0.01 N/ND T
50	15	8	3	0.01 N/ND T
47	3	2	1	0.01 N/ND T
37	5	2	1	0.01 N/ND T
38	2	1	1	0.01 N/ND T
39	2	1	1	0.01 N/ND T

[1]To obtain the number of hits required to achieve 30 percent serious damage to individual important buildings, multiply the appropriate entry in the preceding table by 0.5; for 70 percent damage, multiply by 1.7.

F. FUZING OF HE BOMBS

Recommendations of fuzing for preferred HE bombs are made in accordance with the principles outlined in paragraph 3e, M-8–I. Against Class V4 buildings proper fuzes are 0.01 N/ND T.

The value of 6,000 sq. ft./ton is obtained from the 17 pure HE raids mentioned above, for which the average value of α was 0.50, by the formula:

$$6{,}000 \text{ sq. ft./ ton} = \frac{\text{median fire bonus} = 3{,}000 \text{ sq. ft./ton}}{\text{average } \alpha = 0.50}$$

If it were to be decided to use the mean fire bonus instead of the median, the MAE of table III should be increased by 13,000 sq. ft./ton in order to obtain M''.

C. INCENDIARY BOMBS

1. General Remarks

In order to determine the vulnerability of a target to IB, an analysis is first prepared giving the combustibility categories of the various buildings. In addition to this, it is necessary to have a quantitative measure of the combustibility of the contents of the *N* and *R* buildings. In these buildings the percent of the top floor area covered by combustible material is called β. There is evidence that if these combustible contents are ignited in an *N* building the fraction of structural damage to the building will average 1.5 β. In an *R* building the severe fire damage is usually restricted to the contents.

The structural damage which can be expected from an incendiary attack against buildings classified as stated above can best be expressed in terms of a quantity M', the MAE of the incendiary against a building of that particular class. This quantity (M') plays a role in the incendiary theory similar to that played by the quantity *M* in the HE theory. Unfortunately it does not have a simple definition, but methods for calculating it will be described below. M' is best defined as a parameter in the equation:

$$(4) \quad F=\alpha(1-e^{-M'D'})$$

where

F is the fraction of floor area seriously damaged by IB (serious damage is structural damage plus severe damage to contents from internal fire).

D' is the density of IB (tons/thousand square feet).

α is the fraction of the floor area of the target susceptible to damage by fire. (See below for precise definition.)

M' is thus given in thousands of square feet/ton.

For a pure incendiary attack, equation (4) is used for the purpose of predicting the damage to the target. For any such prediction it is clearly necessary to know the values of α and M' which apply to that particular target. M' must be determined for each incendiary suitable for attacking the target.

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JOINT TARGET GROUP
WASHINGTON, D. C.
FIRE SUSCEPTIBILITY PLAN

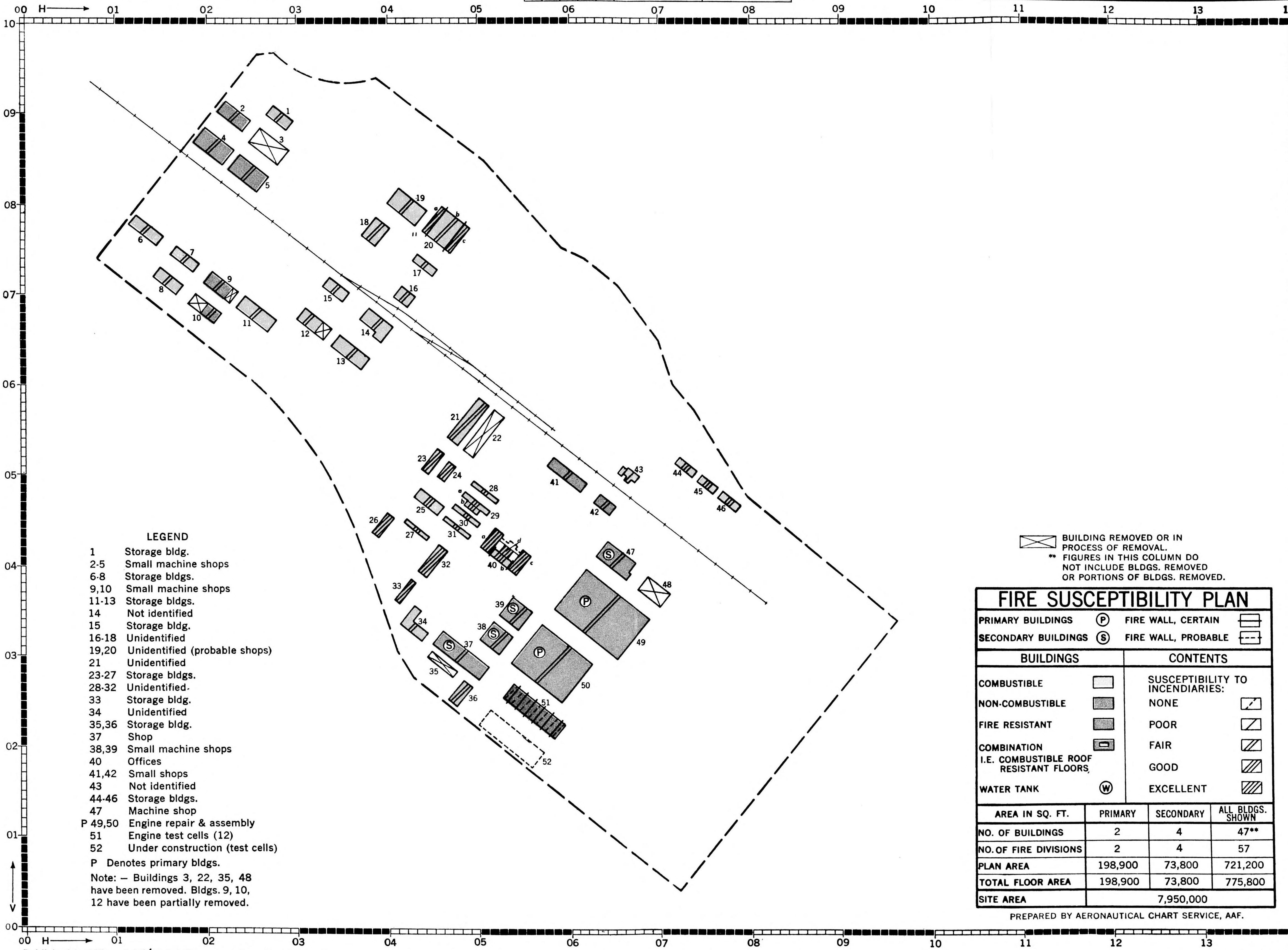
KISARAZU AIRCRAFT ENGINE PLANT, KISARAZU, JAPAN

SCALE 1:6,000

500 0 500 1000 FEET

SHEET	90:14-2016—P5
DATE	28 April 1945
TARGET	90:14-2016
COORDINATES	35°19'N 139°55'E
PHOTOGRAPHED	13 December 1944 and 2 April 1945

REPRINT



LEGEND

1	Storage bldg.
2-5	Small machine shops
6-8	Storage bldgs.
9,10	Small machine shops
11-13	Storage bldgs.
14	Not identified
15	Storage bldg.
16-18	Unidentified
19,20	Unidentified (probable shops)
21	Unidentified
23-27	Storage bldgs.
28-32	Unidentified.
33	Storage bldg.
34	Unidentified
35,36	Storage bldg.
37	Shop
38,39	Small machine shops
40	Offices
41,42	Small shops
43	Not identified
44-46	Storage bldgs.
47	Machine shop
P 49,50	Engine repair & assembly
51	Engine test cells (12)
52	Under construction (test cells)

P Denotes primary bldgs.

Note: — Buildings 3, 22, 35, 48 have been removed. Bldgs. 9, 10, 12 have been partially removed.

BUILDING REMOVED OR IN PROCESS OF REMOVAL.

** FIGURES IN THIS COLUMN DO NOT INCLUDE BLDGS. REMOVED OR PORTIONS OF BLDGS. REMOVED.

FIRE SUSCEPTIBILITY PLAN

PRIMARY BUILDINGS (P)	FIRE WALL, CERTAIN
SECONDARY BUILDINGS (S)	FIRE WALL, PROBABLE

BUILDINGS	CONTENTS
COMBUSTIBLE	SUSCEPTIBILITY TO INCENDIARIES:
NON-COMBUSTIBLE	NONE
FIRE RESISTANT	POOR
COMBINATION I.E. COMBUSTIBLE ROOF RESISTANT FLOORS,	FAIR
	GOOD
WATER TANK (W)	EXCELLENT

AREA IN SQ. FT.	PRIMARY	SECONDARY	ALL BLDGS. SHOWN
NO. OF BUILDINGS	2	4	47**
NO. OF FIRE DIVISIONS	2	4	57
PLAN AREA	198,900	73,800	721,200
TOTAL FLOOR AREA	198,900	73,800	775,800
SITE AREA	7,950,000		

PREPARED BY AERONAUTICAL CHART SERVICE, AAF.

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File No. 65,133

JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET..............M-9
DATE.....21 June 1945
PAGE................1

J.T.G. No. 9 – BOMB DATA SHEET, No. 4
(Bomb, Incendiary, 500-lb., AN-M76)

INTRODUCTION

This is the fourth in a series of data sheets issued on the characteristics of incendiary bombs. See also JTG M-4 (M-17, M-17A1) JTG M-6 (M-18 (E6R2)), JTG M-7 (M47A2).

1. Bomb, Incendiary, 500-lb., AN-M76

Actual weight: 473 pounds.
Length: 59.2 inches.
Diameter: 14.2 inches.
Thickness of case: 0.3 inch.
Bombing table: 500–F–2.
Weight of incendiary filling: 175 pounds.
Composition of filling: Finely divided magnesium, gasoline, and IM polymer to form a paste.
Total heat liberated: 2,210,000 Btu.
Burning time: 20 minutes (approximate).

2. Fuze, Nose Impact, AN-M103 and Tail Inertia, AN-M101A2

Fuze, Nose Impact, AN-M103A1:

Actual weight: 3.7 pounds.
Over-all length: 7 inches.
Maximum diameter: 2.7 inches.
Functioning: Instantaneous.
Arming time: 330 vane revolutions, 1,000 feet air travel; minimum altitude to arm: 185 feet at plane speed 200 mph.

Fuze, Tail Inertia, AN-M101A2:

Actual weight: 2.9 pounds.
Over-all length: 12.6 inches.
Maximum diameter: 1.5 inches.
Functioning: Nondelay.
Arming time: 555 feet air travel; minimum altitude to arm: 60 feet at plane speed 200 mph.

3. Burster, AN-M14

Actual weight: 2 pounds (approximate).
Length: 35.8 inches.
Diameter: 1.43 inches.
Contains 1.25 pounds of tetrytol.

4. Igniter, AN-M5

Weight: 20 pounds.
Length: 35-5/16 inches.
Diameter: 3.2 inches.
Contains 9 pounds of white phosphorus.

5. Ballistic Data

Striking velocity from 25,000 feet: 1,000 ft./sec. (approximate). Trajectory is almost identical to that of the AN-M64, 500-lb GP bomb, trail difference at 250 mph and 25,000 feet being only 12 mils.

6. Penetration

Will penetrate 12 inches of reinforced concrete from 25,000 feet.

7. Plane Loadings

Can be carried on all 500-lb bomb stations of Army and Navy planes.

8. Remarks and Recommendations as to Uses of the AN-M76

a. On functioning on hard ground or concrete, burning fuel is scattered over a radius of 150 feet. On soft ground the fuel is largely confined to the crater.

b. The M76 is far too large a weapon for most incendiary attacks. Only in low level or dive bombing against single targets, or against targets that require high penetration (greater than 5 inches of reinforced concrete) is this bomb preferred. Clustered small bombs have proved more effective for medium and high altitude bombing against industrial and urban areas.

JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET M-10
DATE.......7 May 1945
PAGE 1

J.T.G. No. 10 – BOMB DATA SHEET No. 5
CLUSTER, AIMABLE, INCENDIARY BOMB, 500-LB., E48

1. Cluster, Aimable, 500-lb., E48

Total weight: 525 lbs.
Overall length: 59.5 inches
Diameter: 14.75 inches
Cluster adapter: E23
Bombing table: 500-T-1
No. of bombs: 38 M74
Weight of bombs: 320 lbs.
Weight of fuel: 107 lbs.
Total heat liberated: 1,440,000 Btu.

