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Note No. ARP.121/HJHS.
December 1940.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Road Research Laboratory

REPORT FOR THE MINISTRY OF HOME SECURITY

METHODS OF LIMITING THE ACTION OF UNEXPLODED BOMBS

SUMMARY

A description is given of experiments conducted in order to determine the amount of sand which it is necessary to place over delayed-action bombs buried at various depths so that the effects of the subsequent explosion may be restricted. Full scale tests have been performed using 250 lb. A.S., 500 lb. G.P. and 250 kg. bombs buried at different depths in clay and sand soil and with different amounts and distributions of sand cover. By means of experiments with smaller charges (8 lb. Polar Ammon gelignite) the effect of a cavity round a bomb has been examined, as well as the protection afforded by a wall and by a circular sandbag revetment. The movement of the earth near the bombs has been measured and high speed cine pictures of the explosions have been obtained. The results show that:-

(1) In clay soil, 80 tons of sand in the form of a cone 6 ft. 6 in. high and 125 tons in a cone 6 ft. high are sufficient cover for 250 lb. and 250 kg. bombs at depths of 10 and 12 ft. 6 in. respectively. After the explosion, the debris appears in the form of a raised mound.

(2) In sand soil, 120 tons of sand in the form of a cone 10 ft. high, and 180 tons in the form of a cone 6 ft. high, suffice for 250 lb. and 250 kg. bombs at depths of 10 ft. and 13 ft. respectively. After the explosion, a well-defined crater is observed.

(3) Sandbags are as effective as loose sand provided the weight of sand and its distribution are the same.

(4) A given weight of sandbags stacked in the form of a frustrum of a cone is not as effective as the same weight of sandbags piled in a cone.

(5) The permanent horizontal and vertical earth movements in sand soil near covered 250 lb. A.S. bombs 10 ft. deep are practically the same as those at corresponding distances from a similar uncovered bomb 10 ft. deep but the maximum horizontal earth movement is greater for a covered than for an uncovered bomb.

/(6)

(6) The horizontal and vertical earth movements near a bomb 10 ft. deep in sand soil are very much smaller if a cavity is dug out round the bomb than if the bomb is 10 ft. deep in a cavity filled with loose material.

(7) 50 tons of sand in the form of a cone 8 ft. high is sufficient to stop the emergence of fragments from a 500 lb. G.P. bomb 4 ft. deep in sand soil.

(8) Small scale tests on the protection offered by a straight wall and by a circular sandbag revetment were not conclusive, but they indicated that a very substantial wall or revetment would be necessary to provide protection to nearby buildings against bombs in sand.

(9) The use of a belt conveyor greatly increases the speed with which a sand or sandbag cover may be erected over a bomb, and at the same time affords some considerable measure of protection for personnel engaged on the work.

In the practical application of these results, at least two cases will arise, viz:-

(i) where it is desirable to prevent debris from being thrown more than a few feet from the crater in order to prevent damage to the superstructure of buildings, but where earth movement is of little consequence.

(ii) where it is desirable to minimise earth movement due to the explosion in order to prevent damage to service mains and to the foundations of buildings and structures, but where debris, fragments and blast can be tolerated.

Case (i) may be dealt with by the use of a sand or sandbag cover, whilst Case (ii) may perhaps be dealt with by digging a cavity round the bomb. In order to stop damage by fragments emerging from the cavity a sandbag revetment could be erected round the crater area; in this case, the splinters and blast emerge vertically upwards. An alternative method of dealing with splinters might be to dig a relieving trench to allow splinters and blast to escape mainly in one direction (chosen so that the minimum amount of damage would be done.)

Introduction

In the following Report, a description is given of a general method of restricting the explosive effects of bombs by covering them with sand. The object has been to find the weight of sand required to cover a given size of bomb so that the effects of the explosion above ground level are limited to such an extent that no debris is thrown more than a few feet into the air.

Preliminary experiments

Preliminary small scale experiments were carried out at the Road Research Laboratory using small charges (2 oz.) buried 1 ft. deep in clay soil and covered with sand. The amount and distribution of the sand was varied. The results, which are described in Note No.D.36,

/showed

showed that the distribution of the sand was important and that the greatest tamping effect was obtained by having a conical mound of sand spread over the cratering area. On the assumption of a model law, it was calculated that about 60 tons of sand would be necessary for a 250 lb. bomb 10 ft. deep in the ground.

