THE RELATIVE EFFECTIVENESS OF VARIOUS TYPES OF BOMBS AND FUZES
THE RELATIVE EFFECTIVENESS
OF
VARIOUS TYPES OF BOMBS AND FUZES

"... In evaluating the effectiveness of air attack, the Board should consider the relative effectiveness of various type bombs and fuzes against strategic and tactical objectives. . . ."

Basic Directive to AAF Evaluation Board,
12 July 1944.

AAF EVALUATION BOARD IN ETO
AAF EVALUATION BOARD
EUROPEAN THEATER OF OPERATIONS

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1 June 1945
Preface

In August 1944 the AAF Evaluation Board, recently arrived in the European Theater of Operations, formulated plans for the organization of "field teams" to analyze, in combat areas, the effectiveness of the various bombs and fuzes against different types of targets. Prior to this time the problem had been relegated almost exclusively to the experimental station, where the expense of building suitable structures and the difficulty in simulating combat conditions limited somewhat the possible findings. On the other hand, the war theater of France provided a "natural proving ground" where bombs had been dropped on a scale never before achieved. Preliminary excursions were made during August 1944 to determine the best methods for organizing field teams and setting up their method of operations. Although the initial reports were not definitive, and of doubtful value, results were sufficiently encouraging to make worth-while further development of the idea. By October 1944, analytical procedures were standardized and field headquarters were established in different parts of France and Belgium. During the subsequent nine months to June 1945, 60 reports were published, each both historical and analytical, including lessons learned at the site.

At the same time other organizations in this theater, including the Operational Research Groups of the various air forces and the Tactical Research Group of the Ninth Air Force, were pursuing similar investigations for their respective commands. The degree of overlap was not serious, however, since the method of investigation and the targets visited differed to some extent.

An attempt is made in this report to analyze the findings of the AAF Evaluation Board, as well as of these other organizations; to group samples alike with regard to either the target or the bomb-fuze combination used; and where the number of samples is adequate to generalize on the experience. As additional information becomes available, and new material and techniques are developed, the conclusions may well require alteration. However, it is believed that the basic principles outlined herein will remain valid, and that this report may serve as a point of departure for others of a similar kind. Most important, it is believed that the conclusions that can be drawn from the experience thus far accumulated completely justify the continuance of the "field" method of investigation on the effectiveness of air weapons against targets.

It is desired to acknowledge the generous cooperation of other research groups in this Theater whose findings have been freely drawn upon and incorporated into this study. In particular, the RAF Bombing Analysis Unit, the Eighth Air Force Operational Research Section, the Ninth Air Force Operational Analysis Section, and the US Strategic Bombing Survey have been most helpful.
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CHAPTER I
INTRODUCTORY

THEORY OF BOMB AND FUZE SELECTION

The aim in the selection of bombs and fuzes is to choose from the variety of types and sizes available the bomb and fuze that will inflict, per sortie, the maximum damage of the type desired. This involves, among other things, consideration of size and structural characteristics of the target; type of damage desired and vital areas of the target (areas the destruction of which will constitute or cause the desired degree of damage); loading characteristics of the aircraft to be used; comparative destructive potentials of the various sizes of bombs; probabilities of hitting the target with possible bomb-fuze combinations (dependent on the destructive field of the bomb and the number of bombs that can be carried).

To illustrate the significance of each of these factors, consider for a moment the problem of choosing the proper bomb and fuze to cut a single-track rail line. The target consists of two rails separated by about 5 feet of earthbed. The desired degree of damage is not only to cut the track but to cut it such a way as to maximize the time that the line is impassable. Experience in the ETO has indicated that the time to repair a rail line is largely a function of the volume of earth displaced, and therefore the object of the missions is to maximize per sortie the earth displacement from the target. It is assumed that the crater must overlap both rails in order to cut the track.

Obviously the larger the bomb the better the chance of a cut, since as the crater diameter increases it is possible to hit farther away from the line and still overlap both rails. On the other hand, the larger the bomb the fewer bombs that can be carried per aircraft, and therefore the smaller the chance of a cut.1 These are two opposing factors which together determine the relative probability of a cut with any given bomb load. This relative probability, which can be numerically computed from the comparative cratering characteristics of bombs and the loading characteristics of planes, is easily converted into the expected number of cuts per sortie. Finally, multiplying the crater volume for the various bomb-fuze combinations by the expected number of cuts per sortie, it is possible to select that combination which displaces the most earth from the target, i.e., maximizes the time for which the line is impassable.2

The above represents, in outline, a theory of bomb and fuze selection that is sometimes, but not always, practicable to apply. For many types of targets the evaluation becomes too complicated, and it is necessary to simplify the aim. In these cases it is feasible to choose the smallest bomb that, when properly fuze, will inflict the desired degree of damage on the target or any specified subdivision thereof.

The case of fighter bombers is unique since their bomb load is generally restricted first by the number of shackles on the aircraft and only afterward by the total bomb-weight. Thus, for example, the P 38 can carry any two bombs, each up to and including 2000 pounds (multiple clustering on fighter aircraft, which has been done on a limited scale in the European Theater of Operations, is not considered here). For such aircraft it is obviously desirable to carry the largest available bomb that is consistent with the range of the mission and other operational conditions.

CRATERING CHARACTERISTICS OF BOMBS

The radius of destruction of a bomb against certain targets, e.g., rolling stock, is largely a function of the diameter and depth of the crater formed, for upon these depend the shape and movement of the blast cone. (See Figure 1). The dimensions and profiles of the craters formed by various bomb-fuze combinations have been determined by the Ninth Air Force Operational Research Section. Because they will be referred to in the body of this report, a summary in chart form is presented here (Figure 2). It will be noted that, contrary to expectation, for some of the smaller bombs, the apparent depth of the crater decreases as the delay of fuze increases. This is due to the fact that some of the erupted earth falls back into the crater or to chance statistical variation resulting from a small sample. In any case, the differences are not important.

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1. This excepts fighter bombers which are discussed in a special case below.
2. This problem is numerically worked out in detail, and recom- mendations made, in Chapter V of this report.
FIGURE 1.

BLAST CONES OF CRATERING BOMBS.

"A-A" represents cone of blast of bomb with short-delay detonation.
"B-B" represents cone of blast of bomb with long-delay detonation.
Graphic illustration that a deeper penetration, although causing a larger crater, has a smaller radius of blast effect on objects (X) beyond crater.
## COMPARATIVE CRATER SIZES FOR VARIOUS BOMBS AND FUZES

### CRATER PROFILES AND FUZING

- **INSTANTANEOUS NOSE**
- **NON-DELAY TAIL**
- **.01 SEC. TAIL**
- **.025 SEC. TAIL**
- **.10 SEC. TAIL**
- **260 LB. FRAC.**

### DIMENSIONS IN FEET

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- Craters shown are for the 100 pound GP bomb. (Clay soil)
- Craters in dry sand, chalk or gravel will be smaller.
- Craters in super-stable soil will be larger.
CHAPTER II
BUILDINGS

GENERAL

A discussion of the vulnerability of buildings to bomb damage immediately involves the question of the desired degree of damage. Sometimes the complete collapse of a structure may be necessary, while in other cases, such as residential buildings, rendering them uninhabitable, may be the aim. Consider, as an example, a brick dwelling with a wood roof. If the degree of destruction desired is no more than to make it unsuitable as living quarters, an incendiary attack against the roof and inflammable interior is sufficient. If it is intended to cause the collapse of the structure, a high-explosive bomb that will destroy the brick walls is necessary. And if the purpose of this complete destruction is to form a road block, a larger high-explosive bomb, which will hurl debris into the street, may be needed.

Buildings vary greatly in size and structural detail, and these factors have a direct bearing on vulnerability to bomb damage and therefore on the selection of bombs and fuzes. For example, buildings of the same type of material may have either steel or wood roof trusses; they may be constructed with either short spans between column supports, as in the standard office building construction, or long roof spans, as in hangars. But despite these numerous variations in structural details, a classification according to basic design, as it relates to vulnerability, can be made, namely:

a. Structural-steel frame.
b. Reinforced-concrete
c. Stone masonry and load-bearing brick walls.

STRUCTURAL STEEL FRAME BUILDINGS

CONSTRUCTION

In structural-steel frame buildings each member has a higher safety factor, and therefore a relatively smaller weight to bear, than is usually found in other types of structures. This means that to inflict substantial damage or to cause total collapse a large number of members must be destroyed. The small surface that these members present to blast and fragmentation effect, however, means that only when a bomb detonates very close to them is there more than negligible damage.

In numerous instances even complete severance of vertical supporting members, longitudinal roof members, and purlins, produced only localized damage and not a general collapse of the structure. For example, photograph 1 shows a stanchion completely detached from its base, but no additional damage.
As another example, photograph 2 pictures severe but localized damage to roof members.

**PHOTO 2**

**TYPES OF DAMAGE**

Damage to structural-steel buildings may be classified into two types according to the type of bomb strike. In the first type, when bombs are fused to detonate in the air immediately after contacting the roof or roof members, the damage is caused by blast and fragmentation (Figure 3, Bomb A). In the second type, that caused by cratering strikes, the destructive effect is obtained by undermining wall members (Figure 3, Bomb B or C).

Obtaining air bursts on light roofs has not been easy because of the failure of tail inertia-type fuzes. The resulting incomplete information on the damage caused by this type of strike makes difficult a study of comparative effects of various bomb types. This section is therefore limited to describing in more general terms the extent of damage to be expected.

**AIR-BURST STRIKES**

The report on Les Mureaux\(^1\) records two incidents of damage caused by air bursts of 500-pound general-purpose bombs fused .01-second delay. The first of these strikes, according to the management of the plant, caused the abandonment of the building and damaged it more than did five 1000-pound cratering bombs striking it at a later date; the second air burst mentioned in the report made necessary the replacement of 14 of 22 steel trusses in another building and the reconstruction of an estimated 90% of the structure.

At a structural steel locomotive shed at the Versailles-Matelot marshalling yard, an air-burst strike by a 500-pound general-purpose bomb severed a steel truss roof member from a vertical supporting column, as shown in photograph 3.

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FIGURE 3.

TYPICAL SECTION
STRUCTURAL STEEL FRAME BUILDING

INDICATING DAMAGE AT VARIOUS POINTS OF DETONATION

NOTE
Type "A"—Causes considerable damage to structural members, but not over an area extensive enough to cause structural collapse. Damage to installations within the building is most extensive.

Type "B"—Due to greater distance of detonation to trusses, damage to these is ineffective. When hit is near supporting column, the column can be cut, but effective damage to building is negligible. Damage to interior installations is more severe than from hit Type "A" but not as extensive in area.

Type "C"—Damage is usually limited to destruction of wall and portion of secondary roofing members, and deformation of adjacent steel framework. Damage to installations within building is limited to very little over crater radius.
The dropping of this member caused the destruction of the other roof members between the adjoining roof trusses but no additional damage.

Photograph 4 shows the damage caused by an air burst in the railway station at Cologne, Germany. The size and fuzing of the bomb are unknown. This hit completely severed five I-beams (one 8"x3", four 6"x2½") and three steel angle bars (3"x2½") but damage was localized and no general collapse resulted.
CRATERING STRIKES

Other factors being equal, the damage caused by cratering hits depends on the location of the strike within the structure. When, for example, vertical supporting members are within the crater area, damage is much more extensive, for displacement of the vertical member usually damages the roof members it supports. Depending on the details of construction, a portion of the building may or may not collapse, but in any case, the collapsed portion is confined to the area between the two adjacent vertical members outside the crater.

The AAF Evaluation Board report, already referred to, records 19 strikes by 1000-pound general-purpose bombs fuzed .025-second tail-delay, all of which cratered into the floor. In no instance was the damage sufficient to cause complete collapse or to require major repair, but it varied sufficiently to permit a comparative study of damage to structural members lying inside and outside the crater area.