2. Fuze, Tail, Mechanical Time, M-152 (T53E1)

Fuze Functioning: Aerial burst, 5 to 92 seconds after release from plane. Clock and arming vane freed simultaneously by the withdrawal of the arming wire. The fuze is armed by the revolving of the vanes in from 2 to 3 seconds (200 mph.). The firing pin, then held solely by the trip mechanism of the clock work, is released at the end of the set time period, and the fuze functions.

Fuzing of the E48: With the E23 cluster adapter, two (2) M-152 tail fuzes are used. One acts with a 31-inch length of primacord which is channeled to the cluster tail retaining cup. On fuze functioning, the retaining cup is blown off, the tail drags in the wind stream and on separating from the cluster withdraws the cluster buckle release wires, thereby mechanically releasing the individual M74 bombs. The second fuze, insurance against failure of the first, is set to function 2 seconds after the first. This acts with a 60-inch length of primacord extending the entire length of the cluster, detonation of which explodes the holding straps and opens the cluster. A lower percentage of malfunctioning bombs due to air bursts is believed to result from the mechanical opening of the cluster.

3. Ballistic Data

Striking velocity of unopened cluster from 25,000 ft.: 910 ft/sec (approx.).

Recommended altitude for cluster opening: 5000 ft. (dropped from above 10,000 ft.).

Striking velocity of the individual M74 bombs when cluster is dropped from 25,000 ft., opening at 5000 ft.: 250 ft/sec (approx.).

The ballistics of the E48 make it unsuitable for dropping with HE bombs from the same plane. The E48 will trail the AN-M30, 100-lb. G.P. bomb, by 38 mils when dropped from 25,000 ft., cluster opening at 5000 ft., plane air speed 250 mph.

4. Plane Loadings

	B-17 or B-24 (max.)	B-29 or B-32 (max.)
No. of clusters/plane......	12	40
Total load, lbs/plane......	6300	21000
Weight of bombs lbs/plane	3840	12800
Incendiary fuel, lbs/plane..	1284	4280
Bombs/plane	456	1520
Bombs/group (9 planes)...	4104	13680
Bombs/group (12 planes)...	5472	18240

5. Bomb Patterns

Individual cluster pattern (cluster opening at 5000 ft.): 95% in circle 200 yds. in diameter. Bomb pattern/group (release altitude: 25,000 ft., minimum intervalometer, cluster opening at 5000 ft.)

12 B-17's or B-24's	12 B-29's
1700 x 1700 ft.	2500 x 2400 ft.
2,890,000 sq. ft.	6,000,000 sq. ft.
321,000 sq. yds.	667,000 sq. yds.
66 acres	127 acres
.10 sq. miles	.22 sq. miles

6. Ground Densities

	Groups of: 12 B-17's	12 B-29's
Sq. yds./bomb	58.7	36.5
Actual tons of bombs/acre....	.26	.56
Actual tons of bombs/sq. mile..	163	349

7. Bomb, Incendiary, 10-lb., M74

Actual weight: 8.4 lbs.
Length: 19.5 inches
Diameter (across flats): 2⅞ inches
Weight of fuel: {2.8 lbs. PT mixture; 0.4 lbs. WP}
Total heat liberated: 38,000 Btu.
Normal terminal velocity: 250 ft/sec.
Fuzing: M-142 (all-ways fuze), functioning instantaneous
Overall length (with telescopic tail extended): 24.4 inches
Burning time: 4-7 minutes

8. Penetration

Striking velocity M74: 250 ft/sec (approx.), cluster released at 25,000 ft., opening at 5000 ft. Will penetrate heavy roof construction—3 inches concrete.

9. Performance, Probability, E48 Cluster containing M74 bombs

Malfunctions	Percentage
Clusters not opening..................	4
Air bursts	3.5
Fuze failures, mechanical failures.........	2

Probability of bomb functioning as expected: (.96) (.965) (.98) = .91.*

10. Remarks and Recommendations as to Uses of the E48 Cluster

a. The M74 contains a charge of white phosphorous which obscures the initial fire center and acts as an effective deterrent to fire fighters.

* This factor, a characteristic of the bomb; does not consider the type of target.

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b. Proof testing has displayed varying degrees of yaw for individual M74's released from E48 clusters. However, striking velocity/weight characteristics of the bombs are such that flat or near-flat landers offer no problem in penetrating normal Japanese roofs. Functioning for all angles of impact is provided in the M-142 all-ways fuze.

c. In level bombing the recommended minimum altitude of operation with the E48 is 3000 ft. (opening at 1000 ft.). Inability to set the M-152 fuze at less than 5 seconds limits the utility of the cluster at lower altitudes and for dive bombing, as the action of the cluster striking as a unit is not efficient.

d. The tail ejection feature of the M74 enhances the probability of the fuel coming to rest in or adjacent to easily ignitable material. Also, immediate ejection of the fuel after impact of the bomb on a roof is believed to better the chances of a fire being initiated in the attic out of reach of fire fighters.

e. The E48 has proved effective in setting appliance type fires in typical Japanese dwellings. It is believed that the use of a WP charge and the all-ways fuze make this munition slightly superior to the E46 cluster containing M69 bombs for incendiary attack of Japanese urban areas. However, sufficient data are not available at present to indicate a decided superiority.

f. Owing to its greater weight, the E48 cluster has a substantially smaller trail than the E46 (M69) cluster, but a greater trail than that of the M17 (M50 bomb) cluster. It requires off-set aiming to correct for excess cross trail when released in a cross-wind.

g. The E48 cluster is suitable for the attack of industrial targets with light roofs, but its efficiency when so used is expected to be less than that of the E46 or M17 clusters.

JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET M-11
DATE.....19 June 1945
PAGE 1

J.T.G. No.11 – ANALYSIS OF OSAKA URBAN AREA INCENDIARY ATTACK OF 14 MARCH 1945

1. Summary

The purpose of this study is to attempt to determine, in the absence of reliable bomb fall data, the critical or optimum density of incendiary bombs required to obtain a fraction of damage of .80 on a congested Japanese residential zone, R_1. It is concluded that this density is approximately 4.5 tons per million square feet.

This attack was chosen for analysis because it appears that the bomb distribution was normal about the mean point of damage. This situation is favorable to the method of analysis that was used. However, it should be noted that when the method of delivery is aiming by individual aircraft at aiming points closely spaced, the result appears to be that the zone or belt of optimum density is relatively very small, that between this zone and the MPI there is overbombing and that beyond this zone there is underbombing. Methods of delivery that result in a more diffuse bomb pattern, with density as close to optimum as possible, appear desirable.

2. Introduction

The 14 March attack of the XXI Bomber Command on the Urban Area of Osaka was chosen for this analysis since it appears to be a good sample of a successful incendiary attack. Not only were conditions favorable for an incendiary attack, but the operation was successfully carried out as is evidenced from a survey of the damage. The aiming points are close to the center of the damaged area and the area of damage is fairly well concentrated about these points. Also a study of the perimeter of the burned out area indicates that there was little tertiary fire spread the presence of which would have complicated the analysis. It has thus seemed feasible to assume that a large percentage (90%) of the bombs reported dropped over the target actually fall in the target area. A summary of the attack data is given in Table I.

3. The Bomb Fall

Since no strike photos were available the only indication available as to where and how the bombs fell over the target area is contained in the damage plot. In order to see what information about bomb fall is contained in the damage plot, the damaged area was analyzed in the following fashion. The accumulated distribution of the damage about its mean point (called M.P.D.—mean point of damage) was obtained by placing a square grid over the damaged area with one axis of the grid corresponding to the axis of attack. The amount of damage for each grid square was determined and the M.P.D. computed by determining the mean values of the distributions in range and deflection. Next the accumulated damage about the M.P.D. corresponding to increasing radii was determined. These accumulations were obtained by using squares of the grid whose combined center of gravity is the M.P.D. and by then associating with each set of squares the radius of a circle whose area equals the combined areas of the squares. Table II tabulates the values and in Figure 1 the points from Table II are plotted and an accumulative normal curve is fitted to the observed points. Since the distribution of damage was essentially normal about the M.P.D. and since the attack was made by individual planes aiming at the fires set by the pathfinder planes the assumption was made that the bombs were normally distributed about the M.P.D. One should note that the CEP for the damage distribution is 6600 feet. Since no information was available as to the CEP of the distribution of bombs it was decided to take several values for the CEP and to see how the analysis was affected by using these different values. The unit of density used in this study was bombs per thousand square feet. In computing densities only the M-69 bombs were considered. The M-47 bombs which were used by the pathfinder force were disregarded since they accounted for a small percentage of the total tonnage. The assumption mentioned above that 90% of the bombs reported over the area actually fell in the target area led to the assumption that 321,343 M-69 bombs were dropped on the target. The densities corresponding to increasing distances from the M.P.D. and for various CEP's are tabulated in Table III. Figure 2 illustrates these various densities graphically.

4. The Relationship Between Density of Bombs and Fraction of Damage

In order to study the relationship between density of bombs and fraction of damage, the target area was broken down into zones. To keep the effect of variations in the target at a minimum only the damage to Zone R_1 (highly built up residential) was considered. Because of the small areas of other zones contained in the damaged area, no study of these has been undertaken. The fraction of R_1 damaged within annual rings centered at the M.P.D. was determined. These data are given in Table IV and Figure 3.

According to certain assumptions, the relationship between density of bombs, D', and fraction of damage, F, is given by the formula $F = 1\text{-}e\ {-M'D'}$ where M' is called the mean area of effectiveness and is a constant. To check whether this relationship governs the behavior of R_1 zone in an incendiary attack, values of M' were computed for the annular rings using the density values from Table III and the fractions of damage from Table IV. These values are given in Table V. The variation in the values of M' within each column clearly indicates that the use of the formula $F = 1\text{-}e\ {-M'D'}$ with a single value of M' for the entire area would lead to large errors of estimation.

In order to see if some other relationship than the one considered above could be used a graph showing the relationship observed by combining Table III and

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Table IV was made for the three central CEP values. These graphs are shown in Figure 4. It is apparent from the graph that the scatter of points greatly increases in the region of low values and high values of F but that for the middle range of values of F, say $.30<F.<.90$ the relationship between the points is essentially linear and that the different CEP values have but a small effect on the actual line of best fit. It was, therefore, decided to restrict the use of our relationship between F and D′ to the central range and to assume that within this range the relationship is linear.

5. The Linear Relationship Between F and D′

It was decided to use the relationship $F = M(D' + d)$ where the parameters M and d are obtained from the observed data within the central limits of F by minimizing the square of the F errors. Where the points corresponding to $\sigma = 5600$ were used they yielded the equation.

$$F = 1.201\ (D' - .205)$$

Since these points represent somewhat central values, it was decided to use this relationship to determine F within the central range for a given D. Thus we have three ranges of values.

$D'<.45$, F very erratic but less than .30
$.45<D'<.954$, $F = 1.201\ (D' - .205)$
$D'>.954$, F very erratic but greater than .90

6. Critical Density

From the above results one can conclude that the critical density to obtain a fraction of damage of .80 on an urban area which is predominantly residential R_1 but may contain some mixed residential and industrial is .871 bombs (M69) per thousand square feet (approximately 4.5 tons per million square feet assuming the average weight of cluster to be 400 lbs.). It is believed that the critical density would be higher for an area containing a larger proportion of industrial zone, or of a less densely built-up residential zone.