Further tests were made in clay soil at Stewartby using 8 lb. charges of Polar Ammon gelignite buried to a depth of 4 ft., and 67 lb. charges buried to a depth of 8 ft. A cone of sand, 12 ft. in diameter and 4 ft. 6 in. high, containing approximately 9 tons of sand was sufficient to tamp the 8 lb. charge, whilst a cone 24 ft. in diameter and 6 ft high containing approximately 44 tons of sand sufficed for the 67 lb. charge.

Full scale experiments

Full scale experiments were performed at Stewartby in clay soil and at Ashley Walk in sand soil, using 250 lb. A.S. and 250 kg. bombs buried 10 ft. and 12 ft. 6 in. deep respectively. The cover consisted of either loose sand or sandbags, and three methods of loading were compared, viz:-

(a) hand shovelling with a portable belt conveyor,
(b) piling sandbags with a belt conveyor, and
(c) stacking sandbags by hand.

Arrangement of tests

Particulars of the sand coverings over the various bombs are given in Table 1. In the Table, the depth of the bomb refers to the depth of its centre of mass below ground level whilst the weight of the sand cover is an approximate figure which is considered reliable to within ±10 per cent.

/Table 1

Bomb	Covering	Weight of Cover (tons)
Clay Soil		
250 lb. A.S. 10 ft. deep.	Sand cone 30 ft. dia. 6 ft.6 in. high.	60
" "	Sand cone 35 ft. dia. 6 ft.6 in. high	80
250 kg. 12 ft. 6 in. deep.	Sand cone 40 ft. dia. 6 ft. high.	125
Sand Soil		
250 lb. A.S. 10 ft. deep.	Nil.	Nil.
" "	Sand cone 17 ft. dia. 8 ft. high.	25
" "	Sand cone 32 ft. 6 in. dia. 10 ft. high.	120
" "	Sandbag cone 28 ft. dia. 9 ft. high. 3,400 sandbags.	90
" "	Sandbag frustrum of a cone 30 ft. dia. of base, 12 ft. dia. top, 5 ft. high. 3,000 sandbags.	80
" "	Ditto 35 ft. dia. of base, 19 ft. dia. of top, 5 ft. high. 4,500 sandbags.	120
250 kg. 13 ft. deep.	Mound of sand, 40 ft. dia. of base, 5 ft. 8 in. high.	180

Measurements

The following measurements and observations were made:-

(1) A profile of the ground configuration and sand covering before and after the explosion.

(2) The maximum horizontal earth movement at various distances near the bomb, as observed by means of inertia-type displacement meters.

(3) The permanent horizontal and vertical earth movement at various distances near the bomb, as revealed by pegs in the earth.

(4) High speed cine photographs of the explosion.

(5) The time required to erect the sand covering.

Results

(1) Cover necessary for 250 lb. and 250 kg. bombs.

Clay soil   In clay soil, 80 tons of sand in the form of a cone 6 ft. 6 in. high is sufficient cover for a 250 lb. bomb 10 ft. deep in the ground, whilst 125 tons in a cone 6 ft. high suffices for a 250 kg. bomb 12 ft. 6 in. deep in the ground.   After the explosion the debris is found in the form of a raised mound over the crater area. (Fig.1 and Plate 3).

/sand

Sand soil In sand soil, 120 tons in the form of a cone 10 ft. high is sufficient cover for a 250 lb. A.S. bomb 10 ft. deep in the ground whilst 180 tons in the form of a cone 6 ft. high suffices for a 250 kg. bomb 13 ft. deep in the ground. After the explosion, a well-defined crater is found. (Fig.2.)

A conical heap of sandbags 9 ft. high containing 3,400 bags is more effective than 4,500 sandbags stacked in the form of a frustrum of a cone 5 ft. high and 35 ft. diameter of base (Fig.3 and Plates 1 and 2)

(2) Earth movements in sand at various distances from covered bombs

The results of the measurements of earth movement show that:-

(i) The permanent horizontal and vertical earth movements at distances up to 50 ft. from covered bombs were approximately the same as those at corresponding distances from uncovered bombs buried at the same depth in sand soil. (Fig.4)

(ii) The maximum horizontal earth movement at various distances from a covered bomb was, however, greater than at the corresponding distances from the uncovered bomb. The maximum horizontal movement at a depth of 1 ft. was in all cases greater than that at 3 ft. 6 in. deep in the ground. (Fig. 5).