In photographs 5, 6, and 7 the damage was caused by a single hit in which the vertical supporting member of an interior wall did come within the crater area. The member was undermined and displaced, causing damage and distortion to the roof members it supported.
A second bomb of the same size and fuzing cratered in the same type of building. But with no vertical members within the crater area, the flying debris caused only negligible damage to roof members, which can be seen in the background of photograph 8.

A 1000-pound general-purpose bomb fuzed .025-second delay struck outside a building but close enough to include vertical columns within its crater area. Two columns and two supported trusses collapsed, and the longitudinal beam from these two columns to the columns on either side was distorted. All other trusses were intact, but the light steel roof purlins in the area between them were destroyed.

Another AAF Evaluation Board report records the collapse of one end of a two-bay structural-steel hangar by a hit of a 500-pound general-purpose bomb fuzed .025-second delay and a near-miss by another of the same size and type fuzed .01-second delay. Photograph 9 shows the crater at the corner of the building and the damage to the end of the hangar.


MULTIPLE-STORY STRUCTURES

A number of hits on multiple-story structures have been studied and the results have been quite uniform. In these buildings the column supports were steel H-beams enclosed in concrete and the floor supports steel I-beams and reinforced-concrete beams. This type of construction, as compared with that entirely of steel, proved to be more susceptible to blast damage.

Two typical examples were found at the Orleans-Bricy Airfield. Photograph 10 shows the damage caused on the second and third floor by a 500-pound general-purpose bomb fuzed .01-second delay which detonated within the third story. Approximately 800 square feet of the third and fourth floors collapsed, and about 350 square feet of the second floor. Damage was confined to blast, however, and there was no secondary or progressive collapse beyond the area of blast vulnerability.
A second strike, this time with a 1000-pound general-purpose bomb fused .01-second delay and detonating in the third story of the same type of building, produced the damage shown in photograph 11. As can be seen, the concrete was destroyed but the steel beams and columns resisted damage and prevented secondary collapse.

TAIL-FUZE ACTUATION

The hundred-series inertia-type tail fuzes often fail to function on the type of light roofing material found on most structural-steel buildings.

Of the 21 hits scored on one plant, only two burst in the air, and the remainder cratered, having been detonated by impact with the ground. There is a similarly wide difference in the damage caused by cratering strikes, but for this type it is possible to distinguish the cause. The degree of damage from a cratering strike depends primarily on whether, and how many, vertical supporting beams are included in the crater area.

In an attack on some Le Havre warehouses, of 11 bombs fused tail non-delay, 8 were initiated at floor level, 2 burst in the air after being detonated by striking steel truss members, and 1, apparently also initiated after striking a structural member, caused a small crater, indicating a delayed functioning of the fuze.

The evidence indicates that against structures having light roofs the primary initiating fuze should be of the nose-impact type.

SUMMARY

Of four air bursts considered in this report, two caused almost complete destruction but two only localized damage. The statement that in one case 90% of a building was destroyed may be an overestimate, but even so there is a significant difference here, the cause of which it is difficult to judge with so small a sampling. There is a similarly wide difference in the degree of damage caused by cratering strikes, but for this type it is possible to distinguish the cause. The degree of damage from a cratering strike depends primarily on whether, and how many, vertical supporting beams are included in the crater area.

In general, it is impossible to collapse completely a structural-steel frame building, by either a cratering hit or an air burst. The choice between the two types must then be based on the degree of damage short of complete collapse that can be expected from each. Air bursts are to be preferred in most cases, since the damage from them to the interiors, including such valuable equipment as heavy machinery, tends to be greater.

CONSTRUCTION

Concreted buildings inspected in this theater can be divided into two classes: those with reinforced-concrete column and beam construction, and hangar-type buildings.

The first type is basically the typical office-building design with various minor differentiating features. These structures are usually of more than one story, with brick walls and either concrete-slab or, occasionally, tile or slate roofing, supported by steel trusses.

The second type is characterized by wide roof spans. The buildings have usually only a single story, with separate offices, and walls of brick or cellular tile. The varying designs of truss suspension may be divided into two classes: truss support under the roof, and above the roof.

Concrete Column and Beam Construction

Types of damage to this kind of structure may be divided into three classes, according to the point of detonation of the bomb. The most serious damage, often causing the general collapse of an entire section of the building, results from a cratering hit that undermines and dis-

FIGURE 4.

TYPICAL SECTION REINFORCED CONCRETE BUILDING
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

NOTE

TYPE "A"—Detonation at this point causes destruction of floors of second and third stories and enclosing walls, as well as severe damage to adjacent bays and lower floor. If hit fractures a supporting column, the damage is rendered more extensive by collapse of considerable portions of floors and roof.

TYPE "B"—Cratering hit undermines concrete columns at ground level causing extensive collapse. But this type of hit depends on a lucky strike at a point where columns can be undermined and is, therefore, not readily achieved.
places two or more vertical supporting columns (See Figure 4, Bomb B). Secondly, the detonation of a bomb within one story of a structure normally destroys two stories above and one below and causes partial or complete collapse of that section of the structure. (See Figure 4, Bomb A.) The third and least serious type of damage is that caused by a bomb that penetrates below ground level and craters but fails to take out more than one vertical supporting column. Damage from this type of hit is limited to the destruction of the floors of the first and second stories, and interior walls.

An excellent example of a cratering hit that undermined and displaced more than two vertical supporting columns was that scored at a Paris airfield. A 500-pound general-purpose bomb fuzed .025-second delay passed through the roof of the second story and detonated below ground level near the edge of the first floor. The undermining of the lower supporting columns collapsed a considerable portion of the structure above. The building is shown in photograph 12.

The second type of damage is illustrated by photograph 13 of a building in which a 500-pound general-purpose bomb fused .025-second delay detonated within the second story. This type of hit collapsed both the floor above and below the point of detonation.

A bomb of the same size, type, and fuzing detonated within the second story of the building pictured in photograph 14. The less extensive damage resulted from a difference in design of the two buildings; the second is of more modern and stronger construction than the other.
Illustrating the third, least damaging, type of strike is photograph 15. A 500-pound general-purpose bomb cratered below ground level but did not undermine any columns. The damage was due to blast and was confined to the walls and floors of the first and second stories.

PHOTO

SUMMARY. The findings on bomb damage to reinforced-concrete column and beam structures indicate that to produce the maximum destructive effect delay fuzing is necessary. Detonation within a building will destroy one or two floors above and below the point of detonation, and bombs cratering at ground level and undermining two or more vertical columns will cause extensive collapse. For buildings of two to four stories the 500-pound general-purpose bomb fuzed .025-second delay was found to be very effective.

HANGAR-TYPE BUILDINGS

Types of damage to structures of this class are based on the location of the point of detonation and variations in structural detail from the basic hangar type.

To produce the maximum destructive effect, the bomb must detonate as close to the supporting trusses as possible. This implies variation in fuzing according to whether the building is supported by trusses above or below the roof. To destroy truss supports under the roof a short delay is necessary to allow penetration before detonation (See Figure 5). To destroy trusses above the roof instantaneous fuzing is necessary (See Figure 6). This is parallel to the difference between bombing deck-type and through-type bridges.

TRUSS ABOVE ROOF. One variation of the type of structure having trusses above the roof was found in a hangar with a cantilever truss supported from a double row of columns at the center, as shown in Figure 7. Over the central piers there were offices, the roof of which was above the trusses. The roof slab of the wings to either side of these offices was a 3-inch reinforced-concrete shell, with stiffening ribs, integral with the bottom chords of the trusses. This structure was hit on two raids, and in both cases the strike happened to be on the central portion over the offices. In the first raid, a 1000-pound general-purpose bomb fuzed .01-second delay destroyed a roof area 60 by 85 feet. In the second raid, a 500-pound general-purpose bomb fuzed .01-second delay increased the damage to 200 by 215 feet. In both raids the roof of the superstructure initiated the fuze, and the bomb detonated close to the central portion of the truss.

When the hit is over the central portion of this type of building, fuzing with a .01-second delay allows penetration before detonation to a point where maximum damage results; for this comparatively small portion of the building is a special case of the type of hangar with the trusses under the roof. However, hits with this fuzing near either side of the structure allow penetration
FIGURE 5.

TYPICAL SECTION
CONCRETE HANGAR—SIMPLE TRUSS ROOF SUPPORT
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

NOTE
Roofing is reinforced concrete, integral with upper chord of truss.

AAF EVALUATION BOARD IN ETO

FIGURE 6.

TYPICAL SECTION
CONCRETE HANGAR—HINGE TRUSS ROOF SUPPORT
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

NOTE
Roofing is corrugated asbestos sheeting, lightly attached to top of roof truss.

AAF EVALUATION BOARD
below the point of maximum damage. It is therefore recommended, in spite of the extensive damage in these two strikes, that instantaneous or non-delay fuzing be used on hangars of this type.

**TRUSS UNDER ROOF.** Hangar-type structures supported below the roof are more common. Within this general class the main difference in structural detail concerns the roofing. The roof slabs are either integral with the supporting framework or merely secured to it. The first of these types has proved to be more vulnerable to blast effect, probably because the blast wave has more surface on which to exert force; i.e., the pressure on the roof is transmitted to the supporting trusses and produces general collapse. Where the roofing is not an integral part a similar hit will merely destroy the roof, and, unless the point of detonation is very close to the supporting trusses, they remain undamaged. This factor has no bearing on the proper fuzing, but it helps to determine the amount of destruction that can be obtained on either of the two types of hangar with a particular size of bomb.

At Villacoublay Airfield various hangars with reinforced-concrete arch roofs integral with the supporting members were damaged or destroyed. Direct hits by 500-pound general-purpose bombs fuzed .01-second tail-delay destroyed 4 1/2 out of 10 units. This fuzing, after initiation by the roof, allowed penetration of 8 to 10 feet before detonation. Portions of three of these hangars are shown in photograph 16. The one in the middle is badly damaged, and those at either side completely destroyed.
Photograph 17 shows the destroyed portion of a two-bay reinforced-concrete hangar roofed with a concrete shell integral with concrete truss support. This structure was destroyed by hits of 500-pound general-purpose bombs fused .01-second delay.

Air bursts very close to truss members have resulted in the destruction and collapse of those members. Photographs 18 and 19 show two views of the damage caused by the detonation of a 500-pound general-purpose bomb approximately 16 feet below the roof. The truss was severed from its vertical support and collapsed.
An air burst within the hangar but too far from the structural members will result in only superficial blast and fragmentation damage. For example, at Villacoublay Airfield a three-bay structure of this type was hit by five 500-pound general-purpose bombs fused .025-second delay, without any damage visible on aerial photographs. On a following raid four hits by bombs of the same size and type but fused .01-second delay completely destroyed the building.

**SUMMARY.** Cratering hits have proved relatively ineffective against either type of hangar-type structures. In no recorded instance did the undermining and displacement of vertical supporting columns produce collapse. When no vertical members were within the crater area, there was only minor blast damage.

In general, a 500-pound general-purpose bomb fused .01-second delay has proved effective against hangars trussed below the roof. The roofing of concrete-arch hangars, when it was not integral with the truss or arch supports, was completely destroyed by blast. But, with this type of roofing, only when the point of detonation was very close to the structural roof members were these damaged or destroyed. An integral roofing offers more surface on which the blast pressure can react, as a result of which the supporting members are weakened and collapse. The extent of collapse is sometimes very widespread, especially with an arch roof without truss support.

No relevant examples of hangars trussed above the roof are included in this report, but from theoretical considerations it can be said that the fuzing should be instantaneous or non-delay.

**STONE MASONRY AND LOAD-BEARING BRICK WALLS**

**GENERAL**

Buildings of stone masonry and load-bearing brick walls, since they react similarly to bomb strikes, may conveniently be discussed in the same section. That is to say, the degree of susceptibility of wall to blast damage and the probability of collapse of the roof when supporting walls are destroyed are about the same for both types of buildings. Details of construction varied slightly from one case to another, but in each it was damage to the walls that determined the extent of destruction to either type of building.