TABLE I
Preliminary Summary of Attack Data–Area
(as of 6 April 1945)

Mission No. 42
Target Area. Urban Industrial Area, Osaka
Aiming Points. 4
Date of Attack. 13 and 14 March 1945
No. of A/C Attacking. 274
Altitude of Attack. 5000 to 9600 feet
Direction of Attack. 30°-60°
Duration of Attack (local time). 23.57 to 03.25   3 hours 28 min.
Direction and Intensity of Surface Wind. NW at 7—10 mph
Weather: Humidity: low for 6-7 days preceding attack
Precipitation: Probably 8 days without rain preceding attack
Bombing Run. Individual attack by radar and pathfinder.
Bombs Reported Dropped in Area:

Type	*Number*	*Actual Weight* (Tons)
M47A2	1586	56
E28	1167	204
E46	3357	713
E36	4872	974
		1947

Damage Analysis:

Roof Area of Buildings Damaged	Area Damaged	Damage per Ton Roof Area	Damage per Ton Area
85.4 MM ft²	182.5 MM ft²	43.9 M ft²/ton	93.7 M ft²/ton

TABLE II
Distribution of Damage About the MPD

Distance from MPD	Total Damage	Percentage
1782	645	.042
3564	2615	.171
5350	5586	.365
7100	9506	.621
8900	11932	.779
10700	13441	.878
12500	14119	.922
14300	14702	.960
16100	15124	.988
17800	15264	.997
19600	15314	1.000

TABLE III
Density of Bombs for Annular Ring's Assuming Normality and Various Values of σ

Ring No.	Mean r	Density (bombs per 1000 sq. ft.) CEP = 4600 σ = 3920	CEP = 5300 σ = 4500	CEP = 6600 σ = 5600	CEP = 7650 σ = 6500	CEP = 8800 σ = 7500
1	500	3.300	2.509	1.625	1.207	0.906
2	1500	3.092	2.389	1.574	1.178	0.892
3	2500	2.715	2.165	1.475	1.125	0.861
4	3500	2.233	1.864	1.343	1.046	0.816
5	4500	1.722	1.533	1.182	0.952	0.760
6	5500	1.244	1.211	1.005	0.855	0.694
7	6500	0.842	0.890	0.832	0.735	0.624
8	7500	0.534	0.628	0.665	0.622	0.552
9	8500	0.317	0.424	0.515	0.515	0.478
10	9500	0.177	0.272	0.385	0.416	0.408
11	10500	0.091	0.165	0.241	0.330	0.342
12	11500	0.045	0.101	0.198	0.253	0.280
13	12500	0.021	0.054	0.135	0.192	0.227

TABLE IV

Area of Annular Ring and Percentage of Residential Damage Within Each Ring

Ring No.	Area of Ring (Million of sq ft.)	Percentage of Residential Damage
1	3.14	100
2	9.42	97
3	15.71	98
4	22.00	99
5	28.27	94
6	34.56	91
7	40.84	80
8	47.12	59
9	53.91	33
10	59.69	25
11	65.97	14
12	72.27	16

TABLE V

M′ for Annular Rings for Various Values of σ

Ring No.	Mean r	M′ (in thousand of sq. ft. per bomb)				
		$\sigma = 3920$	$\sigma = 4500$	$\sigma = 5600$	$\sigma = 6500$	$\sigma = 7500$
1	500					
2	1500	1.136	1.466	2.228	2.976	3.932
3	2500	1.442	1.806	2.651	3.476	4.544
4	3500	2.063	2.471	3.427	4.398	5.641
5	4500	1.636	1.835	2.379	2.956	3.699
6	5500	1.927	2.010	2.393	2.816	2.466
7	6500	1.908	1.806	1.942	2.189	2.578
8	7500	1.670	1.418	1.359	1.432	1.617
9	8500	1.262	0.942	0.583	0.777	0.840
10	9500	1.621	1.058	0.510	0.689	0.704
11	10500	1.665	0.913	0.631	0.456	0.442
12	11500	3.850	1.728	0.884	0.689	0.621