(iii) The difference between loose sand and sandbags for covering bombs is inappreciable, judging from the similarity in earth movements at corresponding distances. The total weight of sand and its distribution over the crater area must, however, be the same.

(3) Time required for piling sand by different methods

(i) Stacking sandbags by hand

The time required to build a frustrum of a cone containing 4,500 sandbags and with dimensions 35 ft. diameter of base, 19 ft. diameter of top and 5 ft. high was about 360 man-hours. This time included filling bags, transporting about 25 yd. on a light railway, carrying and stacking. The standard rates as given in the R.A.F. Pocket Book for 1937, p.824 aggregate 475 man-hours for this work, made up as follows:-

(a) Filling sandbags - 20 bags per man per hour. (225)

(b) Carrying sandbags 25 yd., dumping and returning - 30 bags per man per hour. (150)

(c) Building revetment - 45 bags per man per hour. (100)

The figures in brackets denote the number of man-hours necessary for 4,500 bags. In the present experiments, some considerable time was saved by using a light railway for transporting the bags and the number of man-hours required for this part of the work was much less than 150. The actual construction of the frustrum involved 9 men working for about 13 hours on or near the frustrum. Under practical conditions they would have been within the danger area during this time.

(ii) Piling sandbags with a belt conveyor

A small belt conveyor driven by a $3\frac{3}{4}$ H.P. Lister petrol engine with a maximum loading rate of about 40 cu.yd. per hour was used to pile sandbags (Plate 4). The maximum rate of loading was found to be 20 bags per minute (or 32 tons per hour). The time required for 3,400 bags was $3\frac{3}{4}$ hours, during which time it was unnecessary for personnel to approach to within 30 ft. of the bomb. In order to maintain this rate of working it was found necessary for 6 men to work in shifts of about 10 minutes each and to ensure that there was an adequate supply of sandbags at the loading end of the conveyor.

/(iii)

(iii) Piling sand by belt conveyor

Sand was fed on to the belt conveyor by shovel and the maximum rate of loading was found to be 38 tons per hour; this rate was attained by employing 10 men (the maximum number which could be accommodated round the loading end of the conveyor) and could only have been maintained by very frequent shifts. The average rate of loading was 26 tons per hour over a period of 4 hours. During this time it was unnecessary for personnel to approach to within 30 ft. of the bomb.

It may be concluded, from a study of these three methods of loading that, both from the point of view of speed and safety of personnel, the belt conveyor has a great advantage over manual methods for covering bombs. In order, however, to take full advantage of the possibilities of the belt conveyor, it is essential to ensure that there is an adequate supply of material at the loading end. In the tests described, the conveyor used was one of the smallest models made, but it may be possible to use conveyors with a much greater rate of loading. Further consideration will be necessary to arrive at the best type of machine and at the quickest method of loading it.

(4) High speed cine photographs

Cine films were taken before, during and after each explosion. The speed of the film varied from 64 to about 150 frames per second in different experiments.

A few prints from these films are reproduced in Plates 1 - 7.

Plates 1 and 2 show four different coverings over 250 lb. A.S. bombs 10 ft. deep in sand soil. The photographs show clearly that the maximum height of eruption is very much less with a conical covering than with one in the form of a frustrum of a cone. The maximum radius of scatter of sandbags for the three sandbag coverings was as follows:-

(a) 3,000 bags in a frustrum - 30 ft.
(b) 4,500 bags in a frustrum - 27 ft.
(c) 3,400 bags in a cone - 22 ft.

It may be concluded that the distribution of the load in the cover is important and that a cone provides a better covering than a conical frustrum.

Plate 3 shows photographs taken during and after the explosion of a 250 kg. bomb 12 ft. 6 in. deep in clay soil covered with a sand cone containing 125 tons of sand.

Plate 4 illustrates the portable belt conveyor used in the tests to pile sand and sandbags. Plate 5 shows the crater produced by the explosion of a 250 lb. A.S. bomb in an open cavity 8 ft. x 4 ft. at the top, 6 ft. x 4 ft. at the bottom and 11 ft. 6 in. deep.