**CONSTRUCTION**

Brick buildings are usually of either one or, less frequently, two stories. The walls are of double-course brick, about 9 inches thick in all. The buildings with wide roof spans occasionally have brick buttresses at the points where roof trusses are supported. Roofing is of tile or slate, supported by steel trusses, combination steel-and-wood trusses, or wood rafters and purlins.

Of the stone-masonry buildings encountered in this theater, most are constructed of uncut field stone (See Figure 8). They are of one to three stories, usually with roofing of tile supported by wood trusses, or, in one case of a three-story building, by steel trusses. Wall thicknesses vary approximately from 12 to 20 inches. The height of the multiple-story buildings is comparable to modern construction, but many of the one-story buildings have high walls with steeply pitched roofs of unusually heavy timbers.
**FIGURE 8.**

TYPICAL SECTION FIELD STONE MASONRY BUILDING INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

NOTE
Type "A"—Hit will cause collapse of wall and roof trusses.
Type "B"—Will cause extensive damage to wall, often causing roof collapse.

**FIGURE 9.**

TYPICAL SECTION CUT STONE MASONRY BUILDING INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

NOTE
TYPE "A"—Blast completely collapses a considerable portion of surrounding walls causing roof collapse over the same area. Building shock together with blast also causes considerable damage to interior walls and ceiling for a substantial distance from the hit.

Damage to building is sufficiently effective if detonation occurs at any place between points indicated by "A."

TYPE "B"—Cratering hit is not so effective, damage being much less to either exterior wall or interior construction.
More recently constructed are the cut-stone multiple-story buildings, with roofs of slate or tile supported by steel trusses (See Figure 9). The walls are approximately 16 inches thick, often with concrete exterior-facing and plaster interior.

**TYPES OF DAMAGE**

The brick and uncut-stone masonry buildings were extremely vulnerable to blast damage from either near-misses or direct hits. Cratering near-misses tended to vent the blast upward, which quite often reduced damage to walls to a minimum.

Buildings of uncut-stone masonry proved vulnerable to near-misses by 250-pound general-purpose bombs fused either short or non-delay. But since the short-delay fuze is superior in case of direct hits, this is the more desirable. For buildings of one or two stories the delay should be .01 second, and for those of over two stories it should be .025 second.

Among the cut-stone masonry buildings studied at St. Cyr, there were a number of hits and near-misses by estimated 500-pound general-purpose bombs fused short-delay. The hits on the four-story buildings detonated in the first or second story, and destroyed the walls, the floors above the point of detonation, and about 1500 square feet of the roof. Building interiors suffered severe damage, similar for all hits unless there was contributory damage from fire. Partition walls and ceiling plaster were destroyed, due to the shock from the blast. The damage to the interior from near-misses seemed to be only slightly less severe than when this type of building sustained a direct hit.

With either direct hits or misses as far as 40 feet distant, buildings of load-bearing brick walls could be effectively destroyed by a 500-pound general-purpose bomb fused short delay. No strikes by 250-pound bombs were reported on brick buildings but, in view of their performance against uncut-stone buildings, it can be reasonably assumed they, like the 500-pound bomb, would also be effective against brick.

**BRICK AND UNCUT-STONE MASONRY**

A hit against a one-story brick building with steel roof support, recorded in a report of the Board, was by an estimated 500-pound general-purpose bomb. The resulting air burst inside of the building, near the front wall, caused the damage shown in photograph 20.

Photograph 21 shows the damage caused by a 500-pound general-purpose bomb fuzed .01-second delay, which hit 40 feet from a two-story brick structure. The blast destroyed 40 feet of wall and a considerable portion of the second floor, allowing collapse of the roof.


Photograph 22, an example of a near-miss on structures of uncut-stone masonry,\textsuperscript{1} shows the result of a strike by an estimated 250-pound general-purpose bomb fuzed .01-second delay, with the point of impact 21 feet from the wall.

\textsuperscript{1} “Target Report on Le Bourget Airfield,” AAF Evaluation Board, 3 October 1944.
Photograph 23 shows the result of a strike by a bomb of the same size but fuzed non-delay, with the point of impact 5 feet from the wall.

PHOTO 23

Photograph 24 shows the damage to a three-story structure at St. Cyr with the point of impact within 10 feet of one corner of the building. Approximately 1250 square feet of floor space was destroyed, and the remainder of the structure irreparably damaged by an estimated 500-pound general-purpose bomb fuzed .01-second delay.

Several direct hits were reported at St. Cyr by estimated 500-pound general-purpose bombs fuzed short-delay. Photograph 25 shows the typical damage to a one-story building by one such hit, which cratered within the building. It destroyed the entire structure, and threw debris a distance of 50 feet from the hit. (The debris in foreground, however, is from a direct hit on a similar building.)

PHOTO 25

CUT-STONE MASONRY

Photograph 26 shows the exterior view of damage to a cut-stone masonry building by a 500-pound general-purpose bomb fuzed instantaneous or non-delay. The strike was about 10 feet from the corner of the building on the right. End walls, and 15 to 20 feet of side walls required replacement.

PHOTO 26
Photograph 27 shows the interior of the left building in the picture on the previous page. This is typical of the damage throughout the St. Cyr Ecole, although it is more severe close to direct hits.

Photograph 28 pictures damage by a direct hit of an estimated 500-pound general-purpose bomb, with detonation in the second story. The second and third floors were of concrete, supported by concrete beams; the fourth floor was wood, supported by steel I-beams. The floor of second story appeared to be undamaged, but the first-story interior required extensive repairs. Blast damage to the three wings of the building near the hit was severe enough to make them irreparable.
GENERAL

As bombardment targets, bridges present two important problems, the first of which is their invulnerability to near-misses. Often strikes at the base of supporting piers have resulted in only minor blast and fragmentation damage, even though in some cases the entire pier has been within the crater area.

Photograph 29, an example of this comparative invulnerability, shows the damage inflicted on the pier of a stone arch-type bridge by a bomb, the crater area of which included the base of the pier. A sizable quantity of the stone was blasted out, but no structural damage resulted.
Another example is pictured in photograph 30, which shows the damage to a reinforced-concrete supporting member caused by a similar miss. Since the bridge was not materially weakened, this strike did not stop the road traffic.

PHOTO 30

The second factor of prime importance, which is discussed in more detail later in this section, is the very small surface area that a bridge offers to blast and fragmentation effect. To achieve its maximum effect, a bomb must detonate as close to the vital supporting members as possible, and the selection of the fuze, which determines the point of detonation, is of great importance.

BRIDGE TYPES

Before attempting to choose the proper bomb and fuze, one must ascertain the type of construction of the bridge to be attacked, either from intelligence information or photographic interpretation. To assure a successful mission, proper identification of the bridge according to type is absolutely essential. For example, the Vernon highway bridge, reported by intelligence as being a seven-span masonry-arch bridge, was attacked with bombs fuzed .025-second tail-delay. Reconnaissance photographs later revealed that the bridge consisted of four spans of steel truss and three spans of continuous plate girder, against which instantaneous nose or non-delay tail fuzing should have been used. Four hits had produced only superficial deck damage, and the entire effort had been wasted.

Bridges may be divided into two types, through and deck. Construction material of either may vary, but the choice of the bomb and fuze to be used will depend mainly on this classification of the structure.

THROUGH-TYPE

Through-type bridges have the main structural members above the floor level. This superstructure may be a lattice truss, continuous truss, cantilever truss, or an arch. The trusses are made of steel, and the arches of either steel or concrete. The roadway load is transmitted by the secondary vertical and diagonal members to the truss or arch. The transverse members furnish lateral strength. Typical examples are the railway bridges at Pontabault and Oissel and the Rouen highway bridge.

DECK-TYPE

Deck-type bridges have the main structural members below the floor level. These may be in the form of lattice girders, plate girders, continuous trusses, cantilever trusses, or arches. Arch bridges of the deck type may be constructed of steel, concrete, or masonry; truss and girder types are of steel. As of through-type bridges, the primary structural members of deck-type steel bridges are the heavy horizontal members. The vertical and diag-
on members furnish lateral stability. Typical examples are the railroad bridges at Courcelles-sur-Seine and Mantes-Gassicourt, and the highway bridges at Poissy and St. Lo.

FUZE SELECTION

THROUGH-TYPE

To destroy the primary supporting members of a through-type bridge requires a fuze that will detonate as soon as possible after the bomb hits any portion of the bridge, for all these members are above the floor of the bridge. Figures 10 and 11 show the optimum point of detonation respectively for lattice and simple-truss through-type bridges. The destructive area of a bomb is small, and the members of a bridge present little surface, so detonation must occur very close to the vital members to be effective. Photograph 31 shows the damage inflicted when a bomb with instantaneous fuzing detonated immediately adjacent to principal structural members.
FIGURE 10.

TYPICAL

LATTICE TRUSS THRU TYPE BRIDGE

INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

AAF EVALUATION BOARD IN ETO

SECTION AA

FIGURE 11.

TYPICAL

SIMPLE TRUSS THRU TYPE BRIDGE

INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

AAF EVALUATION BOARD IN ETO

SECTION AA
An excellent example of the destruction of a lattice-truss bridge by the detonation of a bomb above the bridge floor is the attack on the railroad bridge at Pontabault. It consisted of two parallel truss bridges, each having a width of 16 feet, a height of approximately 17 feet, and a length of three 150-foot spans. The attack was made with 2000-pound general-purpose bombs, one of which detonated, as indicated by the evidence, approximately 5 feet above the bridge deck and 30 feet from the abutment. One span of one bridge collapsed, and two of the other. Photographs 32, 33, and 34 show the collapsed spans, the severe fragmentation and blast damage, and the severed structural members.
When hits strike the floor of a through-type bridge and penetrate before detonation, the blast and fragmentation are dissipated in the open area below the bridge. The attacks on the highway bridges at Vernon and Rouen, in which bombs fused .025-second tail-delay detonated harmlessly in the river, are typical of what may be expected when delay fuzes are used on through-type bridges.

The fuzing found to produce the greatest amount of destruction on this type of bridge is either instantaneous nose or non-delay tail.

**DECK-TYPE**

To destroy the main supporting members of a deck-type bridge requires a fuze that will permit penetration of the bridge floor and will actuate the bomb as close as possible to those members. Figures 12 to 16 indicate the point of detonation desired for the most effective damage to several deck-typed bridges. The delay to be used varies with the distance required to place the bomb as close as possible to the supporting members. If detonation 6 to 10 feet from the point of impact is required, a .1-second nose x .01-second tail fuzing should be used. If distance is as much as 10 to 20 feet, a .1-second nose x .025-second tail fuzing should be used.

With too fast a fuze, the bomb will detonate on the floor of the bridge, which will vent the force upward and to the sides, causing only superficial fragmentation and blast damage. Examples of this are the bombing with instantaneous fuzing of the bridges at Mantes-Gassicourt and Maison Lafitte. Photographs 35 and 36 show the damage inflicted on the Mantes-Gassicourt bridge on a later attack when two hits were scored using 2000-pound bombs fused .1 and .01 second delay.
TYPICAL
SIMPLE TRUSS DECK TYPE BRIDGE
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

AAF EVALUATION BOARD IN ETO

TYPICAL
SIMPLE PLATE GIRDER TYPE BRIDGE
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

AAF EVALUATION BOARD IN ETO
FIGURE 14.
TYPICAL
CONCRETE OR MASONRY ARCH TYPE BRIDGE
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE

FIGURE 15.
TYPICAL
CONCRETE BOWSTRING SOLID RIBBED ARCH TYPE BRIDGE
INDICATING POINT OF DETONATION DESIRED FOR MOST EFFECTIVE DAMAGE
**FIGURE 16.**

**TYPICAL REINFORCED CONCRETE ARCH TYPE BRIDGE**

Indicating point of detonation desired for most effective damage

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**BOMB SELECTION**

To attack a bridge, a bomb should be selected with a radius of destruction equal to between \( \frac{1}{2} \) the width and the width of the bridge.\(^1\) A hit by too small a bomb will result in the destruction of only a part of a span, while too large a bomb is uneconomical. Photograph 37 shows the destruction of one-half the width of the railroad bridge at Maison Lafitte, using 1000-pound general-purpose bombs fused \( .1 \times .025 \) second. A larger bomb should have been used.