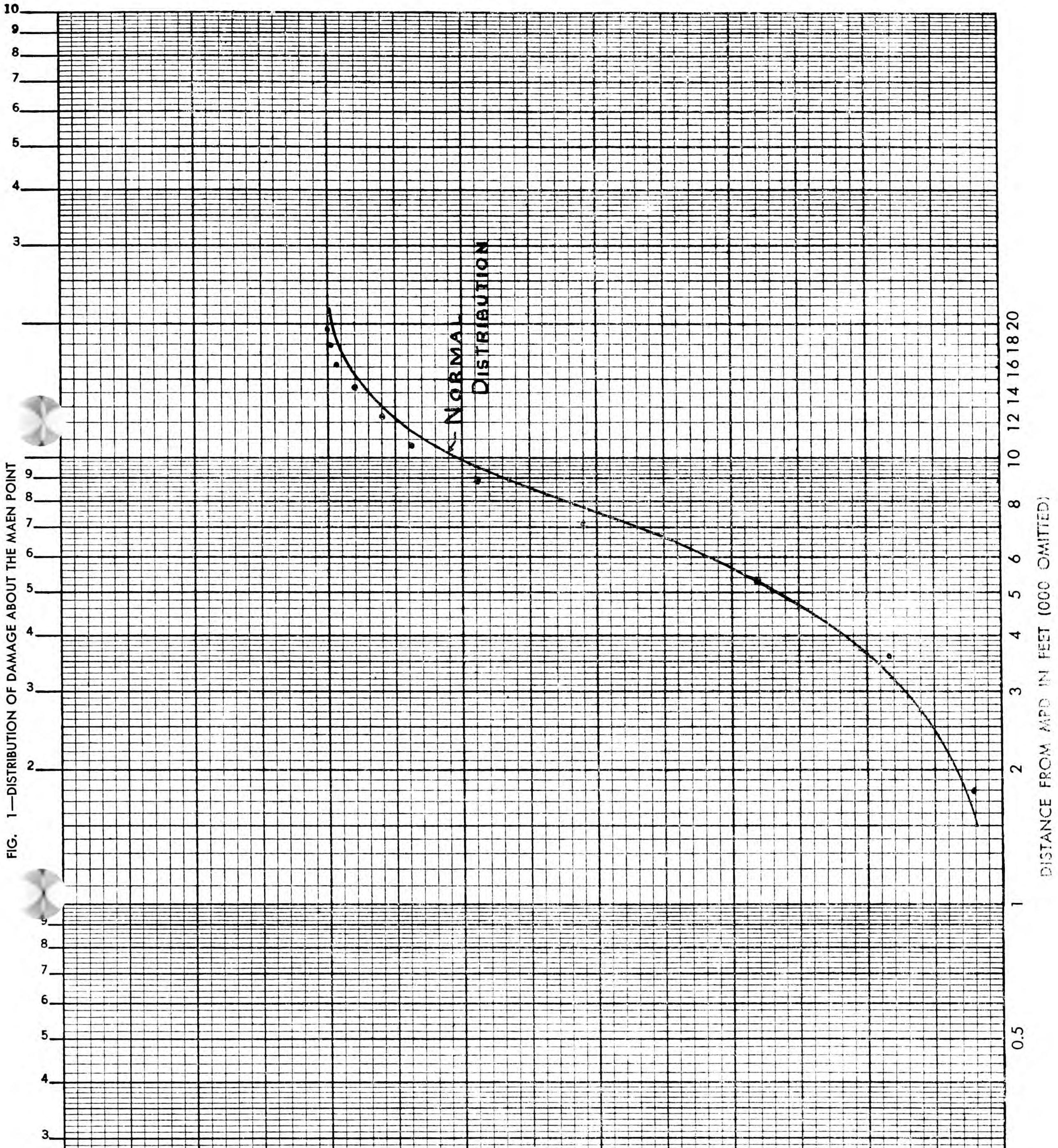


FIG. 1—DISTRIBUTION OF DAMAGE ABOUT THE MAEN POINT

FIG. 2—DENSITY OF BOMBS FOR VARIOUS VALUES OF σ

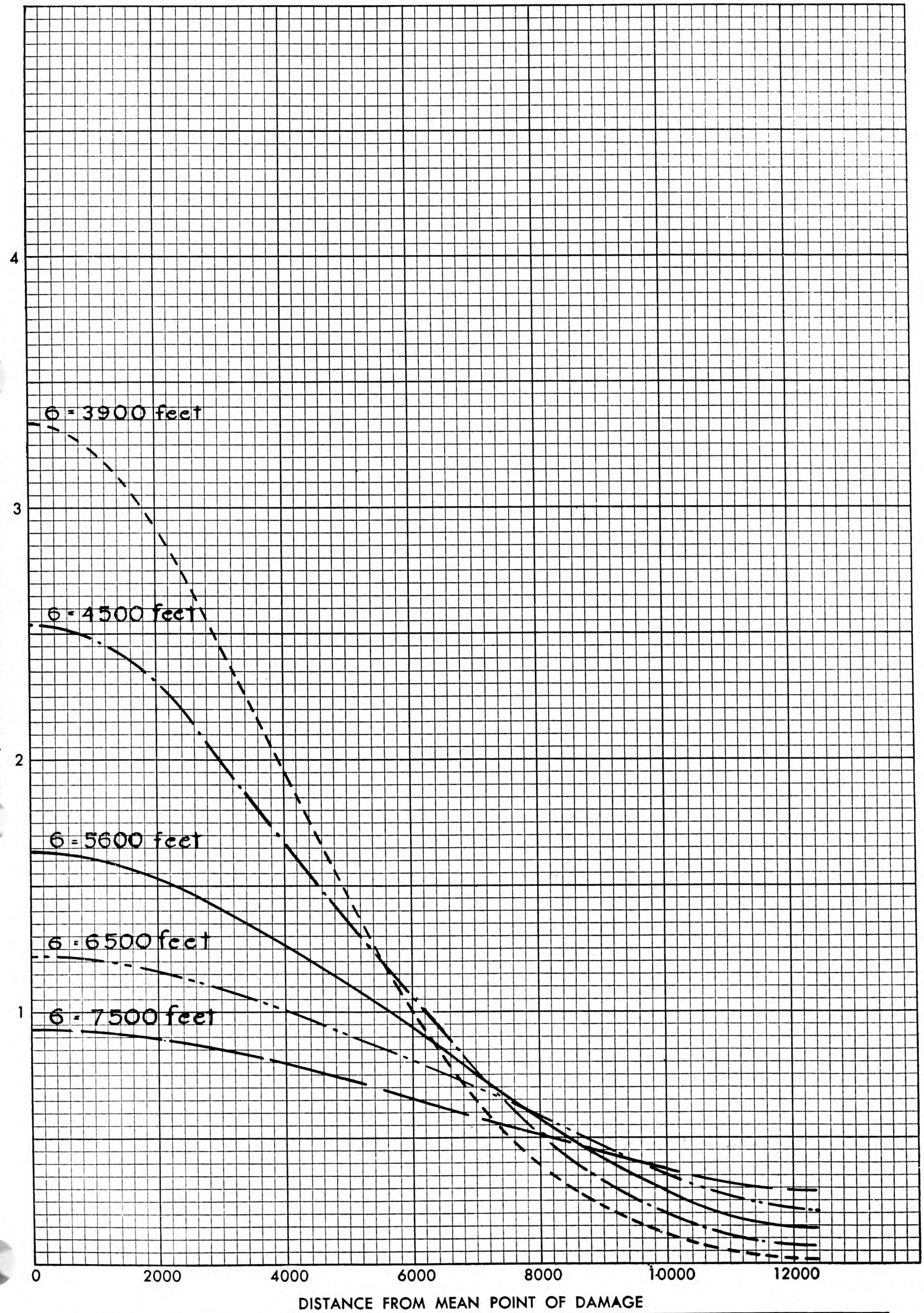


FIG. 3—PERCENTAGE OF RESIDENTIAL DAMAGE WITHIN ANNULAR RINGS

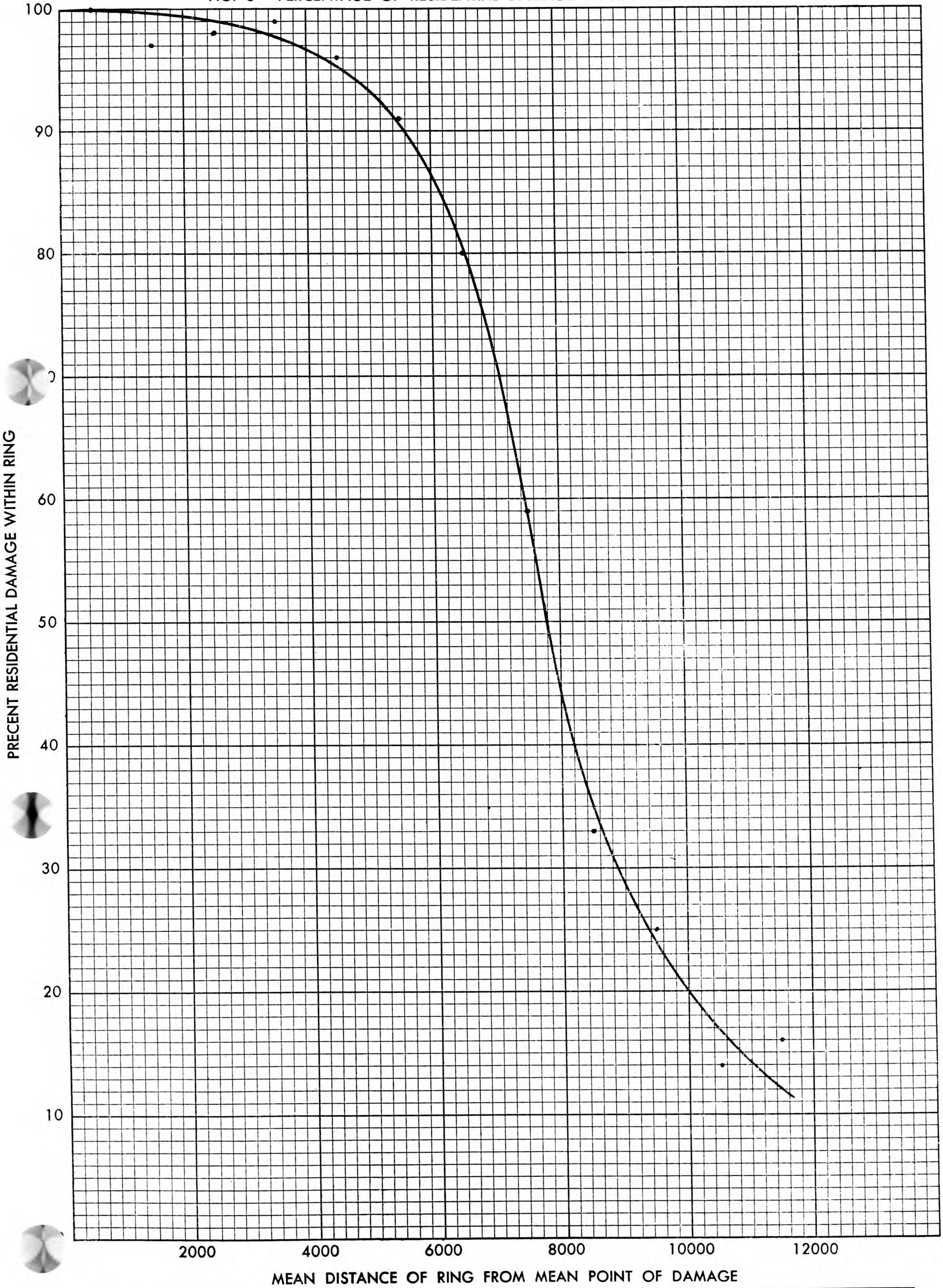
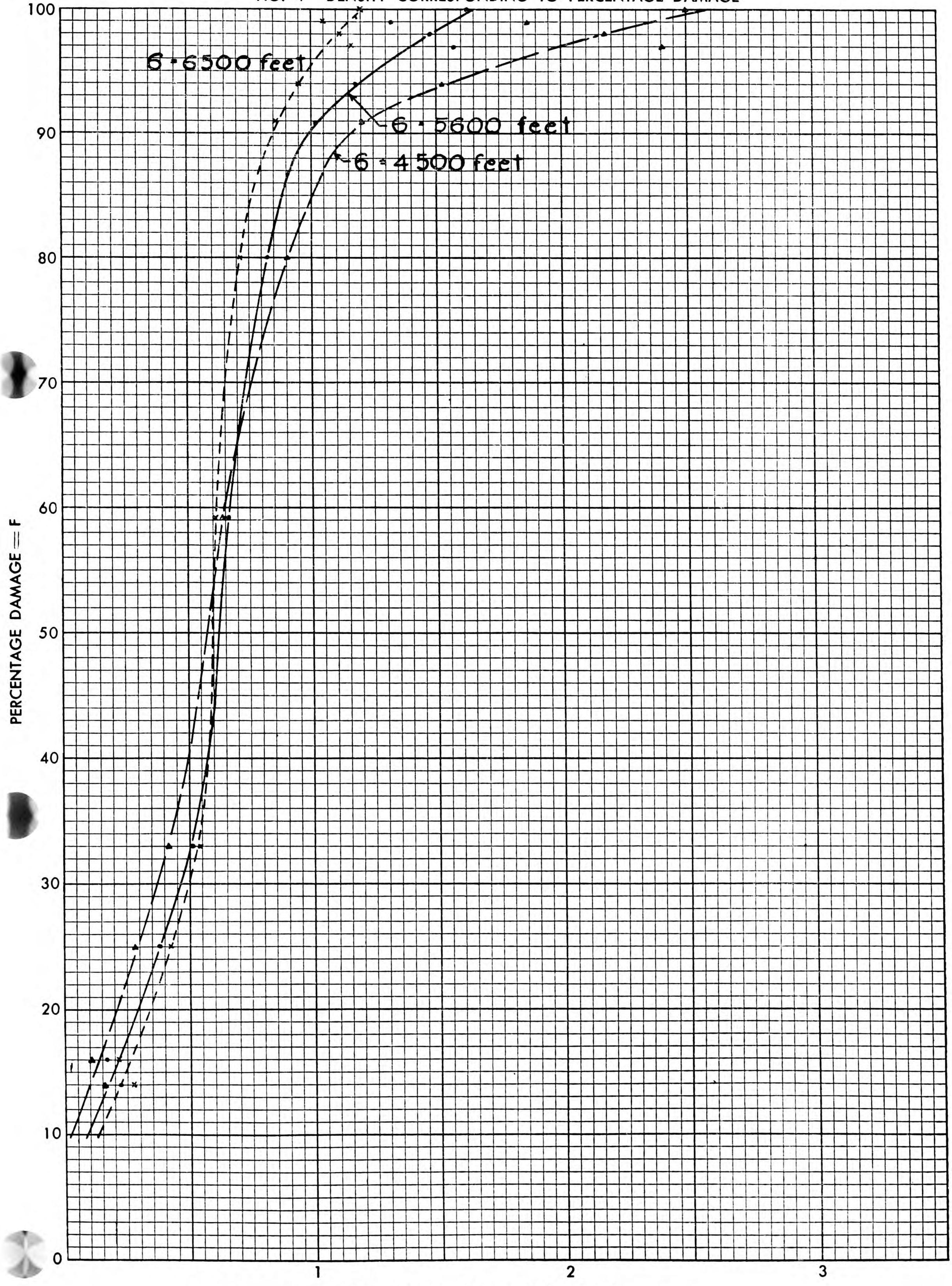


FIG. 4—DENSITY CORRESPONDING TO PERCENTAGE DAMAGE



JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

OSAKA AREA
URBAN DAMAGE PLOT

Refer to Report U/DA-4

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JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET M-12
DATE.....13 June 1945

J.T.G. NO. 12—WEAPONS ANALYSIS FOR ATTACK ON TYPICAL MILITARY TARGETS

FOREWORD

Air attacks on military targets must generally be planned on the spot. The following recommendations are intended to furnish assistance for such planning. Consequently, recommendations are given for attacks of typical, rather than specific targets.

The recommendations are based on the information at present available from operations in all theaters, on the results of trials and experiments at proving grounds and other research centers, and on analysis of the characteristics of typical Japanese targets. As more information becomes available, necessary revisions in recommendations will be made and distributed to the holders of this binder.

JOINT TARGET GROUP, WASHINGTON, D. C.
WEAPONS MEMORANDUM

SHEET M-12
DATE.....13 June 1945
PAGE 1

TARGETS FOR PARTICIPATING ATTACKS
TYPICAL MILITARY TARGETS
PART I—AIRFIELDS AND INSTALLATIONS

A. SUMMARY

1. GENERAL

Weapon selection and target selection for the attack of Japanese airfields will depend upon the aim of the mission. Generally this is neutralization of the enemy's air power. Each specific attack must have a definite aim and this should be clearly defined.

The aim of a specific mission may be *temporary neutralization* of the airfield for a short period of time, or *sustained neutralization* over a longer period of time. The choice of weapons and targets will be determined by this specific aim.

For *temporary neutralization* the chief targets are the grounded aircraft and the landing areas.

For *sustained neutralization* the list of targets is extended to include, in addition to the above, hangars, repair facilities, storage facilities, and auxiliary installations.

2. TEMPORARY NEUTRALIZATION

a. Weapon Recommendations

The primary objectives for temporary neutralization are grounded aircraft and landing areas. No other airfield installations (hangars, ammunition and fuel dumps, etc.) are of sufficient importance in this type of attack to recommend any particular weapons which may be more effective against them than those weapons selected as the most effective against landing areas and grounded aircraft. Damage achieved to these subsidiary installations may be considered as merely bonus. Grounded aircraft are best attacked by strafing with fighter aircraft. Where this is not operationally possible, bombing with high explosive bombs to give fragment damage is most effective. Landing areas are best attacked with high explosive cratering bombs.

TABLE 1

Weapon Recommendations

Target	Weapon	Nose fuze	Tail fuze
Aircraft in the open or in uncovered revetments.	Strafing 20-pound F. (AN-M41).	Inst............	
Aircraft in covered revetments.	100-pound GP[1] (AN-M30).	0.01 if available or 0.1 sec.	0.01 sec.
Landing areas.......	100-pound GP[2] (AN-M30).	0.1 sec..........	0.025 sec.

[1]The 100-pound GP bomb (AN-M30) will theoretically perforate 2 feet of 4,000 p. s. i. reinforced concrete when dropped from 20,000 feet altitude (striking velocity 860 f/s). However there is a high probability that the bomb will break up on 4,000 p. s. i. reinforced concrete slabs of thickness greater than 1 foot when released from altitudes over 4,000 feet. See table 26 in Part III, *Fuel Storage*.

[2]The 100-pound GP bomb (AN-M30) may break up if the thickness of concrete paving is 6 inches or more. The 250-pound GP bomb (AN-M57) is recommended for paved runways of thickness greater than 6 inches (rarely found in Japan).

b. Force Requirements

The weight of attack required to accomplish temporary neutralization will depend on the area of the airfield and the portion under attack. Since there are considerable variations in size, individual estimates must be made for each target. These can be made by using as a basis the quantities given in tables 2 and 3 for an airdrome area equal to 10 million square feet (2,000 by 5,000 feet for instance). These give the total weight to be delivered to the target. Total weight to be dispatched must be determined in the field from known operational conditions peculiar to each unit.

Load requirements to damage or destroy grounded aircraft in the open, with the desired level of damage are given in table 2. An upper and a lower limit are given and it is believed that the required weight will fall between these two limits. (See appendix A for assumptions and computations.)

Load requirements for cratering landing areas sufficiently to destroy all possible strips usable by fighter aircraft are difficult to determine with any degree of certainty. Operational experience is the most reliable basis, but little exists, unfortunately. An analytical means of obtaining approximate requirements can be based on the assumption that all usable strips are parallel to each other; this is a reasonable assumption for long, narrow landing areas. The degree of temporary neutralization depends mainly on the number of bombs dropped, and only slightly on their size (provided they are large enough to perforate any surface layer), since for temporary neutralization, time of repair is usually a secondary consideration. Table 3 gives recommended numbers of bombs per 10,000,000

(240)

TABLE 2
Fragment Damage by HE Bombs to Grounded A/C

Expected proportion A/C damage	Total weight required in tons for target area 10,000,000 square feet of target									
	Lower limit (4 fragment perforations 100 square feet)					Upper limit (7 fragment perforations 100 square feet)				
	20-pound F.	90-pound F.	100-pound G. P.	260-pound F.	500-pound G. P.	20-pound F.	90-pound F.	100-pound G. P.	260-pound F.	500-pound G. P.
0.10	1.2	2.5	2.0	4.0	4.0	2.0	4.0	2.5	5.5	5.5
.20	2.5	5.0	4.0	8.0	8.5	4.0	8.5	5.5	12.0	12.0
.30	4.0	8.0	6.0	12.0	14.0	6.5	13.5	9.0	20.0	20.0
.40	5.5	12.0	9.0	18.0	20.0	10.0	20.0	12.5	27.0	27.0
.50	8.0	16.0	12.0	25.0	27.0	13.0	27.0	18.0	37.0	37.0
.60	10.0	20.0	15.0	32.0	35.0	17.0	35.0	24.0	50.0	50.0
.70	13.0	27.0	20.0	42.0	48.0	22.0	46.0	30.0	64.0	64.0
.80	18.0	36.0	27.0	55.0	62.0	32.0	61.0	40.0	86.0	86.0
.90	25.0	52.0	39.0	80.0	88.0	42.0	88.0	57.0	125.0	125.0

square feet dropped at random within target area for achieving neutralization of fighter strips.

TABLE 3
Number of Cratering Bombs per 10,000,000 Square Feet for Temporary Neutralization of Landing Areas

Absolute minimum (operational data)	200
Recommended minimum (operational data).....	350
Minimum for 50 percent probability of success (theoretical)	450

c. Delay of Repairs

To discourage and interfere with the filling of craters and other repair work in addition to damaging grounded A/C, it is recommended that Butterfly bombs (M83) and long delay GP bombs be used against airfields. These would be particularly effective if dropped just before dark to halt repair work during the night. It is also believed that night fighters carrying out small night raids would discourage repair work.