Plate 6 shows the explosions of an 8 lb. charge of Polar Ammon gelignite 4 ft. deep in sand soil, surrounded by a circular sandbag revetment.

Plate 7 shows a series of photographs taken during the explosion of a 250 lb. A.S. bomb in an open cavity. The initial phase of the explosion consists in the expulsion of a spherical mass of incandescent gas which has an initial rate of expansion of not less than 4,000 ft./sec. The mass of incandescent gas is projected upwards where it burns relatively slowly; some of it persists for about $\frac{1}{2}$ second.

Plate 8 shows photographs taken during and after the explosion of a 250 kg. bomb 13 ft. deep in sand soil covered with a sand cone containing 180 tons of sand.

/Subsidiary

Subsidiary experiments

Certain additional experiments were carried out at the suggestion of the Director of Bomb Disposal.

(1) Two 500 lb. G.P. bombs with their centres of mass 4 ft. deep in sand soil were exploded (a) with no cover and (b) with a sand cover containing about 50 tons of sand. The movement of the earth near the bombs and the vertical distribution of fragments at a distance of 15 ft. from the bombs were measured. The object of this test was to determine how the vertical distribution of the fragments was affected by a covering over the bomb.

(2) A 250 lb. A.S. bomb was exploded in an open hole 8 ft. x 4 ft. at the top, 6 ft. x 4 ft. at the bottom and 11 ft. 6 in. deep. Measurements were made of the earth movement near the bomb. The object of this test was to examine the reduction in earth movement resulting from digging a cavity round the bomb.

(3) Small scale tests employing 8 lb. charges of Polar Ammon gelignite were performed to obtain some idea of the protection afforded by a sandbag revetment in the form of a straight and a cylindrical wall against earth movement and debris respectively. The earth movement on either side of the straight wall was measured.

The results obtained are summarised below and in Figs.5 and 6.

500 lb. G.P. bombs 4 ft. deep in sand soil. A vertical canvas screen 28 ft. high, 10 ft. wide and 15 ft. distant from an uncovered bomb 4 ft. deep in sand soil was pierced by 70 fragments. No fragments pierced a similar screen at the same distance from a bomb covered by a conical mound of sand 22 ft. diameter of base and 8 ft. high containing about 50 tons of sand. The maximum horizontal earth movement at various distances from the covered bomb was nearly twice as great as that at the corresponding distances from the uncovered bomb. (Fig.6)

250 lb. A.S. bomb in open cavity. The crater dimensions and earth movement at various distances from a 250 lb. A.S. bomb exploded at a depth of 10 ft. in a cavity 8 ft. x 4 ft. at the top, 6 ft. x 4 ft. at the bottom and 11 ft. 6 in. deep are much smaller than when a similar bomb is exploded in a cavity 5 ft. x 3 ft. x 11 ft. 6 in. deep filled with loose (Fig. 7and Plate 5). It is evident that the open aperture allows a considerable proportion of the energy due to the explosion to be expended vertically upwards rather than dissipated in the ground. As a result there was appreciable blast pressure which was noticed by observers at 90 and 150 ft. from the bomb.

Small scale tests

Sandbag wall. An 8 lb. charge of Polar Ammon gelignite was exploded at a depth of 4 ft. in sand soil immediately below one side of a straight sandbag wall 20 ft. long, 4 ft. 6 in. wide and 4 ft. high containing 650 sandbags (about 16 tons). The centre of the wall collapsed and bags were flung away from each end. The crater was approximately circular. There was no significant difference between the earth movements on the two sides of the wall. The results of this test are inconclusive but they suggest that a much larger wall is necessary to afford protection against earth movement in sand soil.

Circular sandbag revetment. An 8 lb. charge of Polar Ammon gelignite was exploded at a depth of 4 ft. in sand soil at the centre of a circular sandbag revetment with an internal diameter of 9 ft. 6 in., an external diameter of 16 ft. and 5 ft. 6 in. high. There were 1,200 sandbags with a sand content of about 30 tons. A section about 10 ft. long (measured circumferentially) and 2 ft. high was flung from the top of one side

/of

of the revetment. The sandbags near the centre of the wall were displaced outwards, so that the whole wall assumed a bulge at the centre. Debris was flung about 200 ft. vertically upwards (Plate 5).

It was concluded that the sandbag wall had some effect in limiting the projection of the debris mainly to a vertical direction.