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\(^1\) For a discussion of the general principles governing this selection, see the introductory section of this report, page 1.
Photographs 38 and 39, of the railroad bridge at Coutance, show the effect of a direct hit on the center of a span of a masonry-arch bridge. The rails twisted upward indicate that the bomb was fuzed to allow partial penetration before detonation. This has proved to be the most effective fuzing for this type of bridge.
Photograph 40 shows the damage inflicted on the thin cut-stone arch-type highway bridge at St. Lo. The shape of the crater in the arch indicated that detonation took place approximately half the distance through it, which is the optimum point of detonation. The detonation did not cause the collapse of the span, however, because the bomb was not large enough, although the damage to the span was such that it was necessary to install a Bailey bridge.

PHOTO 40

RECOMMENDED BOMBS AND FUZES

The following recommendations are made on the basis of considerations presented in the previous paragraphs.

<table>
<thead>
<tr>
<th>Type of Bridge</th>
<th>Single or Double Track*</th>
<th>Weight of GP Bomb</th>
<th>Fuze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel-truss, Single</td>
<td>1000 lb</td>
<td>Instantaneous nose x</td>
<td></td>
</tr>
<tr>
<td>plate-girder</td>
<td></td>
<td>non-delay tail</td>
<td></td>
</tr>
</tbody>
</table>

* Single-track bridges are up to 20 feet wide, double-track over 20 feet.
† The choice of the tail fuze is on the basis of the required distance between impact and detonation.
CHAPTER 4
RAIL CENTERS

GENERAL

The term “rail center” is one that has gained currency during the present war. It refers to a large assemblage of structurally and functionally heterogeneous objects, usually including (a) a marshalling yard, with its tracks, hump, switches, control tower, etc.; (b) a locomotive depot, with its locomotive shed and running repair facilities, or sometimes a major repair shop; (c) coaling facilities; (d) watering facilities; (e) communication and signal installations; (f) an administration building; (g) waiting locomotives and rolling stock; (h) through lines. Thus a rail center contains elements of some or all the factors that make up the carrying, moving, and loading capacity of a railroad.

The role of rail-center attacks in an aerial campaign has been variable. They may be an integral part of a systematic attempt to reduce the capacity of a railroad system, as, for example, the attacks against the French rail centers, designed primarily to destroy the locomotive repair and servicing facilities, and only incidentally to damage the marshalling yards, rolling stock and goods in transit. Or air attacks may be an adjunct to air-ground cooperation, as when, for example, in repulsing the counter-offensive in the Ardennes-Eifel sector, planes attacked German rail centers as rail heads, primarily to destroy goods in transit.

As will be seen, an analysis of the relative effectiveness of various types of bombs and fuzes against each of the components of a rail center leads in each case to a recommendation of either 500 or 1000-pound general-purpose bomb fuzed .01-second delay.

COALING STATIONS

The one facility examined consisted of a pit for unloading coal from railway cars and a tower into which the coal was elevated and fed by gravity into the locomotive tender. The unloading pit was struck by three bombs, one of which was identified as a 500-pound general-purpose bomb. The three hits destroyed the conveyor belt and the lower end of the elevator belt.

Bombs also destroyed two of the three tracks leading to the coaling station.

TRAVELING CRANE

The traveling crane examined operated in a large coal yard on rails along the top of reinforced-concrete supports as shown in photograph 41. Note the rail from the craneway lying on the ground, having been displaced by one of the bomb hits.

Several cratering hits by 250 and 500-pound general-purpose bombs fuzed delay were scored close to the reinforced-concrete crane trackway. These hits destroyed sections of the structure, as illustrated by photographs 42 and 43. In one instance the steel rail was completely torn loose from the concrete structure. These cratering hits near the base of the craneway limited the operation of the crane to the portion between the two hits.

WATER TANK

The one watertank examined was approximately 40 feet in diameter. Both it and the supporting tower were made of reinforced concrete. An estimated 1000-pound general-purpose bomb hit 6 feet from the base of the tower causing the collapse of the entire structure. There was also fragment damage to a second adjacent tank.

LOCOMOTIVE SERVICING AND REPAIR FACILITIES

REPAIR BUILDINGS

Locomotive repair sheds are usually of one story, constructed of either concrete or structural steel. Both of these types have been discussed in detail in the section of this report on Buildings, and the recommendation for both was a 500 or 1000-pound general-purpose bomb fuzed .01-second delay.
ROLLING STOCK

Most railway cars examined in France had the conventional steel undercarriage and a superstructure of wood reinforced with steel. These constitute alternative points of attack vulnerable to bombs of different fuzing.

The lighter superstructure is more vulnerable to a bomb fuzed to produce maximum blast and fragmentation, i.e. instantaneous or non-delay. The relatively heavy undercarriage is only slightly affected by blast or fragmentation, except by direct hits or very close misses. The best type of strike against the undercarriage is one that displaces the car and thereby bends and distorts the steel members, which effect is best achieved by bombs fuzed delay striking close enough to include the car within the diameter of the crater.

From examinations of targets the effects of different types of fuzing on rolling stock can be classified as follows: (a) Instantaneous nose and non-delay tail fuzing produces the maximum blast damage with a minimum of earth displacement. (b) Medium long-delay fuzing (.025 and .1-second) produces a progressively larger displacement of earth, with a resulting decrease in the size of the cone area of blast. (c) Short-delay fuzing (.01-second) produces an intermediate and the most desirable degree of both earth displacement and blast effect.

INSTANTANEOUS AND NON-DELAY FUZING

Photographs 44 and 45 illustrate the damage, in both cases highly localized, caused by the detonation immediately beside wood gondolas of 100-pound general-purpose bombs fuzed nose instantaneous.

Photograph 44, of a hit at the Trappes marshalling yard, shows the blast damage to the superstructure of the gondola and boxcar beside the point of detonation. There was only negligible damage to the steel undercarriage of the cars.
Photograph 45, of a hit scored in one of the marshalling yards at Coblenz, pictures reparable damage to the wood superstructure of a gondola and minor fragment damage to the wheels and undercarriage.

Photographs 46 and 47 illustrate the damage caused by two strikes by 500-pound general-purpose bombs in the Trappes marshalling yard.

Photograph 46 shows the point of detonation of a bomb fuzed non-delay. There was extensive blast damage to the wood superstructures of the cars and some damage to the undercarriage of the cars immediately beside the point of detonation.
Photograph 47 is that of damage caused by a bomb fuzed nose instantaneous, which after being actuated by the roof of a car detonated without causing a crater. There was widespread damage to car superstructures, but the undercarriages even of the cars very near the point of detonation suffered only minor damage.

The area within which anything more than the wood superstructure of rolling stock is affected by blast is very small. Photograph 48 is of a hit by a 500-pound general-purpose bomb fuzed nose instantaneous that detonated 18 feet from a flatcar. The blast against the flat bed of the car raised it up, causing it to break loose from the trucks, but this was the total extent of the damage.
MEDIUM LONG-DELAY FUZING

As previously indicated, bombs fuzed .025 and .1-second delay rely mainly upon earth displacement for their destructive effect on rolling stock.

Photographs 49 and 50 show the damage caused by 1000-pound general-purpose bombs fuzed .025-second delay and illustrate the fact that damage is limited almost entirely to the area within the crater size.

In photograph 49 the car in the background still standing on the track was at the edge of the crater but suffered no damage from either blast or fragment.

In photograph 50 the car within the crater size was completely destroyed. But the wood boxcar in the background, even though partially within the crater area, suffered only slight, reparable damage.
SHORT-DELAY FUZING

Bombs fuzed .01-second delay have proved the most effective against rolling stock. All cars within the crater area are completely demolished or severely damaged, and the sizable blast cone produces considerable damage outside this area as well.

Photographs 51 and 52 illustrate the damage caused by 500-pound general-purpose bombs fuzed .01-second delay. From both hits cars within the crater size were completely demolished and those outside the crater size suffered severe damage.
PHOTO 53

Photograph 53 shows the damage caused by a 1000-pound general-purpose bomb fuzed .01-second delay. The two cars in the center of the photograph, though beyond the crater area, suffered very severe damage. Cars within the crater size were hurled great distances and were completely demolished.

INCENDIARY BOMBS

One marshalling yard in Coblenz contained sufficient evidence for a study of the effects on rolling stock of the 4-pound magnesium incendiary bomb AN-M50A1.

Most of the cars damaged or destroyed by fire consisted of wood superstructure reinforced with steel. In all instances the wooden portion of the cars had been completely burned away. When the cars contained non inflammable material, the damage by fire was confined to distorting the reinforcing steel members of the superstructure and inflicting minor damage to the frame, trucks, and wheels of the cars. Some 90% of the cars containing inflammable material suffered irreparable damage to the frame and undercarriage.

Photograph 54 is a close-up showing the severely damaged frame and superstructure of a car that had contained inflammable material. The trucks and wheels were also severely damaged, rendering the car irreparable.
Photographs 55 and 56 are general views of cars damaged and destroyed by fire. Bent frames and undercarriages may be seen.
The 250-pound general-purpose bomb fused nose instantaneous acts somewhat like an incendiary against rolling stock.1 In an attack with these bombs on the marshalling yards at Ronet (Namur), Belgium on 23 April 1944, 1100 loaded and 200 empty cars in the congested yard were destroyed by fire. The heat of the instantaneous detonation was sufficient to ignite the cars or their contents, and the fire spread among the many cars in the yards at the time.

SUMMARY
Both on the theoretical grounds discussed in the text and on the basis of observed results, the .01-second delay fuzing is recommended for use against rolling stock. The 500-pound general-purpose bomb thus fused has proven effective.


LOCOMOTIVES
As revealed by ground surveys, the causes of damage to locomotives may be classified into the following types: (a) direct hits, (b) near-misses by delay-fuzed bombs, (c) near-misses by instantaneous-fuzed bombs, and (d) collapse of structures.

DIRECT HITS
The most severe damage, from direct hits detonating within the locomotive, not only rendered the locomotive irreparable but also decreased possible salvage. For example, at the Versailles-Matelot yard a 500-pound general-purpose bomb fused .01-second passed through the boiler of the locomotive and detonated between the drive-wheels at axle level. This hit demolished the boiler, part of the frame, two drivewheel axles, four drivewheels, and most of the driving and valve rods.
Another direct hit on a locomotive, which is shown in photograph 58, tore the boiler completely from the undercarriage. The front wheels of the locomotive, still on the track, may be seen in the left foreground and the completely destroyed boiler section in the background.


The same principles apply to the destruction of locomotive tenders as to that of locomotives. Photograph 59 shows a direct hit on a locomotive tender by a 500-pound general-purpose bomb fuzed .01-second scored at the marshalling yard at Niedernhausen, Germany. The tender was completely destroyed, the locomotives in front and behind were seriously damaged, and the driving mechanism and controls of the locomotive beside the tender were severely damaged.
DELAY-FUZED BOMBS

The second type of damage, that caused by the near-misses of delay-fuzed bombs, has proven in a number of cases to be quite extensive. One case was reported in which a large locomotive was overturned at the edge of a repair pit by a hit of a 1000-pound general-purpose bomb fuzed .025-second delay.

At Herdorf, Germany, a locomotive was overturned by a strike of a 1000-pound general-purpose bomb fuzed .01-second delay. As shown in photograph 60, the track on which the locomotive was standing was within the crater area and the locomotive was seriously damaged by the blast and earth movement.

Two instances of this type of damage were reported at the marshalling yard at Trappes, France. Photograph 61 shows an entire locomotive that had overturned into a crater produced by a 1000-pound bomb. The drivewheels and undercarriage were in the crater under the boiler, which had turned on its side.

PHOTO 61

In the second incident at Trappes the damage was caused by two strikes, one a direct hit that demolished the cab and rear portion of the locomotive and the second a crater into which the front portion of the locomotive dropped. These hits were by 500-pound general-purpose bombs with short-delay fuzing. The wreckage was being salvaged at the time photograph 62 was taken, and damage to the cab could not be accurately determined.