It is recommended that 10 percent of the total load carried be composed of Butterfly bombs fuzed delay and antidisturbance and that 5 percent of the total load be 100-pound GP's fuzed long delay in equal numbers at 2, 6, 12, and 24 hours.

3. SUSTAINED NEUTRALIZATION

a. Grounded Aircraft and Landing Areas

The most effective weapons against these two targets are those recommended for temporary neutralization. Whereas grounded A/C are always an important target, landing areas are not a worth-while target unless they are bombed often enough to keep them inoperative.

b. Hangars and Repair Buildings

In the attack on these installations it is generally agreed that the primary object is to destroy their contents. Experience has shown that high-explosive weapons are most effective against hangars (unless the hangars themselves are of combustible construction), and incendiary weapons are most often effective against repair facilities.

The most destructive effects of HE bombs to hangars, repair facilities, and their contents are due to blast, fragmentation, cratering and debris. HE bombs may also start fires in hangars by fragment penetration of fuel tanks in the aircraft.

Structures are of various types, particularly C1.1, C1.2, C1.4, C2.1, C2.2, C2.3, and of vulnerabilities V4A and V5, as defined in JTG Memorandum 8. For the effects of various weapons, reference should be made to that Memorandum.

Incendiary bombs are recommended for the small repair shops and the larger repair shops of combustible construction. The AN-M50 and M69 IB are recommended because of the greater chance of multiple hits required to start sustaining fires. Next choice is the AN-M47, 70-pound IB. This will be particularly effective against the larger combustible structures if bombing techniques give a high degree of accuracy.

c. Storage Facilities and Auxiliary Installations

For the attack of these, reference should be made to the recommendations contained in Parts III, IV and V (Fuel Storage, Supply Depots, Ammunition) of this Memorandum.

B. GENERAL ANALYSIS

The aim of attack of airfields is the neutralization of the enemy's air power. This may be accomplished in a number of ways other than the attack of airfields. The other methods can be the destruction of the enemy's aircraft manufacturing and assembly facilities, the destruction of his sources of fuels and lubricants, etc. The tactical decision to attack the enemy's airfields will result from the need to neutralize his air power as a prerequisite for impending occupation of enemy held territory by our own ground forces, or when necessary to prevent the enemy from interfering with the movements of our supply forces or our strategic bombing operations on the enemy's military power.

Neutralization of the enemy's air power by attacking his airfields is difficult to accomplish, even for short periods, but it is possible. Recent reports from the Pacific Theater have indicated the need to accomplish neutralization with more certainty and less cost. The object of this report is to present the accumulated experience gathered from all parts of the world and to utilize this experience to establish the guiding principles needed to determine the most profitable methods and points for attack.

Most efficient destruction of the component parts of an enemy airfield will result from the proper choice of tactics and weapons. The *choice of tactics* will be governed by the conditions peculiar to the time and place of attack, and can best be *determined in the field.* It is the purpose of this report to indicate those tactics which have proven successful in all theaters of war so that this experience can be utilized to improve future operations. It is realized that in planning any particular attack the governing conditions will vary. This report can only suggest guiding principles.

Weapons recommended will be limited to those which are *immediately available in quantity* in the field. Other weapons, now available only in limited quantities, may become obtainable in greater amounts and restrictions on their employment lifted. An attempt will be made to assess their probable performance. Operational experience with these weapons is limited and therefore their probable performance can be based only on limited experimental experience and theoretical reasoning.

One outstanding fact, which has been established by experience in all theaters is the necessity for *sustained effort* if the airfield is to be kept out of action for more than a short period. Well-timed attacks, both day and night, at frequent but irregular intervals are essential to accomplish sustained neutralization. Spasmodic bombing is of little value.

The effect of repeated attacks in lowering the *efficiency and morale* of airfield personnel is attested to by experience drawn from all theaters of war. This effect can be an important factor in the neutralization of the enemy's air power, even when the actual physical damage is relatively small. This lowering of efficiency and morale from repeated attacks is intangible and difficult to evaluate. Experience to date does not indicate that it has been overestimated.

One of the chief aims of the attack of airfields is the *destruction of aircraft.* Aims which are usually secondary, such as the destruction of hangars, buildings, installations, bomb and fuel dumps, etc., may, in certain circumstances, form the primary object of the attack. It is the purpose of this report to present a structural analysis of the component parts of Japanese airfields and to indicate the effects of damage or destruction of these component parts upon the operation of aircraft and hence upon the strength of the enemy's air power.

For temporary neutralization of enemy airfields (a few hours to a few days at most) the two most important targets are *grounded aircraft* and *landing* areas. Experience has shown that it is easier to destroy aircraft on the ground than in aerial combat. Tactical surprise to catch the aircraft on the ground will pay dividends in planes destroyed. The relative importance of these two targets will be governed by the conditions peculiar to each airfield. Where the landing areas are restricted to paved or unpaved runways by the nature of the terrain, and alternate landing areas are not available, the importance of the runways as a target increases. It must be emphasized, however, that destruction of the landing area by cratering is extremely difficult to accomplish because of the great weight of bombs required to assure damage to all possible strips which can serve as runways. The ease with which runways can be repaired, even with limited mechanical equipment, does not make these desirable targets. Attack of landing areas is best accomplished at the beginning of the attack when it is desired to prevent the grounded aircraft from taking off for the balance of the raid. They are then vulnerable to attack from succeeding elements.

If *continued neutralization* is desired, the list of targets must include grounded aircraft, hangars, repair facilities, storage facilities, personnel facilities and defensive armament. The sustained effort required for continued neutralization must be emphasized.

C. GROUNDED A/C

1. GENERAL

When the tactical decision has been made to render an airfield inoperative by damaging or destroying grounded aircraft, frequent attacks, both day and night, at irregular intervals, and opportunely timed (for example, when planes are being refueled) are essential if the airfield is to be kept out of action for more than a short period. Spasmodic attack has proven of little value whenever used. Attack of satellite airfields, concentrated in time, should be given due consideration in the over-all plan.

2. STRAFING ATTACK

In general, whenever operational conditions permit, *strafing is the most efficient method* of achieving damage or destruction to grounded aircraft. The great effectiveness of fighters and fighter/bombers in strafing attacks with machine guns (particularly with incendiary ammunition) and cannon has been proven by experience in all theaters of war. Operational evidence is not sufficiently complete to assess the effectiveness of air-borne rocket projectiles against grounded aircraft. Nevertheless, consideration should be given to their employment. The comparative accuracy of the air-borne rocket projectile at longer ranges, and the possible decreased risk to the launching aircraft because of this greater range, point to the possible advantages of this weapon.

3. HE ATTACK

Damage or destruction of the grounded aircraft in *the open or in uncovered revetments with HE bombs* is accomplished primarily by projected bomb fragments. The 20-pound frag. bomb is most efficient (except for minimum altitude attacks) for this purpose. On a pound for pound basis its superiority is marked in that the total ground area that can be covered with fragments capable of effective damage to grounded aircraft is from one to three times that of any other HE bomb. The 20-pound frag. bomb is most effective when used from low to medium altitudes. From high altitudes an important percentage of effective fragments (perhaps up to 50 percent) is lost to usefulness because of the deeper penetration of the bomb into the ground before detonation, and because of the greater downward deflection of the fragments due to the greater vertical velocity of the bomb when the explosion occurs.

Comparative efficiencies of several HE bombs are given by the curves of Sheet M-12–C5 in appendix A. These give the total weight of bombs required to damage or destroy the grounded aircraft with the desired degree of assurance. It is assumed that the target area covers 10,000,000 square feet and that all bombs are dropped at random within this area.

Where operational conditions permit its use from *minimum altitudes,* the 23-pound parafrag. bomb may be more efficient than the 20-pound frag. bomb. Because of a striking angle nearer to the vertical and a lower striking velocity, fragment density from the 23-pound parafrag. bomb may be as much as three times that of the 20-pound frag bomb.

Where aircraft are in *uncovered revetments,* a hit (surface burst) within the revetment or at its mouth is required to damage or destroy the aircraft within. The greater probability of a hit within the revetment with the 20-pound frag. bomb follows from the greater number that can be carried per plane load. Operational evidence has shown that a 20-pound frag. bomb which lands inside a revetment up to 80 feet in width will effectively damage or destroy the aircraft within the revetment.

Neither present limited experimental evidence nor theoretical reasoning point to any superiority of the larger bombs *airburst* to the surface burst of an equivalent weight of 20-pound frag. bombs against aircraft in revetments. Although air-burst will overcome shielding provided by natural ground contours or artificial revetment with the 20-pound frag. bomb (for equal to aircraft in revetments by a surface burst within the revetment with the 20-pound frag. bomb (for equal total loads) is still two or more times greater than for the larger bombs airburst at optimum height located over the target within effective range.

Grounded aircraft may be destroyed or effectively damaged by *debris* resulting from cratering. The vulnerable radius for damage from debris may be from two to four times the crater radius, depending upon the depth of penetration before detonation and the type of ground. Since, however, the effective ground area for debris damage is less than the effective ground area for fragment damage, this type of attack is not recommended when the primary target is grounded aircraft. Where the objective is neutralization of landing areas *and* damage to grounded aircraft, the successful cratering of the landing areas may be accompanied by considerable incidental damage to dispersed aircraft in the landing area, particularly if the debris is concrete or rock.

Where the attack is directed against aircraft in *covered revetments* (except in those cases where the covering acts merely as camouflage) the 20-pound frag. bomb (because of its instantaneous fuzing) will not penetrate the roof. The 100-pound GP bomb, fuzed 0.01-second delay, will be most effective. If the roof cover is heavy enough to preclude the use of the 100-pound GP bomb, attack of these targets is not profitable and neutralization of the airfield is best accomplished by attacks directed at other installations.

4. INCENDIARY ATTACK

Attack of grounded aircraft with *incendiary weapons* is generally not recommended. Incidental damage may be obtained when incendiary weapons are directed at other installations. Where low-level or minimum altitude attacks are operationally possible, consideration should be given to the employment of napalm bombs. There is insufficient operational evidence at present to draw any conclusions as to their comparative effectiveness.

D. LANDING AREAS

1. DESCRIPTION

Japanese landing areas are of two types. One is the long, narrow "landing strip" with adjacent areas of cleared and leveled ground. There may be one or more paved or unpaved runways whose orientation will be dependent upon the limitations of the terrain and the direction of the prevailing winds. The dimensions of the runways are determined by the type of aircraft using the airfield. Usually, runways for fighter aircraft will be about 100 to 200 feet in width and 3,000 to 3,500 feet in length. Runways for medium and heavy bombers will generally be 200 to 300 feet in width and 4,500 to 6,000 feet in length. The other type of landing area, known as a "landing ground," is a broad rectangular, triangular, or circular area which permits aircraft to take off or land in a variety of directions. It may have paved runways similar to those for landing strips or the entire area may be a cleared and leveled surface of grass, packed clay, or rolled earth.

The material used in surfacing the runway may be:

(1) concrete,
(2) asphalt,
(3) macadam,
(4) gravel,
(5) crushed stone,
(6) crushed coral,
(7) packed earth,
(8) grass (turfed or sodded).

Paving material used at any particular airfield can best be determined in the field from a knowledge of materials available, the amount and type of traffic, general climatic and geographic conditions, and any other intelligence information that may be obtainable. Many of the Japanese airfields do not have paved runways but there is a definite trend towards paving to provide all-weather fields. Information about the thickness of paving is limited, but in general it will be thinner than American paving. The thickness will vary with the nature of the subsurface material and the thickness of the base course. Concrete pavements are probably 4 to 6 inches thick, and asphalt paved runways (including base course) are probably 6 to 8 inches thick.

2. CRATERING ATTACK

Attacks on landing areas are intended to deny their use to enemy aircraft. This is accomplished by cratering the landing areas with high-explosive bombs, delay fuzed, to assure penetration into the ground before explosion. A successful attack requires a great weight of bombs, uniformly distributed over the area so that all possible strips in the area will be covered. In this connection it must be recognized that Japanese fighter aircraft require a comparatively small strip (50-75 feet in width and 1,500-2,000 feet in length) from which to operate. Because of the ease with which craters can be filled and the surface repaired, even with limited mechanical equipment, the airfield can be kept inoperative for only short periods. Even with extensive cratering, it is only necessary to make emergency repairs to the least cratered part of the landing area to enable aircraft to take off and land.