Practical application of the experimental results

In practice, the most suitable protective treatment to be applied to an unexploded bomb will depend on a number of factors, the more important being the size and depth of the bomb and its location relative to buildings and service mains. Usually, however, it will be possible to decide whether it is more desirable to minimise damage due to earth movement or to debris, splinters and blast.

Earth movement tends to damage the foundations of buildings, service mains, bridge supports and railway lines whereas debris, splinters and blast usually have little destructive action on them. Debris, splinters and blast, on the other hand, have a more serious effect than earth movement on the superstructure of buildings.

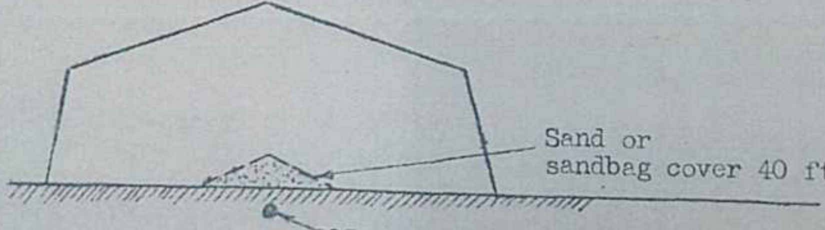
The results show that earth movement may be minimised by offering relief to the explosion by excavating a cavity round the bomb, whilst damage likely to be caused by debris, splinters and blast may be minimised or eliminated by covering the bomb with sand or sandbags.

The following suggestions may assist as a guide for dealing with certain typical cases.

Case 1.

In the case of bomb buried several feet deep in the ground on one side of a railway line, the treatment to be applied would depend on the distance of the bomb from the line. If the distance were 50 ft.or more, the aim of protective work would be to stop debris falling on the line; if 25 ft., the aim would be to stop debris and to minimise earth movement and if the distance were 15 ft. or less, it would be desirable to minimise earth movement. Fig.8 illustrates the types of treatment suggested. For the more distant bombs, a sand or sandbag cone placed over the bomb would afford adequate protection against debris and would permit traffic to continue on the line. For bombs at about 25 ft., a sand or sandbag cover would stop debris and a trench, preferably semi-circular in section, dug out between the bomb and the line, would minimise earth movement. Suitable dimensions for the trench might be 5 ft. wide in clay soil (or less in sand or gravel), about the same depth as the bomb and either 50 ft. long or approximately semicircular with a radius of 20 ft. For bombs close to the line, it is suggested that a trench 12 ft. long, 4 ft. wide and about the same depth as the bomb, dug out as shown in the figure, would materially reduce earth movement. There would, however, be some debris and appreciable blast so that it would probably be necessary to limit traffic on the line to slow goods traffic owing to the likelihood of serious window damage in passenger trains.

Case 2.



If a bomb were buried at a shallow depth in the floor of a

/hangar

hanger or large factory building, blast might damage the building and splinters might damage valuable aircraft or machinery. A sand or sandbag cover would afford adequate protection to the building and its contents.

Case 3.

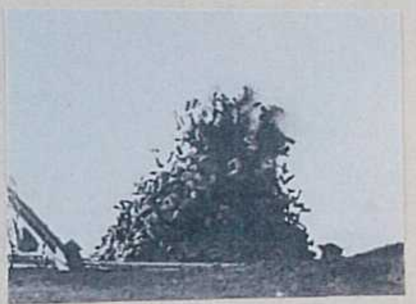
In the case of a bomb which has fallen close to a busy thoroughfare, but has penetrated to only a shallow depth, serious consequences due to splinters and blast might result from the explosion. If there were no buildings or service mains in the immediate vicinity, earth movement could be neglected. The erection of a pile of sand or sandbags over the bomb would eliminate any likelihood of damage by splinters or blast.

PLATE 1

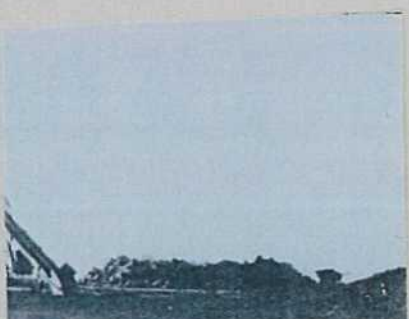
Sandbag coverings over a 250 lb. A.S. bomb 10 ft. deep in sand soil.