PHOTO 62
Another case of damage caused by a cratering hit was an instance at the Versailles-Matelot yard in which a 500-pound general-purpose bomb fuzed .025-second struck between two tracks situated over the repair pits in a shop. Four locomotives were so situated that they dropped partially into the crater that was formed, and a fifth suffered severe blast damage. No attempt had been made to salvage these locomotives nine months after the attack, although the building had been torn down and the yards were in running order. Photographs 63 and 64 show the damage caused by this hit.
INSTANTANEOUS-FUZED BOMBS

Considerable fragment and blast damage has been found to result from near-misses by bombs fuzed instantaneous or non-delay. If a 500-pound general-purpose bomb strikes within 20 feet, the damage is very severe, as illustrated by two typical hits of this type at the Trappes marshalling yard.

In the first case, the bomb detonated in a coal car on an adjacent track and demolished the cab and damaged some of the controls, as shown in photograph 65.

Photograph 65

Photograph 66 shows the fragment damage to a locomotive located approximately 20 feet from the point of detonation of the second of these 500-pound general-purpose bombs, this one fuzed non-delay. The front of the locomotive was blasted about 6 feet from the track.

Photograph 66
A strike 15 feet from a locomotive was scored at Niedernhausen, Germany, with a 500-pound general-purpose bomb fuzed nose-instantaneous. Photograph 67 shows the very severe fragment and blast damage.

**COLLAPSE OF STRUCTURES**

At many railway targets in Belgium a U. S. Strategic Bombing Survey unit found locomotives damaged and isolated by the collapse of locomotive shops. Damage in all of these cases was slight with the exception of a few where heavy structures falling on locomotives produced appreciable damage. Photograph 68 shows a locomotive, the rear portion of which was caught under the collapse of a reinforced-concrete structure. The estimated time required to repair this damage was one to two weeks.

**SUMMARY**

Direct hits on locomotives with instantaneous nose, non-delay tail, or .01-second tail fuzing, which will actuate the bomb inside the locomotive, produce the maximum amount of damage. The second most severe type of damage is produced by a bomb fuzed delay, the crater area of which includes the locomotive. In hits beyond this point, bombs fuzed instantaneous or non-delay are superior to those fuzed delay.

A direct hit by a 500-pound general-purpose bomb fuzed to produce detonation within the locomotive will destroy it completely. A 500-pound general-purpose bomb fuzed delay will produce major damage to a locomotive within the crater size.
INTRODUCTORY

If a rail interdiction program is to be economically carried out, proper bomb and fuze selection for missions against open track is essential. The problem readily lends itself to analysis, chiefly because of the simplicity of construction of the target and the ease with which the cratering characteristics of bombs (about which information is available) can be related to desired damage to the target. It is the opinion of the Evaluation Board that the method of approach to the problem, outlined in the subsequent pages, surpasses in import the particular numerical answers obtained. For, as will be shown, the most economical bomb-fuze combination to use against track depends upon the type of plane used, the method of bombing, the altitude of attack, and the type of soil upon which the track is laid; whereas the equations from which the most economical bomb-fuze combination can be determined are perfectly general and applicable from one rail system to the next.

This chapter is based upon experience in the European Theater of Operations. Two types of planes are considered, viz., fighter bombers and medium bombers; though of the latter class only the B26 is discussed since this was the only type of medium bomber employed by the Ninth Air Force in the European Theater.

GENERAL

In this report the term “rail cut” will be used to mean damage to open-line track, resulting from air bombardment, which renders the track impassable to a locomotive.

Although it is possible to block line by damaging rolling stock or causing an earth slide, attention is confined here to the more general technique of cratering roadbed and displacing track. From the point of view of bomb and fuze selection, tracks in stations and yards present particular problems because of the frogs, switches, etc.; bridges, viaducts, and tunnels, being structurally unique, also require special consideration. Hence these cases are excluded from this section.

TYPES OF PLANES USED

During the months of June, July, and August 1944 the Eighth and Ninth Air Forces expended considerable tonnage on rail-cutting operations, most of which was dropped by fighter bombers, although a small part was dropped by medium bombers. Heavy bombers have not been used in this theater against open line, except as targets of opportunity, in view of the obvious lack of economy in such employment.

The type of plane used is an important factor in making bomb-size recommendations because the loading characteristics differ. For example, the P38 can carry two bombs, each of any weight up to and including 2000 pounds. In the B26, on the other hand, weight, and not the number of bomb shackles, is the limiting factor. Hence the choice is between eight 500's, four 1000's, two 2000's, etc. Because of this difference separate recommendations are made for fighter bombers and for medium bombers.

FACTORS DETERMINING THE MOST EFFICIENT BOMB-FUZE COMBINATION

The objective of attacks against open lines is to damage the roadbed and rail in such a way as to make the line impassable for the longest possible time. This minimizes the number of missions required to maintain a route closed over any desired period of time.

The period for which the track remains impassable depends on (a) the difficulty in getting a repair crew to the spot; (b) the urgency of restoring traffic at the point cut; and (c) the amount of repair work necessary. The only one of these factors that is affected by the choice of bomb and fuze, excepting particular cases, is the last one.

The amount of repair work necessary is primarily a function of the volume of earth displaced and only secondarily of the length of track to be relaid. For, except for very small craters, the man-hours of labor necessary to fill the craters is much greater than that for replacing ties and track. The larger the crater, the longer the relative time for filling compared with track laying, since the volume of earth displaced increases generally as the cube of the crater diameter, while the length of track increases only as the diameter itself. Though the man-hours necessary for filling the crater would be greatly reduced if bulldozers or similar earth-moving machinery were to be used, the line might or might not remain cut for a longer period, depending on the delays occasioned by bringing
up the equipment. However, until the U. S. Military Railroad Service introduced mechanized repair equipment, the shovel and wheelbarrow were the standard tools in France.

A supplementary question that must be examined is the relative difficulty imposed by one “large crater” versus two or more “small craters.” In general, when the total volume of earth displaced by a number of widely dispersed small cratering hits is equal to that displaced by one large hit, the multiple hits will require more man-hours of repair than the single hit, because of time lost in moving the repair gang and equipment from one crater to the next.1 Ordinarily the bomb load that displaces more earth from the target than any other bomb load is recommended as the most effective.2 If several bomb loads are equivalent from the point of view of expected earth displacement, the load that gives the greatest number of expected hits is recommended.

1. Source: U. S. Military Rail Service. This may not be true in particular cases where there is sufficient man-power available to repair several craters simultaneously.

2. This accepts maximum repair time per sortie as the criterion of the most efficient bomb. Theoretically, immobilization time, i.e., repair time plus overhead time (time to get repair crews and equipment to the crater or craters to be filled), would be a better criterion. But the relationship between overhead time and the number of craters to be filled, and the ratio of overhead to repair time, are variable factors depending, in each case, on the number and location of the cuts and on the availability of personnel and equipment. This precludes consideration of immobilization time except under particular circumstances when these ratios can be estimated.

**COMPARATIVE EARTH DISPLACEMENT**

Assuming a crater to be a cone, the volume of earth displaced is computed according to the formula

\[ V = \frac{\pi}{6} d^3 h \]

where \( d \) is the diameter at ground level and \( h \) is the depth. Although craters are not perfectly conical, the amount of error introduced by this approximation is negligible.3 Results of the computation are summarized in Table 1 below.

The degree of damage inflicted on a rail line depends not only on the volume of earth displaced, but also upon the degree to which the crater overlaps the track. Certainly a crater that overlaps both rails of a single track line is sufficient to create a line cut. Alternatively, if the crater overlaps one rail, the perimeter of the crater being halfway between the two rails, the line may also be cut, though not as severely as in the first case. Either degree of overlap can be accepted as a standard. In this report, the condition is prescribed that the desired degree of damage is for the crater to overlap both rails of a single track line.3 For example, if bombs producing forty-foot craters are used against five-foot track, the line will be cut by craters whose centers are within fifteen feet of either of the outer rails; or in other words by bombs that fall within a band thirty-five feet wide centered on the line.

When bombing double-track line, it is preferable to cut both lines at the same point, i.e., with one bomb, rather than at different points. For in the latter case the laying of crossover track may require relatively little time, resulting in an early resumption of traffic. The desired degree of damage is for the crater to overlap all four rails of a double-track line.3 Thus, if bombs producing fifty-foot craters are used against a double-track line (with ten feet between tracks), the line will be cut by craters whose centers are within five feet of either of the outer rails; or in other words by bombs that fall within a band thirty feet wide centered on the line.

The width of the area within which a hit by any bomb is effective can be determined from the comparative crater diameters given in Chapter II. Two examples for single-track line and two for double-track line are shown on the following page.

<table>
<thead>
<tr>
<th>General-purpose Bomb (pounds)</th>
<th>Fuze (seconds)</th>
<th>Earth Displacement (cubic feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>.01</td>
<td>424</td>
</tr>
<tr>
<td></td>
<td>.025</td>
<td>635</td>
</tr>
<tr>
<td></td>
<td>.10</td>
<td>577</td>
</tr>
<tr>
<td>250</td>
<td>.01</td>
<td>1056</td>
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<td></td>
<td>.025</td>
<td>1539</td>
</tr>
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<td></td>
<td>.10</td>
<td>1539</td>
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<tr>
<td>500</td>
<td>.01</td>
<td>2413</td>
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<td>3047</td>
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<td>.10</td>
<td>2952</td>
</tr>
<tr>
<td>1000</td>
<td>.01</td>
<td>3367</td>
</tr>
<tr>
<td></td>
<td>.025</td>
<td>6362</td>
</tr>
<tr>
<td></td>
<td>.10</td>
<td>6150</td>
</tr>
<tr>
<td>2000</td>
<td>.01</td>
<td>4846</td>
</tr>
<tr>
<td></td>
<td>.025</td>
<td>10847</td>
</tr>
<tr>
<td></td>
<td>.10</td>
<td>12546</td>
</tr>
</tbody>
</table>

3. These computations are based on comparative crater sizes (in clay soil) for various bombs and fuzes, as determined by the Ninth Air Force Operational Research Section, ETO, (See Chapter I). In applying these results, account should be taken of the differences in crater dimensions resulting from variations in soil types and in the altitude of bomb release. It is believed, however, that while under different conditions the absolute figures for earth displacement will vary, the relative values will remain approximately the same; thus the absolute changes should not affect the final bomb-fuze recommendation.

4. Since the significant factor, from the point of view of bomb selection, is the relative, and not the absolute, volume of earth displaced by the various bomb-fuze combinations, this computation assumes only that the volume of earth displaced is proportional to the crater depth times the square of the crater diameter.

5. Computations were also made under the condition that the crater need overlap only one rail. The bomb-fuze combination that proved most efficient was precisely the same as that determined under the condition accepted above.

6. Computations were also made under the condition that the crater must overlap only two rails, one of each track. The most efficient bomb-fuze combination proved to be the same as that determined under the condition accepted above.
EFFECTIVE WIDTH OF TARGET IN CUTTING RAIL

SINGLE-TRACK LINE

2000 POUND GENERAL PURPOSE BOMB
FUZED 0.1 SECOND DELAY
CRATER DIAMETER 57 FEET

- 28.5' -

EFFECTIVE WIDTH OF TARGET

500 POUND GENERAL PURPOSE BOMB
FUZED 0.1 SECOND DELAY
CRATER DIAMETER 36 FEET

- 10' -

EFFECTIVE WIDTH OF TARGET

DOUBLE-TRACK LINE

2000 POUND GENERAL PURPOSE BOMB
FUZED 0.1 SECOND DELAY
CRATER DIAMETER 57 FEET

- 28.5' -

EFFECTIVE WIDTH OF TARGET

500 POUND GENERAL PURPOSE BOMB
FUZED 0.1 SECOND DELAY
CRATER DIAMETER 36 FEET

- 10' -

EFFECTIVE WIDTH OF TARGET
For single-track line, the 2000 pound bomb will produce a cut if it explodes anywhere within the 31-foot band, whereas the 500-pound bomb must hit within the 31-foot band to be effective; hence the vulnerable area of the smaller bomb as compared with the larger is only 31/52 or 59.6%.