One successful attack on a landing area can be expected to keep the airfield unserviceable for only a limited number of hours. Where there are terrain restrictions upon the number of possible strips, a successful attack may keep the airfield out of operation for a longer period of time. Extensively bombed Japanese airfields which have been occupied by our forces have been put into service in an average time of 2 to 3 days, during which major repairs were made to various installations and repairs to runways were of a permanent nature.

Where surprise is an element of the attack, cratering of the landing area at the beginning of the strike will keep grounded aircraft on the ground and vulnerable to attack by succeeding elements of the attacking forces and will also minimize the possibilities of attack by air-borne fighters.

To insure effective surface damage to the landing area it is necessary for the bombs to be spread uniformly over the whole area. This is most easily accomplished by high-level pattern bombing. Cratering of the landing areas must be planned to do the greatest amount of damage to the surface area and/or to displace the largest volume of material. The decision as to which is more important must be based upon a knowledge of the ground structure and the surfacing material. In certain instances damage to the subsurface drainage system may necessitate major repairs; for this, large craters are required.

The effectiveness of HE bombs in cratering of soils depends upon (1) the type of soil, (2) depth of penetration of the bomb before detonation, (3) the type of bomb (i.e., its charge/weight ratio, etc.). Landing areas are commonly constructed on ground consisting of a compacted mixture of soils rather than only one specific soil. Available information (table 4) leads to the conclusion that the small GP bombs do more damage weight for weight. Damage is here defined to include both surface area destroyed and volume of material displaced. The 100-pound GP bomb will be most effective for this purpose.

Recent experiments by NDRC, Division 2, do not indicate any appreciable differences in crater dimensions between paved or unpaved areas for the common thicknesses of runway pavements when bombing from altitudes above 5,000 feet. Hence, the 100-pound GP bomb will be most effective for both paved or unpaved areas. However, where the paving is 6 inches or more of concrete, the 100-pound GP bomb may break up under impact; in this case the 250-pound GP bomb will prove more effective.

The crater dimensions depend on the depth of penetration before detonation. This will be determined by the delay in fuzing and the striking angle and velocity. Recent experiments and actual field study show that for hard ground the delay in fuzing (for GP bombs)

TABLE 4

(From Div. 2, NDRC) Craters—Surface Area Destroyed and Volume Displaced

Bomb	Fuzing (seconds)	Surfaces area destroyed per pound of bomb (square feet per pound)		Apparent crater volume per pound of bomb (cubic yards per pound)		Volume of additional soil required to fill crater to original compaction per pound of bomb (cubic yards per pound)	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
100-pound GP AN-M 30	0.025 or longer	2.14	2.60	0.099	0.159	0.151	0.227
250-pound GP AN-M 57	0.025 or longer	1.46	1.78	.090	.149	.137	.211
500-pound GP AN-M 64	0.025 or longer	1.19	1.47	.088	.154	.137	.219
1,000-pound GP AN-M 65	0.10 or longer	.97	1.21	.092	.160	.143	.227
500-pound SAP AN-M 58	0.01	.85	1.03	.047	.087	.075	.124
2,000-pound GP AN-M 66	0.01 or longer	.78	.96	.093	.161	.144	.229
1,000-pound SAP AN-M 59	0.01	.67	.82	.075	.124	.075	.124

NOTE.—The above values are for *both* paved and unpaved runways when the bombs are dropped from altitudes *above* 5,000 feet. When the altitude of release is under 5,000 feet, the values are only for unpaved runways.

is unimportant beyond a certain minimum. This results from the curved path of the bomb in the ground. Maximum altitudes of release are therefore only of importance in determining aiming accuracy and dispersion of the bombs. The possibility of ricochet of the bombs when the striking angle is flat will fix a minimum altitude of release. For the type of ground considered, it is believed that the maximum angle of impact should not exceed 45°, which will fix a minimum altitude of release at 3,000 feet for level bombing.

Since successful cratering of landing areas can accomplish only temporary neutralization because of the ease with which repairs can be made, means to interfere with these repairs will extend the time the airfield is unserviceable. Long delay bombs, with fuze settings staggered from 2 to 24 hours and antipersonnel, antidisturbance "butterfly" bombs can be used for this purpose. Experience with the German "butterfly" bomb has shown that it is effective when used to disrupt repairs at night, and that this interference can be accomplished with considerable economy of effort. Consideration should also be given to the use of "crow's-feet" since experience has shown that they have a definite nuisance value, particularly at night.

E. HANGARS

1. TYPES OF HANGARS

The primary function of a hangar is to provide a covered area for the storage, maintenance, and assembly of aircraft. Hangars are desirable but not essential as evidenced by the fact that aircraft have been operated successfully for long periods in tropical, temperate, and arctic climates and through all seasons with only canvas shelters or awnings. However, the hangars will contain aircraft, tools, and other repair and assembly equipment whose destruction will limit aircraft maintenance and assembly. In these cases the contents of the hangar will be the primary target and attack of the hangar should be directed towards this purpose.

Hangar roofs are normally too light to actuate inertia type tail fuzes. Consequently, use should be made of nose fuzes of the proper delay, as recommended in JTG Memorandum 8.

An analysis of about 250 hangars, located in Formosa, Manchuria, Korea, and Southern Japan, from aerial and ground cover, indicates that Japanese hangars can be divided into four basic types.

a. Type 1 Hangar (Simple Truss)

This type of hangar, shown in figure M-12–D1, is the one most commonly used by the Japanese. Approximately 70 percent of the total number of hangars investigated were of this type. The basic shape is shown in M-12–D1a, type of trusses in M-12–D1b and variations in roof details in M-12–D1c. Varied designs result from different combinations of truss selection and roof details. These are of types C2.1 and C2.2, and of vulnerability V5, as defined in JTG Memorandum 8.

Dimensions of hangars vary considerably. The frequencies with which clear span dimensions were observed are recorded in table 5.

TABLE 5

Clear span (feet)	Frequency of occurrence
50-70	2
70-90	14
90-110	58
110-130	16
130-150	45
150-200	11
Over 200	0

It will be noted that clear spans of approximately 100 and 140 feet are the most common. Lengths of hangars vary considerably and no attempt will be made at classification. Truss spacing will generally average 20 feet.

b. Type 2 Hangars (Arch Type)

This hangar is the next most common type of structure, comprising about 25 percent of all hangars investigated. The basic shape is shown in sheet M-12–D2a. The arches may be framed in a variety of ways. Six representative types of arch framing are shown on sheet M-12–D2b. The roof may be either gabled or curved. Since basically type 1 and type 2 hangars have the same shape, they may be difficult to distinguish. The rise to span ratio may be a distinguishing feature in identification since the ratio is generally larger for arches than for trusses, averaging about 1:3 for the former and 1:7 for the latter. This statement only indicates average conditions since arches can be built witha much smaller rise to span ratio.

Frequently, arch type structures do not have walls that can be distinguished from the roof. The arch frame may be carried down to ground level and covered throughout with the same material. This material may be wood sheathing, corrugated asbestos, or corrugated iron. Where walls exist, they will most frequently be of the panel type (nonload bearing) and the wall material similar to that on the roof. If walls are used, the horizontal thrust from the arches will require external buttresses or internal tie rods at ceiling level. The latter will not be often encountered because of the limitations on the clear height within the hangar. Type is C2.1, vulnerability V5 (JTG M-8).

Arches will most frequently be of steel. Of the arch type hangars investigated about three-fourths were of the type shown on sheet M-12–P1. This steel, diamond mesh arch apparently has been developed by the Japanese as a prefabricated hangar of standard design. It has been particularly common at advanced bases to which materials must be shipped, such as the Kurile Islands and islands of the South and Central Pacific. Clear spans are usually 100 or 140 feet. This type of hangar is often found with attached sheds along one or both sides. These sheds are used to house the tools and equipment required for maintenance and repairs to the aircraft.

The shape of the roof may conform to that of the arch, or it may be gabled by using triangular framing above the true arch. The latter is particularly common. Monitors may or may not be added to the roof. The frequency of occurrence does not lead to any conclusions as to which is more common. Type is C1.4, vulnerability V4A (JTG M-8).

c. Type 3 Hangar (Long Multiple-Span)

A hangar of this type is shown on sheet M-12–D3. It is similar to the assembly and manufacturing buildings commonly found in aircraft plants. These hangars are most often found at airfields associated with aircraft manufacture or modification centers.

These structures vary so markedly in size, shape, design, and material that no general description is possible. Doors may be either at the ends or along the sides. Clear spans may be as great as 250 feet, though it is probable that clear spans exceeding 150 feet will be very limited. These structures may be framed in either steel or timber though timber framing will generally not be used for clear spans exceeding 100 feet. Type is C1.2 or C2.3, vulnerability V4A (JTG M-8).

d. Type 4 Hangar (Simple Truss with Side Doors)

This is the most infrequently encountered type of hangar. Only two examples of this style of hangar were found, one of which is shown on sheet M-12–D4. The hangars of this type were constructed with wooden trusses supported on masonry bearing walls. The roofs were covered with corrugated galvanized iron. Type is C1.1, vulnerability V5 (JTG M-8).

F. REPAIR FACILITIES

1. TYPES OF STRUCTURES

Repair shops are used for the assembly of aircraft, major repairs, and overhaul. The buildings usually contain valuable machine tools, machinery, spare parts, and supplies. Destruction of the repair shops will have no immediate effect upon the operation of the airfield. Where sustained neutralization is desired, destruction of the shops and their contents will limit the amount of repairs that can be made to damaged aircraft.

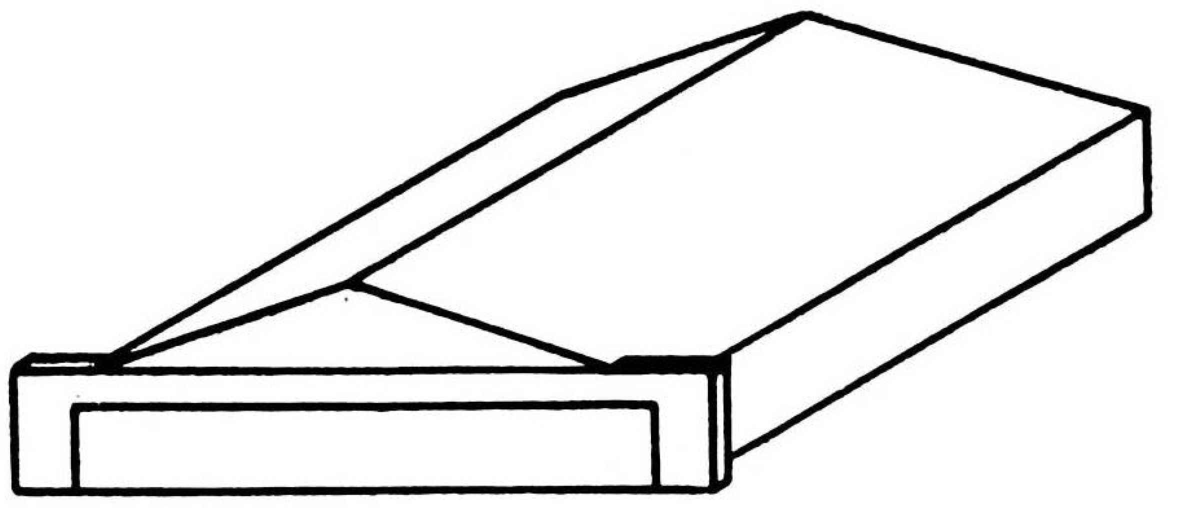
a. Hangar Type Repair Shops—These are similar to the structures discussed under hangars and the structural analysis and weapon recommendations will be the same.

b. Factory Type Repair Shops —The factory type repair shop will generally be found at permanent rear bases which are used as modification centers. The buildings are single story, industrial type with light steel or timber framed members. Saw-tooth roofs, to provide natural interior lighting, are commonly used in single story Japanese factory construction and will often be used for repair shops. In areas subject to high winds and earthquakes they can be expected to be framed and braced to resist these loads. In other areas they may be of wall bearing construction.