4,500 sandbags
Diameter of base 35 ft.
Height 5 ft.
Approximate weight 120 tons.

Before Explosion

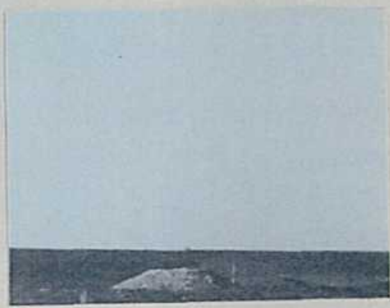


During Explosion
Maximum Height of Eruption

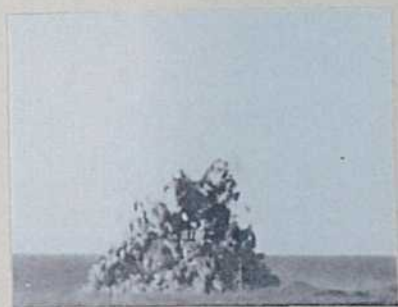


After Explosion

3,000 sandbags
Diameter of base 30 ft.
Height 5 ft.
Approximate weight 80 tons



Before Explosion



During Explosion
Maximum Height of Eruption

After Explosion

PLATE 3

Sand covering over 250 kg. bomb 12 ft. 6 in. deep in clay soil.

Covering:-

Cone of sand

Diameter of base 40 ft.

Height 6 ft.