Similarly, on double-track line the relative vulnerable area of the 2000 pound bomb is 16/37 or 43.2% of that of the 2000 pound bomb. The vulnerable areas for other bomb-fuze combinations, employed against either single track or double-track lines, are shown in Table 2 below.

**TABLE 2**

<table>
<thead>
<tr>
<th>General-purpose Bomb (pounds)</th>
<th>Fuze (seconds)</th>
<th>Single Track Line (feet)</th>
<th>Double Track Line (feet)</th>
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<tbody>
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<td>100</td>
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<td>8</td>
</tr>
<tr>
<td></td>
<td>.10</td>
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</tr>
<tr>
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<td></td>
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<tr>
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<td>37</td>
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</table>

*The crater diameter is too small to cut both tracks of a double-track line.

**RECOMMENDATIONS FOR MEDIUM BOMBERS**

In this theater alternative bomb loads for the B26 consist of 2 x 2000's, 4 x 1000's, 8 x 500's, 16 x 250's, or 28 x 100's. The comparative efficiency of these can be computed on the basis of the factors developed in the previous paragraphs. Suppose, for example, that the bombs are dropped so that 50% fall within a 500-foot circle. Then, assuming a normal distribution, approximately 5.6% of the releases will fall within the 52-foot band centered on a single-track line. Hence, if two 2000-pound bombs were fired .1 second apart, on the average 5.6% of the load or .112 bombs would be effective.

1. Double clustering is not considered here.
2. These figures are averages of the Ninth Air Force for the nine months ending January 1945.

**COMPARATIVE EFFICIENCY OF VARIOUS BOMBS AND FUZES**

**TABLE 3**

<table>
<thead>
<tr>
<th>GP Bomb (pounds)</th>
<th>Fuze (sec.)</th>
<th>% of Load within Vulnerable area</th>
<th>No. of Hits per Sortie</th>
<th>Earth Displacement per Hit (cubic feet)</th>
<th>Total Earth Displacement from Target per Sortie (cubic feet)</th>
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<td>.3328</td>
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</table>
The crater diameter is too small to cut both tracks of a double track line.

**Table 3**

<table>
<thead>
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<tr>
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*The crater diameter is too small to cut both tracks of a double track line.*
CHAPTER 6
HEAVY CONCRETE STRUCTURES

GENERAL

REINFORCED-CONCRETE STRUCTURES

Detailed descriptions of the construction of the various reinforced-concrete structures are included in the several target-damage reports published by this Board and listed in the bibliography. Typical examples are the U-boat pens at Brest, the E-boat pens at Le Havre, and the numerous coastal batteries that composed the so-called Western Wall. In the main, the fortifications built by the Germans were of good-quality concrete with heavy steel reinforcement.

MASS-CONCRETE STRUCTURES

Throughout France many structures of non-reinforced concrete that had been subjected to bombing attacks have been examined. These vary from light underground structures with 6-inch walls, to the forts in the Metz area having roofs 12 feet thick. The concrete also varies greatly, from the high quality in some of the coastal batteries constructed by the Germans to the very poor quality in some of the Metz forts built by the French during the last century.

GENERAL-PURPOSE BOMBS

REINFORCED CONCRETE

General-purpose bombs have proven to be of little value in attacks on heavy reinforced-concrete structures. In no instance were the fortified positions on the Cherbourg peninsula, having reinforced-concrete roofs laid on steel I-beams, found to be penetrated or seriously damaged by these bombs. When reinforced concrete up to 6 feet thick is additionally reinforced with 8-inch rolled-steel I-sections, general-purpose bombs break upon impact, and detonate low-order. "This is due to the fact that the heavy steel in the ceiling minimizes the shearing stress of the roof structure and reduces the deflection from the impact force to the minimum." In four out of five direct hits on heavy concrete installations, nearly complete bomb cases were found, indicating rupture and low-order detonation. Even when the bombs detonated high-order, only minor damage was inflicted. For example, two direct hits by general-purpose bombs on a reinforced-concrete casemate at one Le Havre battery resulted in roof craters 2 by 4 feet and 2 by 6 feet but caused no structural damage. Where precast concrete joists were used instead of I-beams, general-purpose bombs have penetrated a roof thickness of 6-feet, shearing the concrete joists, and detonated high-order.

Four 1000-pound general-purpose bombs and one 500-pound general-purpose bomb, all fuzed .025-second delay, were among the hits on a Noball site at Watten. The results were in each case negative. At the coastal battery at Longues, a bomb hit 3 feet from the corner of a casemate, producing a crater 45 by 14 feet, cracking the concrete under the gun, and damaging the casemate sufficiently to render the gun unserviceable. Thus near-misses with general-purpose bombs may accomplish more structural damage than direct hits, provided the crater size is the theoretical maximum and the fortification is partially within the crater radius.


Photographs 69, 70, and 71 illustrate the minor damage inflicted when the maximum crater size is not developed or the structure is just at the perimeter of the crater. In these instances there was blast and fragmentation damage only, while in the case of the Longues battery the damage was due to a combination of earth shock and mining effect.
Photograph 72 shows a strike at the battery at Pont du Hoe, which exposed the corner of the reinforced-concrete structure but produced only minor fragmentation damage. The minor damage may be attributed either to the size of the bomb or to insufficient penetration before detonation, resulting in less than the maximum crater size which is essential to obtain a mining effect from a near-miss.

PHOTO 72

Photograph 73 shows the damage from a hit, estimated to have been by a 1000-pound bomb on one of the U-boat pens at Brest. It is believed to have penetrated the top 46-inch layer of concrete and detonated in the air space below it. The crater measured 10 by 6 feet.

PHOTO 73
Nine additional hits on the roof of the pens by estimated 500 and 1000-pound general-purpose bombs produced no craters more than 4½ feet deep, and there was no interior damage. Photograph 74 shows the typical crater produced by estimated 1000-pound general-purpose bombs.

The bombing of heavy reinforced-concrete defenses in cooperation with the assault on Calais\(^1\) provided some interesting facts on the effectiveness of .025-second delay compared with nose instantaneous fuzing. Two adjacent strips of coastal installations, similar in the number and types of structures, received an equivalent number of bombs of all types, 500 and 1000-pound, British and American. In order to test the value of the greater blast and fragmentation effect on instantaneous fuzing, one area was attacked with bombs fuzed instantaneous and the other with bombs fuzed .025-second.

As expected, there was marked superiority of bombs fuzed .025-second delay in producing physical damage.

\(^1\) "Appreciation of the Air Support in the Ground Assault on Calais," AAF Evaluation Board (in process of completion).

<table>
<thead>
<tr>
<th>Fuzing</th>
<th>Strikes per Acre</th>
<th>% Damaged or Destroyed All Structures</th>
<th>Military Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>.025</td>
<td>.82</td>
<td>19</td>
<td>8.9</td>
</tr>
<tr>
<td>N.I.</td>
<td>1.44</td>
<td>3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Statements by prisoner of war indicated that enemy morale was less affected by the blast and fragmentation of instantaneous fuzing than by the cratering and damage of delay fuzing. Although many other factors also affected the progress of Allied Troops and enemy resistance, significantly it required about three times as long to fight through the strip bombed with instantaneous fuzing. This is evidence that the .025-second delay fuzing is superior to instantaneous in a tactical attack against heavy reinforced-concrete defenses.

General-purpose bombs were found to be very effective in destroying heavy reinforced-concrete positions during the period of construction.\(^1\) Bombs destroyed forms and materials, and in some instances, in the Le Havre area, persistent bombardment resulted in the abandonment of a construction program. In photograph 75 the casemates under construction require complete rebuilding.

At the Caucraville No. 2 battery, Le Havre, a direct hit by a 1000-pound general-purpose bomb on a position under construction penetrated the 12-inch concrete foundation and destroyed the reinforcing mesh.

\(^1\) "Survey of Bomb Damage to Coastal Batteries between Le Havre and Abbeville," 9 March 1945, and "Close-In Air Cooperation with the Ground Forces at Le Havre, France," 5 April 1945, AAF Evaluation Board.
At Watten, where 1000-pound bombs were completely ineffective against one building, they proved to be highly destructive against a similar one, still in the process of construction. For example, an estimated either 500 or 1000-pound bomb fuzed .025-second virtually destroyed half a roof and damaged the remainder enough to make it sag 2 feet. The roof and first floor are shown in photograph 76.
MASS CONCRETE

General-purpose bombs proved to be effective against the mass-concrete forts in the Metz area. The concrete was of inferior quality, and in one instance a 2000-pound general-purpose bomb destroyed a sizeable portion of a 12-foot roof on Fort Verdun as well as a steel turret atop the fort. Photograph 77 shows the damage caused by this hit.

PHOTO 77

UNDERGROUND INSTALLATIONS

Most reinforced-concrete gun positions have subsidiary underground communication tunnels and storage and housing facilities constructed both of mass and reinforced concrete. General-purpose bombs have been found relatively ineffective against these underground workings. Isolated hits of 500 and 1000-pound general-purpose bombs have inflicted structural damage on them, but a very high bomb concentration is required to effect enough damage to interfere in any way with the operation of the battery. Virtually a direct hit is necessary to achieve such a result; near-misses frequently produce only superficial damage. A hit must be within 10 feet to block an underground passage.

REINFORCED CONCRETE

At the battery at Le Clos de Ronces, Le Havre, a bomb density of 8.8 strikes per acre was obtained, with 9 hits and near-misses scored on underground workings, but only one passage was blocked, and this did not affect the efficiency of the battery.

Underground rooms with 4-foot mass-concrete walls, and 5-foot reinforced-concrete roofs were not seriously damaged by hits of 500-pound general-purpose bombs fused .025-second, as can be seen from photograph 78.

A direct hit by a 1000-pound general-purpose bomb fuzed .025-second on a building with a 5-foot reinforced-concrete roof resulted in a crater 1\frac{1}{2} feet deep, but no structural damage. Photograph 79 shows this hit.

Direct hits with 1000-pound general-purpose bombs fuzed .025-second were scored on the edge of a number of structures, but damage was too slight to have affected the operating efficiency of the battery. Photographs 80 and 81 show the damage inflicted by some of these hits.
Near-misses of 1000-pound general-purpose bombs striking 10 feet or more from a reinforced-concrete chamber at the Caucrauville No. 2, Le Havre battery produced no damage.

These results indicate that a heavier bomb is necessary to produce serious structural damage to underground structures. A 2000-pound general-purpose bomb is therefore recommended, fuzed delay to permit penetration before detonation in direct hits and to achieve a mining effect in near-misses. The mining effect described is illustrated by photograph 82 of a hit on Fort Verdun (St. Blaise) in which a cratering hit 3 feet from an underground passageway and reinforced-concrete building produced extensive damage.

MASS CONCRETE. General-purpose bombs have proved more successful against mass-concrete underground structures. One hit observed at the Caucriauville No. 2 battery, as shown in photograph 83, illustrates this point.

A 1000-pound general-purpose bomb fuzed .025-second struck beside the mass-concrete entrance of a reinforced-concrete underground structure. The mass-concrete passageway was completely destroyed, but the reinforced-concrete underground structure, even though it was within the crater dimensions, suffered only minor external fragmentation damage.

To get a mining effect the structure must be well inside the crater radius. Photographs 84 and 85 illustrate the secondary damage produced by hits 20 and 25 feet away from the 2-foot mass-concrete walls of an underground passageway. Damage was limited to minor cracks in the walls.
SEMI-ARMOR-PIERCING AND ARMOR-PIERCING BOMBS

Up to the present time no field team data on the effects of semi-armor-piercing and armor-piercing bombs on heavy concrete structures have been obtained. The following technical information, based on theoretical considerations, is available.

The 1600-pound armor-piercing bomb will penetrate 6 feet 8 inches of reinforced-concrete, and the 215 pounds of explosive filler is sufficient to inflict severe damage to a position. This would be particularly true if the strike was in the small ammunition magazine located in the rear portion of most of the reinforced-concrete casemates.