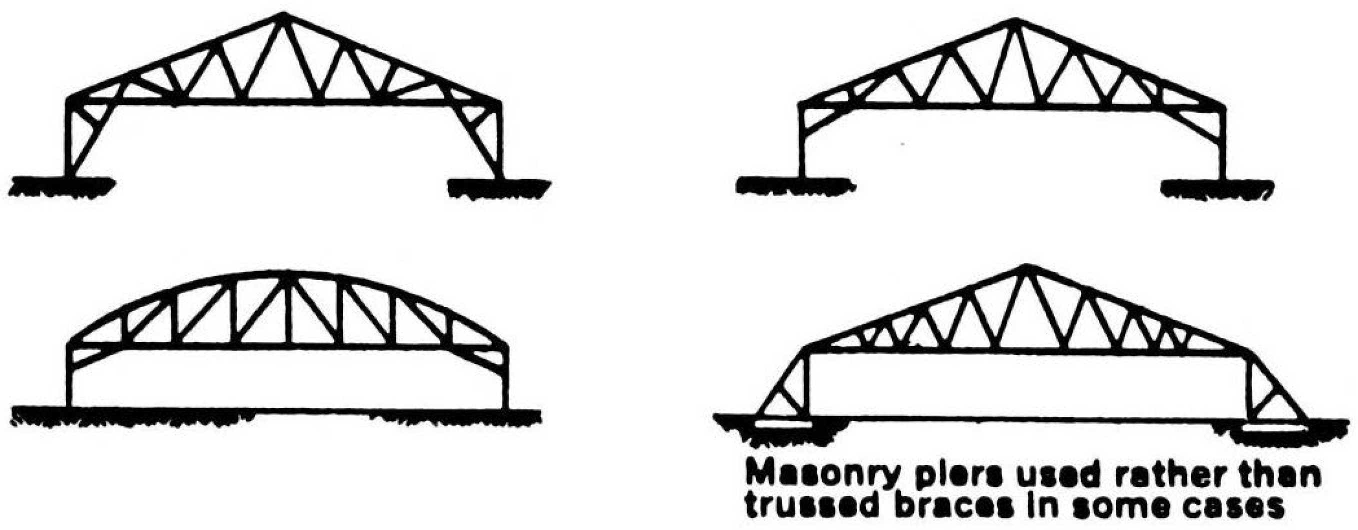
The limited number of structures examined permits subdivision only into two classes (1) short span buildings, (2) long span buildings (see sheet M-12–D5. Types are A1.1, A2.1, A2.3, vulnerability V4 (JTG M-8).

c. Small Repair Shops are the most numerous. They are used principally to house the machine tools, machinery, spare parts, and supplies. These repair shops vary considerably in size and form. The most common type, however, is a rectangular building (long and narrow) with a gabled roof. This permits the use of a simple triangular roof truss, of short span, which can be framed in steel or timber and supported on bearing walls or exterior columns. Since 1937 the Japanese have made a considerable effort to minimize the use of steel. Repair shops of this type will therefore be most commonly framed in wood. In those areas where wood is abundant the walls and roof will be sheathed in wood. In other areas where wood is not easily available, the wall and roof covering may be of corrugated asbestos or corrugated iron.

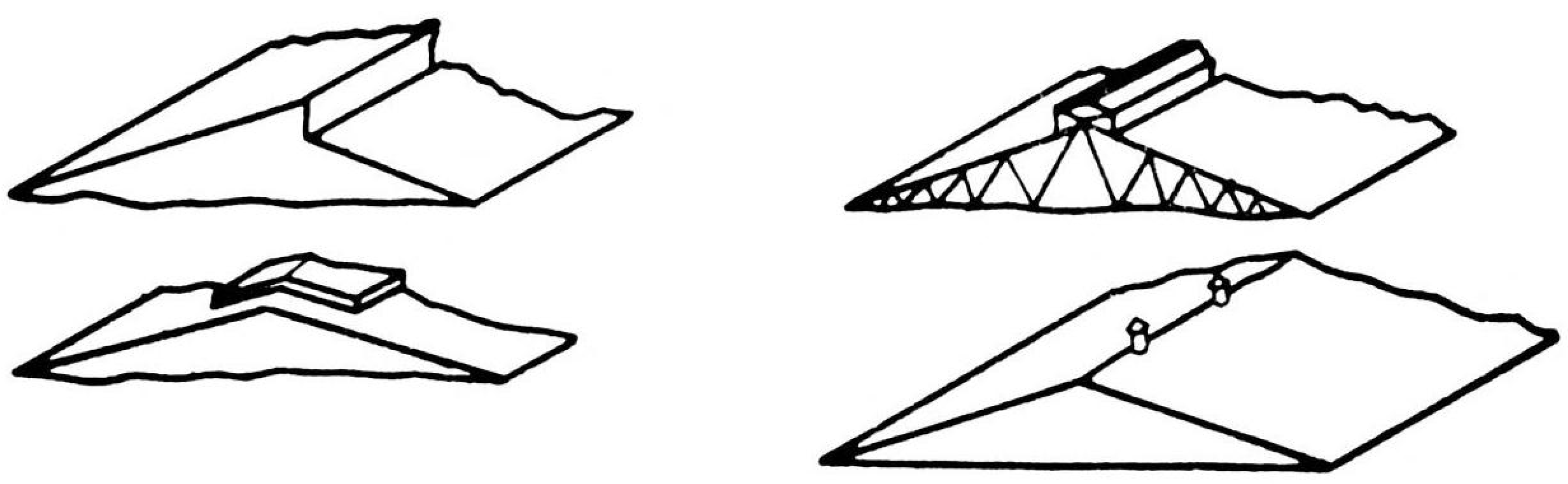
Attack directed at the contents of the small repair shops will generally require the minimum effort. Since a large percentage of repair shops of this type are framed in wood and have walls and roofs sheathed in wood, incendiary weapons will be the most efficient for these structures. Repair shops built of materials other than wood are not vulnerable to fire (unless the contents are inflammable) and HE weapons are indicated for these targets. Type is D, vulnerability V4 (JTG M-8).