In high level attacks, semi-armor-piercing bombs of less than 1000 pounds are ineffective against reinforced concrete of 5 feet or more. When it is possible to obtain direct hits the 1000-pound semi-armor-piercing and the 1600-pound armor-piercing bomb can effectively destroy pillboxes.


TALLBOYS

The only bomb that has proved at all effective against the heavy reinforced-concrete pens of E-boats and U-boats has been the British 12,000-pound Tallboy. This bomb is 38 inches in diameter, and has a main casing of molybdenum steel containing approximately 5,000 pounds of Torpex. The nose is conical and sharply pointed, with approximately one-third of its length consisting of the tail structure.

U-BOAT PENS AT BREST

Of the total of 26 Tallboys dropped by the RAF Bomber Command on the U-boat pens at Brest, nine struck the roof of the structure. The fузing of these bombs was either .5 or 11-second delay; no difference in effectiveness was found between the two.

The roof of the U-boat pens varied in thickness from 12 to 18 feet. At the time of capitulation a program was in progress to thicken and strengthen the roof.

Three of the nine hits blasted holes in the roof, four produced large craters and caused interior scabbing, and two landed on the edge of the roof and caused no damage. The depth of penetration before detonation could not be definitely ascertained, but the evidence indicated that none of the bombs completely penetrated the roof before detonation. Photographs 86 and 87 show the interior and exterior damage caused by one of the hits that perforated the roof. This hole, the largest of the three, was funnel-shaped, measuring 47 feet across the top and narrowing down in 7 feet of depth to a diameter of 19 feet. This particular hit, although causing no structural damage, severed electric cables and cut the craneway, which made it necessary to load submarines by hand.

1. For details of the type of construction, see “Target Report on Brest,” AAF Evaluation Board.
The interior damage caused by the nine hits was limited to the cracking of two supporting walls. There was secondary damage to craneways, electric cables, and the machinery operating a gate. A submarine in one pen at the time a hole was blasted in the roof was undamaged. Though two hits were only 40 feet apart and both blasted holes completely through the roof, the damage was not merged in any observable degree.

E-BOAT PENS AT LE HAVRE

The E-boat pens at Le Havre were attacked by the RAF Bomber Command which dropped 22 Tallboys fuzed .5-second delay. One hit the roof of the structure and a second struck a concrete apron adjacent to the pen. The first strike perforated the roof, which consisted of 9 feet 5 inches of reinforced concrete. Damage to the concrete was quite extensive and repairing would have required considerable cutting out, but the main structure was not seriously damaged. The hole caused by this hit is shown in photograph 88. Note how the upper bars were blown upwards, and the lower ones downwards.

CONCLUSIONS

The damage inflicted by Tallboys on these very heavy reinforced-concrete structures was appreciable but highly localized. Although rather expensive repairs would have been necessary, there was no indication that the damage even remotely approached the point of collapsing the structures. The main effect of the hits was to disrupt installations and make the servicing of U-boats and E-boats more difficult.

The hits scored using general-purpose bombs of various sizes and fuzings produced no damage beyond forming small craters in the roof.

The smallest bomb that should be used on structures of this type is the 12,000 pound Tallboy. A number of hits by this type bomb serves to disrupt services and interferes with normal operations, but probably a prohibitive number would be required to produce sufficient structural damage to cause collapse.
This bomb was specifically designed for the purpose of penetrating reinforced-concrete structures. The added depth of penetration obtained by the attached rocket unit gives the bomb a striking velocity of approximately 1400 feet per second, compared with approximately 1100 feet per second without the rocket assistance.

The bomb is 17 feet long and 15 inches in diameter. Its 4300 pounds is distributed as follows: casing 2900 pounds, charge 500 pounds of Stellite, and rocket-assist unit 900 pounds.

In an experiment at Watten, France, 38 of these bombs were dropped on a huge reinforced-concrete structure. Only two hits were scored on which data could be obtained. The first struck without the assistance of the rocket, which failed to function, on the 17 foot reinforced-concrete roof directly over the center of a 15 foot outside wall. It penetrated to a depth of 9½ feet. There was no structural damage.

The second struck in a similar position on the building, but with rocket assistance penetrated to a depth of 15 feet 8 inches. Approximately 5000 cubic feet of concrete was displaced by this strike. Damage to the structure was limited to a small scabbing of the ceiling closest to the point and to a slight parting of the roof and side wall at an expansion joint located at the point of impact. The fact that the bomb struck at an expansion joint in the roof and also a construction joint in the wall may have increased slightly the depth of penetration, although probably this factor is offset by the fact that the bomb grazed the ends of two heavy steel roof trusses.

Since the two strikes did not fall where full penetration was possible, and since in any case this is a very small sample, it is impossible to judge fully effectiveness of the bomb. However, four significant facts are apparent from the experiment:

a. The bomb has no tendency to break up on impact.
b. The rocket assistance appears to increase the penetration of the bomb in reinforced concrete (5000 lb./sq.in. strength).
c. A miss penetrates so deeply into the earth that near-misses are completely ineffective.
d. A hit with rocket assistance displaces an amount of concrete roughly equivalent to that achieved by a Tallboy hit striking the same type of structure under similar conditions.
NAPALM

Investigations indicate that the use of Napalm against concrete structures is not profitable. To inflict damage on either the concrete positions or the personnel within them would require projecting an extremely high concentration of Napalm through the firing apertures, which present a very small target. Napalm has been used to neutralize open positions protecting concrete structures, thus allowing a flanking movement and the destruction of the heavy position by placed demolition charges.

Napalm was used unsuccessfully on certain of the Metz forts. No hits were found near concrete positions and those landing in open areas made small craters, which contained the burning mixture and localized the conflagration. This concentration of the Napalm may be attributed to the fact that the dive-bombing tactics by which the

1. For further data on the use and effectiveness of Napalm, see report entitled "Napalm Fire Bombs Dropped From High Altitudes Against Fortified Positions," AAF Evaluation Board, ETO, 28 May 1945.

tanks were launched produced small craters. In the South Pacific a wider coverage is apparently gotten by using glide or low-level bombing.

GRAND SLAM

The "Grand Slam" bomb is one that has been developed by the British for use against targets invulnerable to the "Tallboy." The total weight of the bomb is 22,400 pounds, including 9200 pounds of explosive charge of desensitized Torpex D-1. The bomb is 46 inches in diameter and 25 feet 5 inches in length, and has three fuzes mounted in the tail. Delays that have been used include: .05 seconds, 0.25 seconds, 0.5 seconds, 3 seconds, 11 seconds, 30 minutes and 60 minutes.

Due to limited usage of this bomb, only scanty data on its effectiveness is presently available, most of its potentialities being still relatively unknown. It has, however, proved to be effective against heavy viaducts of considerable size, such as the one at Bielefeld, Germany.

SUMMARY

Mass-concrete fortifications can be successfully attacked with 1000-pound and 2000-pound bombs. Against such heavy structures as U-boat pens nothing smaller than a Tallboy has an appreciable effect. For structures intermediate in strength between these two extremes, a suitable bomb would be one more destructive than a 2000-pound general-purpose bomb but smaller than a Tallboy.

RECOMMENDED BOMBS AND FUZES

<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>Bomb (pounds)</th>
<th>Fuze (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass-concrete fortifications, underground installa-</td>
<td>1000 or 2000</td>
<td>.1 nose</td>
</tr>
<tr>
<td>tions, and communications</td>
<td>GP</td>
<td>.025 tail</td>
</tr>
<tr>
<td>Reinforced-concrete casemated batteries, under-</td>
<td>12,000 Tallboy</td>
<td>.5 or 11</td>
</tr>
<tr>
<td>ground installations, and communications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-boat and E-boat pens</td>
<td>12,000 Tallboy</td>
<td>.5 or 11</td>
</tr>
</tbody>
</table>
CHAPTER 7
OPEN GUN POSITIONS

GENERAL

The Western Wall was composed of numerous land and coastal batteries constructed by the Germans for the defense of the western European coast against an Allied invasion. These batteries contained guns of all calibers. At the time of the invasion a construction program was in progress, providing for the relocation of many guns from open positions to reinforced-concrete casemates, although on D-Day most of the guns were still in open positions.

The attacks against open gun emplacements have been made with almost every size and type of bombs, both American and British, and with many fuze combinations.

TYPICAL CONSTRUCTION

The batteries examined may be divided into two main classes according to type of construction and general layout.

In the first type were open emplacements, with the gun at the center, secured to a concrete baseplate. The trail usually rested on a concrete traversing ring calibrated around the baseplate. The positions were surrounded by a revetment of either earth or concrete (mass or reinforced) approximately 5 to 6 feet in height. In some instances small ammunition lockers of light reinforced-concrete were built into the revetments. Underground structures were very light, usually of mass concrete and corrugated iron sheeting; they were used mainly as storerooms. Occasionally control posts of reinforced concrete were provided. Communication between positions was by means of open trenches.

The second type were mainly open emplacements, generally larger than the first type but of the same construction. Reinforced-concrete casemates, however, were usually under construction or had been completed at these batteries. The positions were connected by underground passages of mass or reinforced concrete, with roofs and walls between 1½ and 2½ feet in thickness. There are also underground magazines, stores, and dormitories, some with roofs and walls of mass or reinforced concrete 6 or 7 feet thick. Few of the reinforced-concrete casemates were completed and most were in the early stages of construction.

TARGETS EXAMINED

Early in September 1944, British troops had encircled Le Havre and were prepared to launch a final assault upon the city. Around it the Germans had constructed a ring of defenses consisting of many open and casemated gun positions containing guns of all calibers.

In preparation for this final assault, the ground forces requested an attack by the Royal Air Force. In certain areas, to be covered by "carpet bombing", a sufficient number of aiming points was selected to produce an overall bomb density adequate to neutralize all the batteries. The attacks had a decided effect on German morale and rendered enough batteries unserviceable for it to be considered a success.

Also examined were 13 coastal batteries between Le Havre and Abbeville, mostly open positions, which had been attacked by both the U.S. Army Air Forces and the Royal Air Force.

INSTANTANEOUS vs. DELAY FUZED BOMBS

Bombs fuzed nose instantaneous or tail non-delay were found to have a greater area of destruction than those fuzed delay. This was due to the fact that bombs fuzed delay produce larger craters but at the expense of fragmentation effect. The small amount of fragmentation produced by a bomb fuzed delay is upward from the crater produced and any portion of the target must be in very close proximity to suffer damage. Contrasted to this, a bomb fuzed nose instantaneous or tail non-delay produces a sizable crater but in addition has a much larger cone of fragmentation.

Examination of the coastal batteries in the Le Havre area furnished the best available information for a comparative study of the effects of bombs fuzed instantaneous or non-delay and those fuzed delay. In the case of Caucriauville No. 1 and No. 2 batteries, on which bombs fuzed mainly .025-second were dropped, no serious damage to the guns resulted with a bomb density of five or six strikes per acre being obtained. On the batteries at Fond du Capuchet and Bieville No. 2, bombs fuzed instantaneous were dropped and even though only two or three strikes per acre was obtained approximately half of the guns were rendered unserviceable.
The Fond du Capuchet battery consisted of four circular and four open rectangular emplacements, two of each type contained 150-mm. semi-mobile howitzers, while the remainder were unoccupied at the time of the inspection. In the attack against this battery with bombs fuzed instantaneous one gun was destroyed and one was rendered unserviceable by fragmentation. The one gun was destroyed by two hits 15 and 24 feet away, and the second was rendered unserviceable by a hit 105 feet from the gun, a fragment from the bomb separating part of the liner from the barrel of the gun. Photograph 91 shows the damage caused by the two hits within the position described above.

The Bleville No. 2 battery consisted of four open rectangular emplacements containing 4 x 88-mm. anti-aircraft guns. This battery was attacked employing bombs fuzed instantaneous and all guns were rendered unserviceable by fragmentation. It was impossible to associate the damage with particular bomb hits but the nearest craters were located 14, 17, 45, and 64 feet respectively from the four positions.

Target examinations have revealed that "with .025-second fuzing, serious damage to open emplacements can only be expected within the area of the crater and this will not necessarily affect the gun unless the crater overlaps the concrete baseplate, or unless the part of the parapet included in the crater contains sufficient concrete to provide heavy debris." This finding is confirmed in the study of gun batteries in the Pas de Calais area.

A typical example of a near-miss by a cratering bomb which caused no damage was found at the Caucriauville No. 2 battery, Le Havre, where a 1000-pound general-purpose bomb fuzed .025-second struck 40 feet from an open sunken emplacement.

Photograph 92 shows a crater, the perimeter of which is at the edge of the concrete baseplate and although the gun was thrown from its position all of the piece but the wheels was serviceable.

A near-miss may destroy the concrete or earth revetment around a position but will rarely render the weapon unserviceable, though in some instances heavy debris from the concrete of the revetment caused damage to the piece.

A very good example of the destructive effect of direct hits on open positions by cratering bombs may be found in the study of the bombing of the battery at Pastourelle, Fecamp. Photographs 93, 94, and 95 show the damage inflicted by direct hits on open positions by cratering bombs.

UNDERGROUND WORKINGS

Delay fuzing was found necessary to effect any appreciable damage on underground installations. Most batteries having open gun emplacements were found to have only surface communication trenches, however, and small ammunition shelters near the ground level. Not enough damage was inflicted on the subsidiary structures to affect the efficiency of the battery, and bombs and fuzes should not be selected as if these structures were the primary portion of the target. To inflict damage on underground workings, near-misses have to be so close that the bomb density required would be greater than for a direct attack on the above-ground emplacements. Bombs fuzed instantaneous and non-delay will cause virtually the same damage to surface installations as those fuzed delay, and will, in addition, produce the greatest possible radius of destruction and inflict the greatest damage to the primary weapons of the battery.

RECOMMENDATION

From results observed, general-purpose bombs fuzed nose instantaneous and tail non-delay are recommended for use against open gun batteries.

NAPALM

In attacks against open gun positions and strongpoints in close cooperation with the ground forces, Napalm has been used with a considerable amount of success. To be effective, however, it has to be used “in volume and concentration.” Napalm has not been successful against either pillboxes or the heavy concrete and steel fortifications found in the Siegfried Line. But it has been effective in forcing troops to move from the outer defenses back into a strongpoint, making possible a flanking movement and the subsequent destruction of the strongpoint.

CHAPTER 8
MISCELLANEOUS

TUNNELS

GENERAL

Attacks against tunnels are functionally equivalent to those against bridges and main-line track, i.e. are designed to interdict rail traffic. Because of its unique structural characteristics, however, a tunnel presents special problems from the point of view of bomb and fuze selection. Generally tunnels, rather than cuts, are constructed at particular points because the earth or rock is too thick or too hard, or both, to cut through economically. Hence every tunnel has, in the form of a soil or rock overburden, a certain degree of natural protection.

Despite the obvious difficulties of collapsing part or all of a tunnel roof, attacks against tunnel entrances were suggested in this theater in the spring of 1944 because it was believed that “delays of several months may be expected”.¹ On the basis of the small sample of such attacks attempted in the European Theater of Operations, this statement appears not to be true.

Tunnel entrances can be attacked by level or dive-bombing, aiming at the roof, or by glide-bombing, attempting to throw the bomb inside the tunnel. Evidence from both static tests and combat experience clearly indicate that the damage caused by detonation within a tunnel requires a comparatively short time for repair. The blast from such an explosion is vented toward the entrances, dissipating the effects. Hence a limited amount of debris is created, and the damage to rails is no greater than that caused by ordinary rail-cutting operations. Direct hits on the roof, on the other hand, must be with bombs larger than 2000 pounds if anything more than extremely localized collapse is to be obtained. Even a lucky hit with a 2000-pound bomb will not generally create great damage, as the amount of overburden dropped on the tracks will not be difficult to remove. If very large bombs are used, e.g. Tallboys, both the vulnerable area and the amount of damage may be expected to increase greatly. However vital hits will still be extremely difficult to obtain, probably making the effort uneconomical relative to possible alternative targets.

Thus, tunnels are generally not well suited to air attack. If, under particular circumstances, such an attack is necessary, a better chance for long-delay damage is obtained by hitting the roof of the entrance with the largest bomb that can be carried. In all such cases, since maximum penetration is desired, long-delay fuzing should be used.

BREVAL

The railway tunnel at Breval, France, was successfully attacked by aircraft employing dive-bombing tactics. A 1000-pound general-purpose bomb fuzed either .025 or .01-second struck the light loam above the roof of the tunnel entrance, producing a hole 24 by 12 feet. The soil thus displaced fell on the tracks, which were undamaged, stopping all traffic on the line. It was estimated that 400 man-hours of repair were required to clear the debris. Photograph 96 shows the hole in the tunnel entrance. Note that nothing more than localized collapse was effected.

EVREUX

At Evreux, France, a railway tunnel was subjected to level minimum-altitude attack by fighter-bombers carrying 500-pound general-purpose bombs, fused delay. One bomb was successfully projected 20 feet inside the tunnel entrance and detonated between one track and the side of the tunnel. The blast caused the displacement of 20 square feet of stone masonry with which the tunnel sides and roof were faced; fragmentation damage was visible for 100 square feet. The near set of tracks was severed and the far set displaced; both lines were rendered impassable. There was no general collapse of the tunnel. The estimated time required to place the line in operation was 6 to 8 hours.

The Evreux tunnel incident was virtually duplicated in a test conducted in the Mediterranean Theater and the results obtained were essentially the same. A 1000-pound general-purpose bomb was detonated statically 100 feet inside a tunnel. Rails were bent and broken for a distance of 30 feet, a crater 20 by 15 feet was created, and although the one foot brick wall of the tunnel suffered fragmentation damage, very little debris was created. It was estimated that it would take 4 hours to repair the damage.

SAUMUR

On 8 June 1944, RAF Lancasters dropped 19 6-ton Tallboys on the double-track tunnel at Saumur. In an extremely lucky hit considering the number of bombs dropped, one of the bombs landed just above the entrance, passed through a heavy overburden and also the tunnel roof, and detonated in such a way as to blow the rails upward against the roof of the tunnel. The entrance was undamaged by the bomb, but the removal of about 16000 cu. meters of dirt was required.

Day-and-night work to reestablish traffic, organized at once by the Germans, continued steadily until the job was completed (total time for repair is believed to have been more than one month). The loose dirt was removed either through the mouth of the tunnel or through a hole dug directly into the hill from above the tunnel entrance, which together with about 50 feet of tunnel roof remained in place. It was also necessary to repair damage to the line caused by other bombs. Photographs 97, 98, and 99 show the tunnel after the repair work was completed.
**WIRE BARRIERS**

Most gun batteries and strongpoints are surrounded by one or more belts of barbed wire entanglement. Because of the considerable conjecture on the effects of bombardment on wire barriers, a cursory examination was made from this point of view at two targets surveyed by this Board.1

The tactical purpose of breaching wire barriers is to assist ground troops by creating an avenue of entrance into the strongpoint preliminary to the final assault. This breaching may be accomplished either by cutting the wire or by throwing debris on it over which the attacking troops may pass. Another factor to consider, from the point of view of fuze selection, is that craters in the vicinity of the breach provide natural protection for the assaulting troops against automatic-weapons fire which normally covers the wire barrier.

At the Caucriauville No. 1 battery at Le Havre each of the two or three bands of the wire barrier consisted of tight strands across angle-iron supports, from 2 to 5 feet in height, with loose wire in between. The wire was struck in 13 places by various types of bombs, most of which had an estimated fuzing of .025-second tail-delay. At right angles to its length, the wire was cleared only to the edge of the crater, while in the direction of its length it was cleared 10 feet on both sides of the crater.

A number of the forts in the Metz area were surrounded by wire barriers of one to three bands. These barriers had been struck a number of times by bombs of various types and fuzings. There were no secondary wires between the longitudinal and diagonal, and these appeared to be quite old, sagging from the angle-iron supports on which they were stretched.

At right angles to the length of the wire it was cleared for a distance of approximately 5 feet beyond the edge of the crater and sufficiently covered with debris for approximately the same distance to allow passage by foot. In the direction of the length of the wire, it was cleared for approximately 10 feet beyond the edge of the crater and covered with debris for varying distances.

It can be assumed in general that the damage will vary directly as the crater size, and that either the wire will be cut or debris will cover it for an average of 5 feet on all sides of a crater. Based on considerations of the width of the wire to be breached, and cratering characteristics, comparative bomb loads, and probability of hits, with various types of bombs, the most efficient bomb and fuze can be determined.

**AMMUNITION AREAS**

Of the very few ammunition areas studied, most were of the open-revetment type, usually well camouflaged and located in wooded area. The ammunition was always segregated according to the weapons with which it would be used, and normally it was stored in revetments with earth embankments 5 to 6 feet high and 100 to 300 feet apart. It varied from small-arms ammunition to 6-inch coastal-defense projectiles and propelling charges, land mines, booby-trap components, and aircraft bombs. Firebreaks between groups of revetments were frequent.

Typical of the attacks on ammunition areas was the one in the Foret de Montgeon at Le Havre. This was a part of the air cooperation with ground forces prior to the final assault on the city. The size of bombs varied from 500 pounds up, and all were fused delay. No direct hits on revetments were made. Of the many strikes near the open revetments, some produced craters within 1 foot of the stacked ammunition, but no ammunition was destroyed by sympathetic detonation. The only relevant result of the bombardment was the cratering of the nearby roads, and because the heavy woods made detours impossible, a small portion of the ammunition in the area was isolated.

The typical open-revetment ammunition storage facility is apparently an extremely difficult target to destroy. Each revetment must be destroyed individually, and this requires a high bomb density. Most types of ammunition are stored in containers of wood or another inflammable material, vulnerable to incendiary bombs. The M-17 cluster of 4-pound incendiary bombs will result in a high density of bombs per acre and may be expected to effect the widest destruction.

The subsidiary attack against roads can be best made with 100-pound general-purpose bombs fused .01-second nose x .025-second tail. In the average soil these may be expected to form a crater of 21 x 5 feet, which is large enough to effect a temporary road block. Except in the special case when an early and successful assault on the position is expected, however, this kind of attack is of dubious value. There would usually be alternative routes cross-country, and in the worst case repairing the road would not take very long.

**SURFACE VESSELS**

A German minesweeper that had been successfully attacked by British Beaufighters with 500-pound medium-capacity bombs was examined by members of a British Unit that parallels the AAF Evaluation Board. The bombs dropped were similar to the American general-purpose bomb of the same weight. The estimated fuzing of the bombs in this attack was short-delay, allowing penetration of the deck and detonation at a point somewhere inside the vessel.

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A 500-pound general-purpose bomb, fuzed to produce
detonation within the hull of a light unarmored vessel
of this type, will produce considerable damage and render
the ship unserviceable.

The vessel, an M-type minesweeper with a deck of
\( \frac{3}{8} \)-inch plate x \( \frac{1}{2} \)-inch doubler, had been sunk during a
rocket attack but remained upright and was subsequently
subjected to bombing attack. One bomb struck on the
starboard side about 10 feet from the stern and destroyed
all structure from the starboard side to the middle line
over a length of 20 feet. A portion of the deck was dis­
placed upward approximately 2 feet. Photographs 100
and 101 show the extent of damage caused by this hit.
One or possibly two hits were scored on the port side just abaft the funnel. A portion of the superstructure about 35 feet long by 18 to 20 feet wide was destroyed. Photograph 102 shows the damage inflicted.

PHOTO 102

Another hit was scored just forward of the bridge. The bridge was canted aft, and the bow was severed and sunk at the fore end. Photographs 103 and 104 show the damage resulting from this hit.

PHOTO 103
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61. Close-in Air Cooperation with the Ground Forces at Le Havre, France. AAF Evaluation Board, ETO. 5 April 1945.
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