(a) BASIC SHAPE

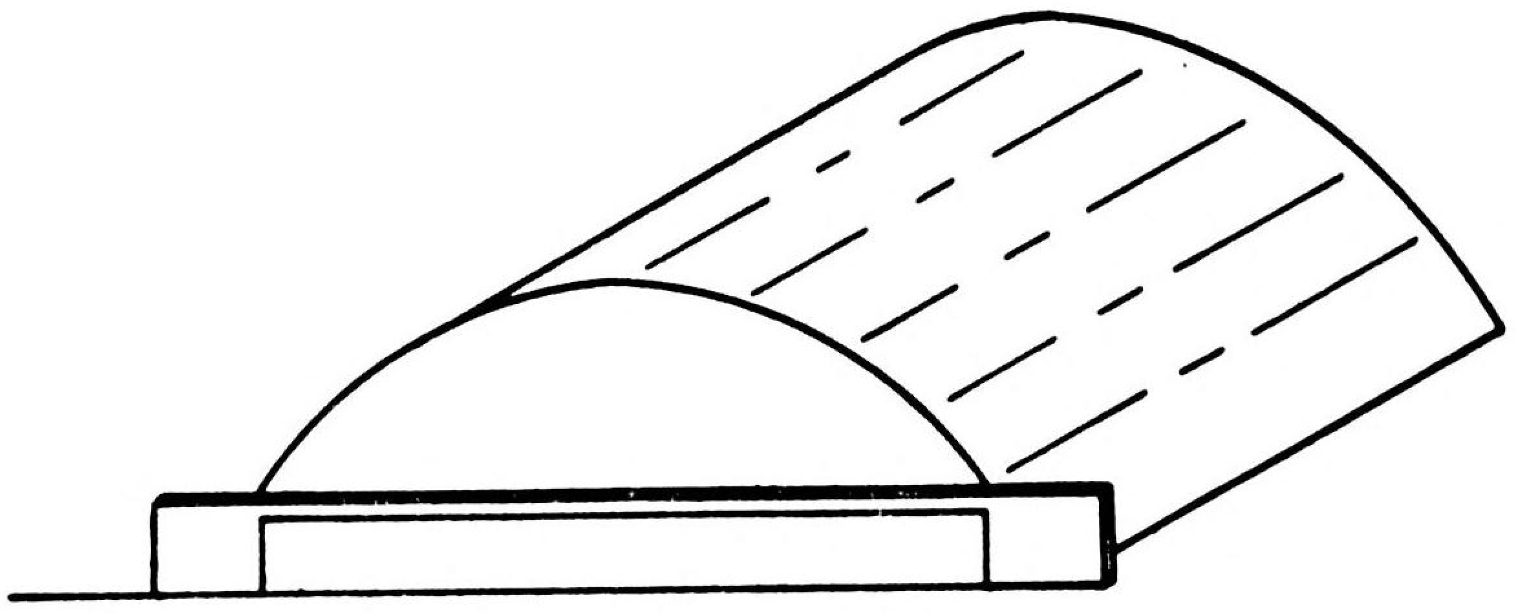


(b) ROOF TRUSSES

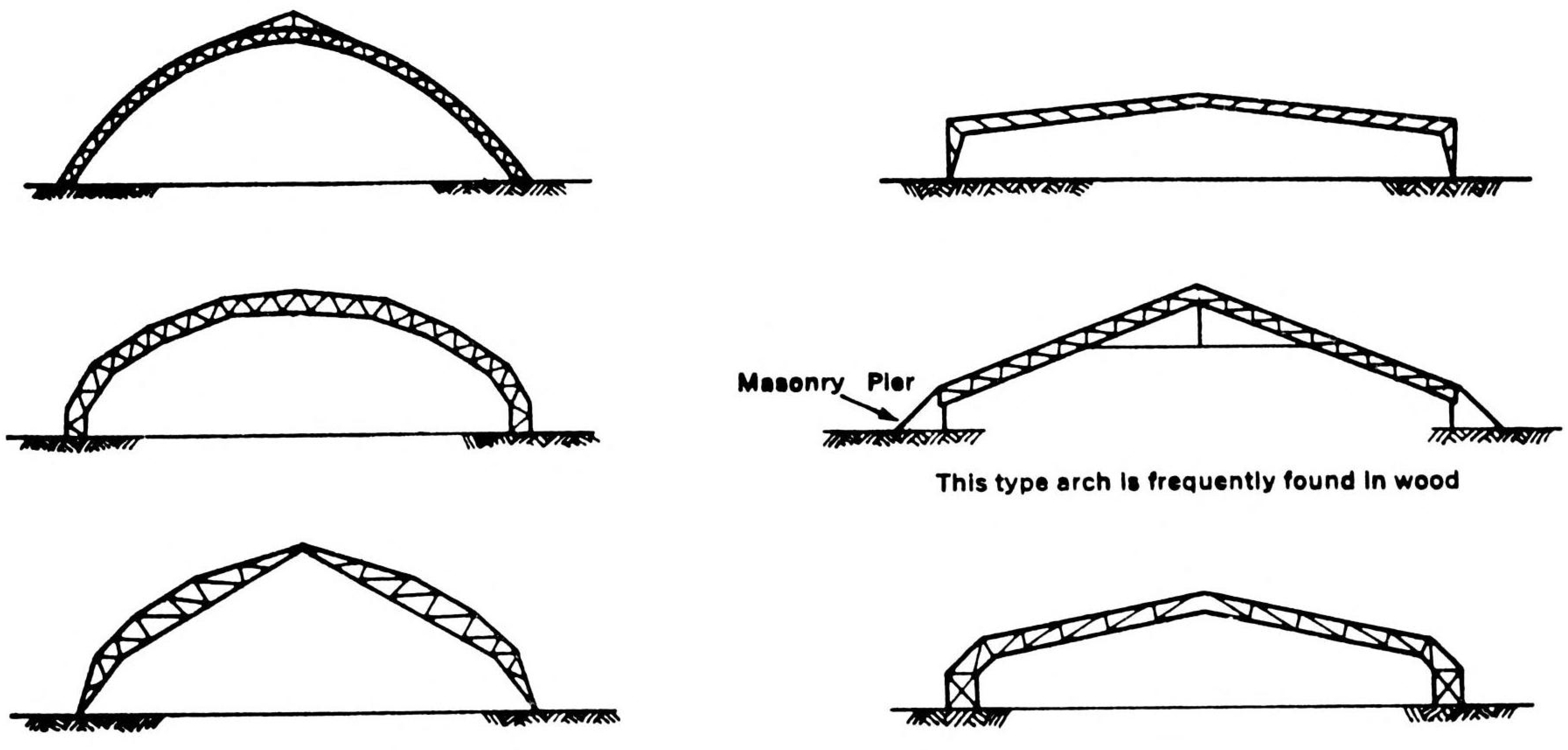


(c) ROOF DETAILS

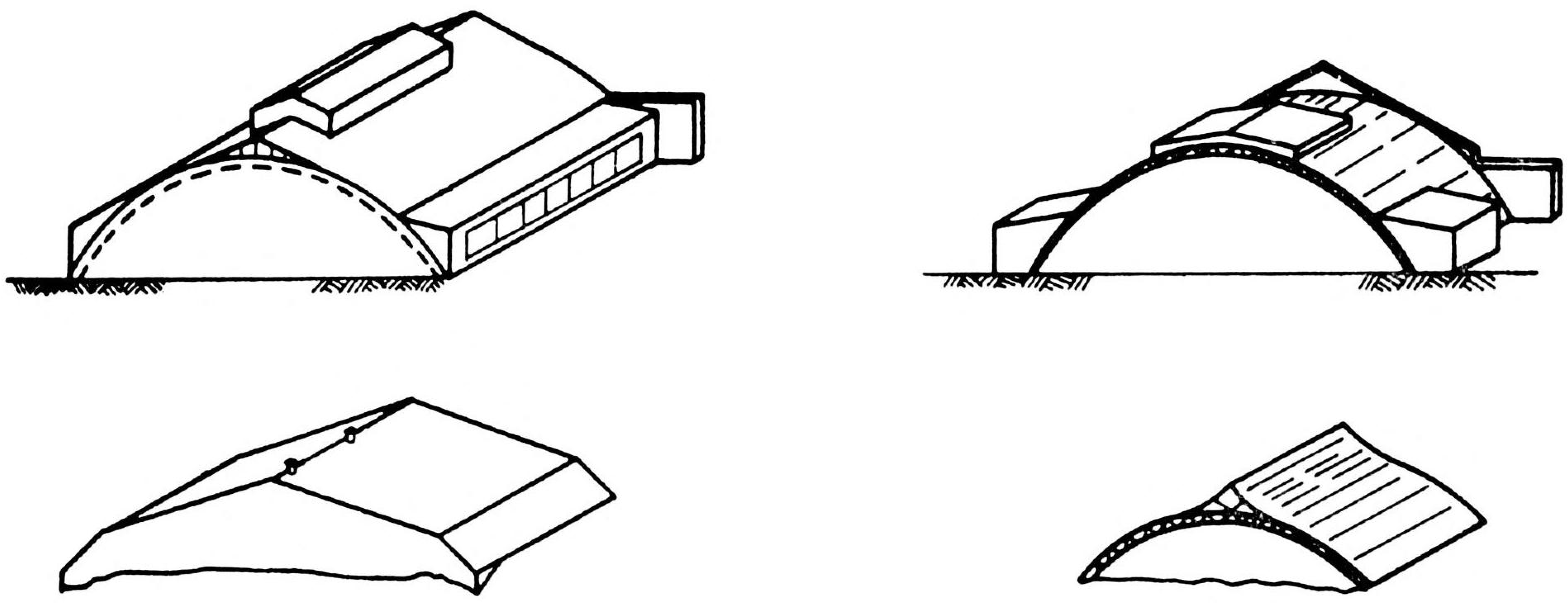
TYPE 1 JAPANESE HANGAR STRUCTURES



(a) BASIC SHAPE

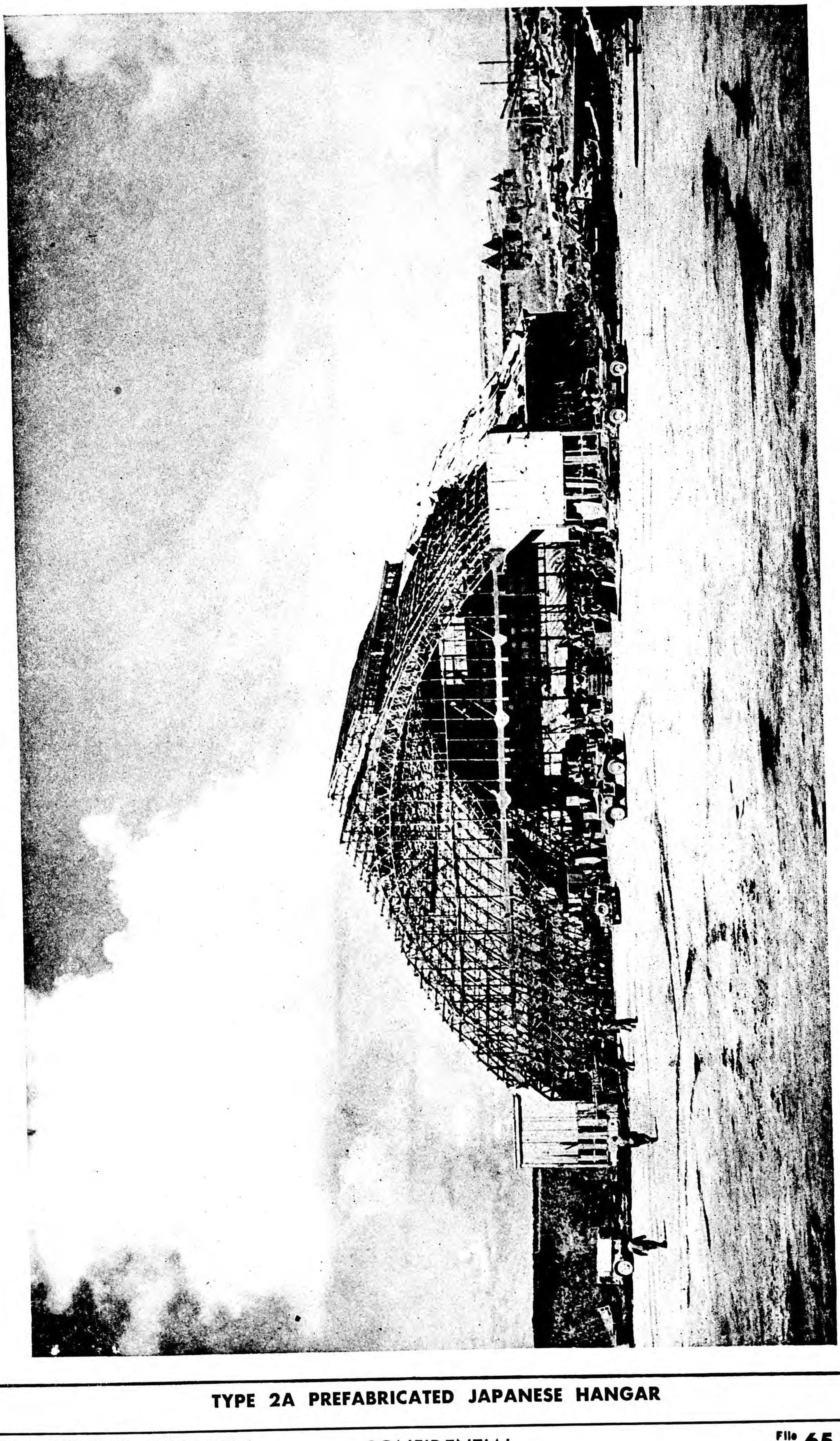


(b) POSSIBLE ARCH FRAMING

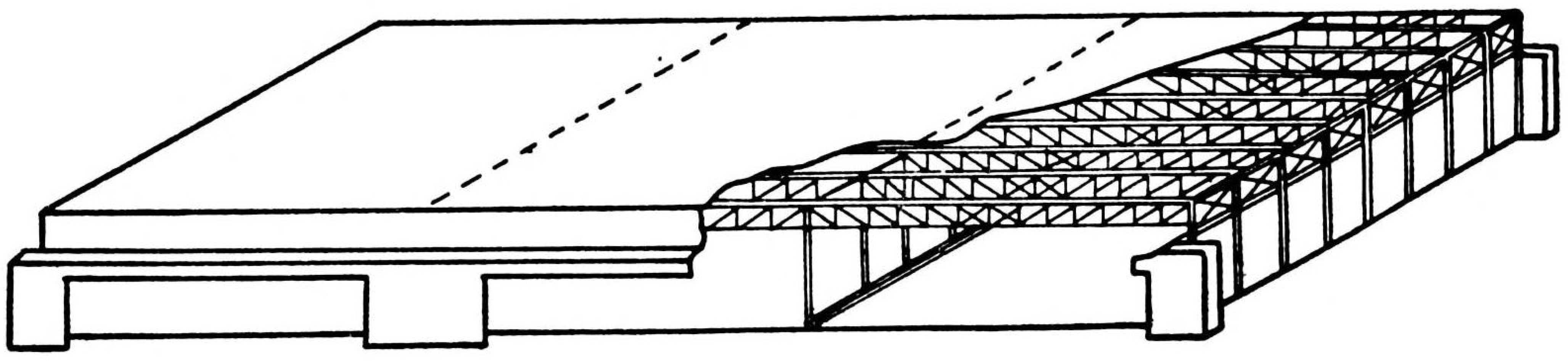


(c) ROOF DETAILS

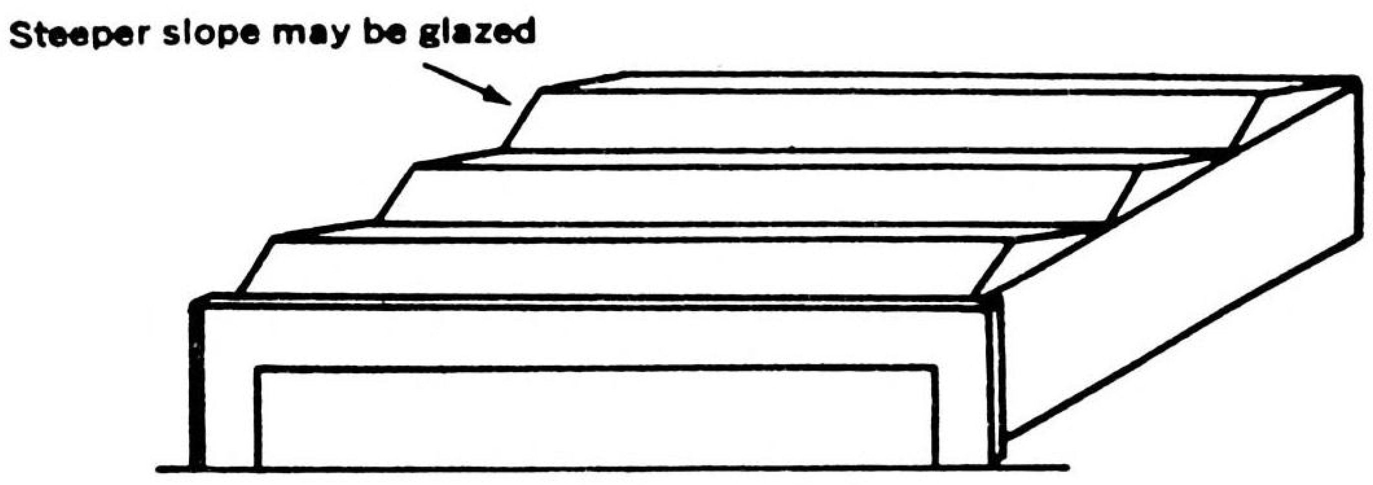
TYPE 2 JAPANESE HANGAR STRUCTURES



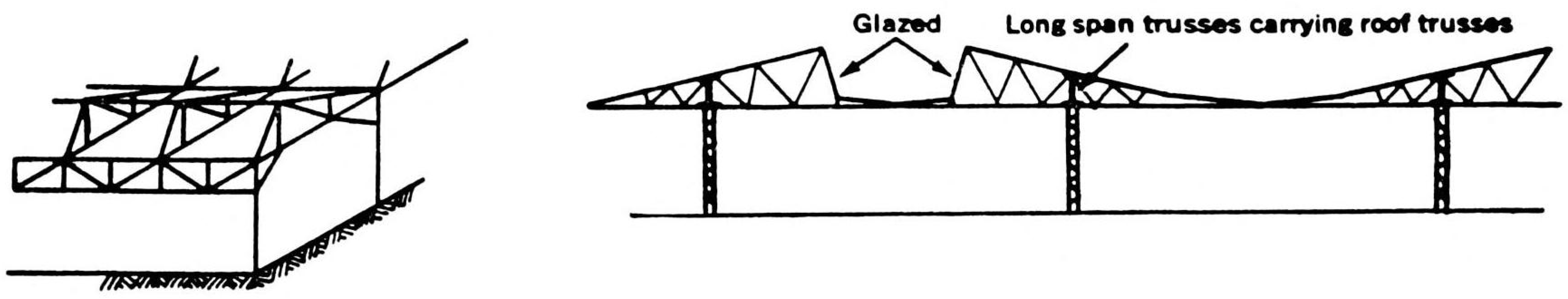
TYPE 2A PREFABRICATED JAPANESE HANGAR



(a) BASIC SHAPE



(b) BASIC SHAPE



(c) POSSIBLE FRAMING DETAILS

TYPE 3 JAPANESE HANGAR STRUCTURES