Approx. weight 125 tons

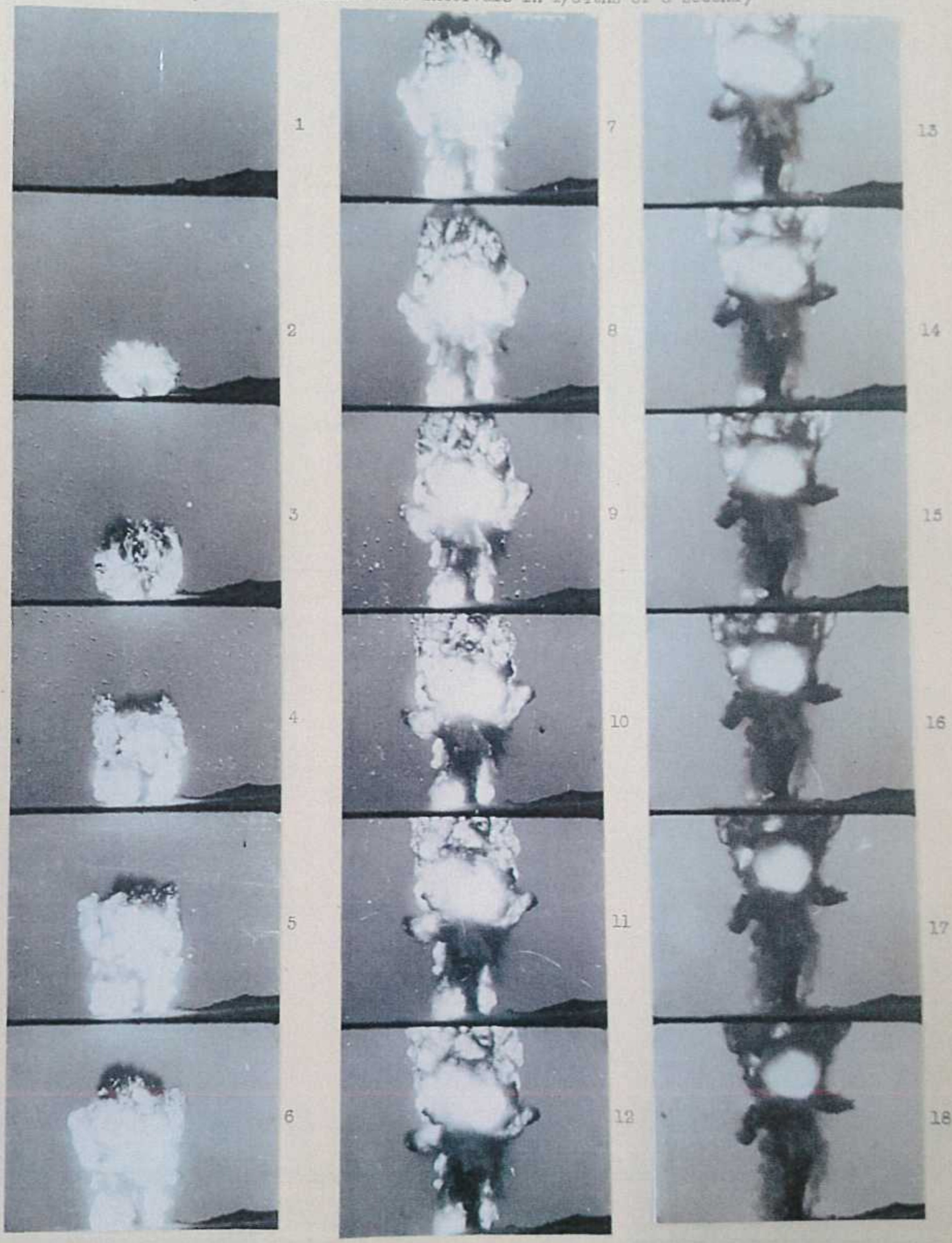
Mound of debris after explosion

During Explosion

PLATE 7

Explosion of a 250 lb. A.S. bomb in an open cavity.

(Numbers indicate time intervals in 1/64ths of a second)



Road Research Laboratory Note No. ARP.121/HJHS.

PLATE 7. (Continued)

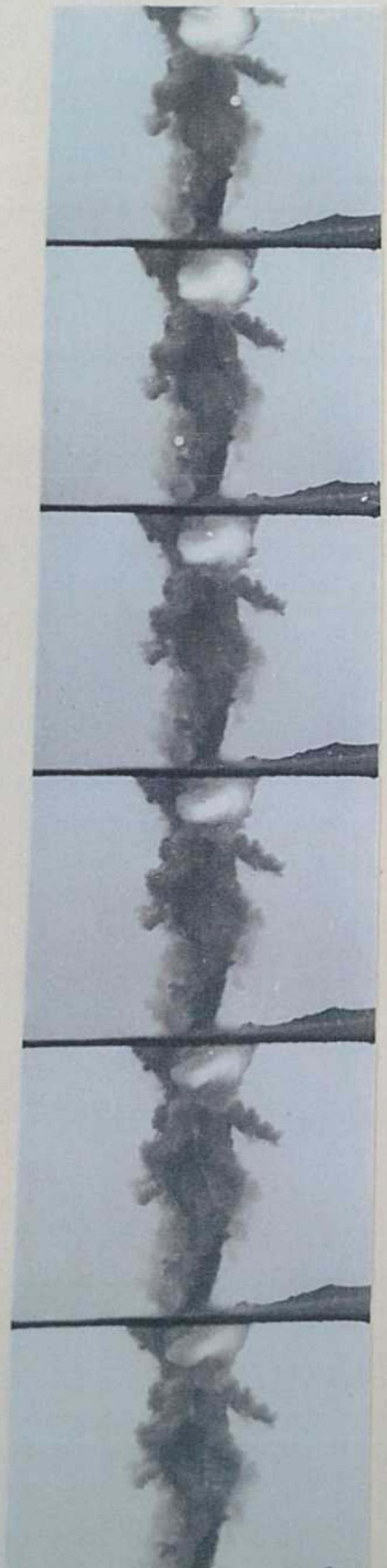


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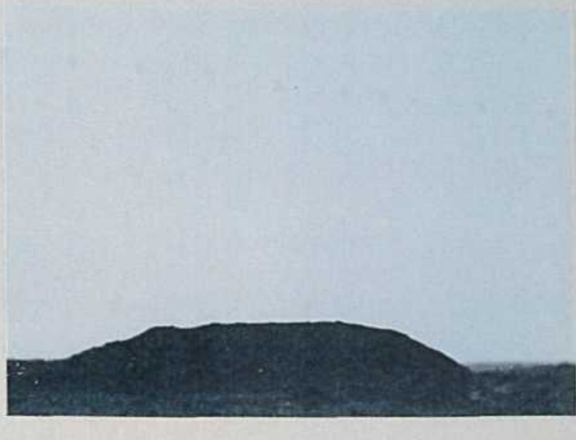
PLATE 8

SAND COVERING OVER 250 KG. BOMB 13 FT. DEEP IN SAND SOIL



Diameter of base 40 ft.

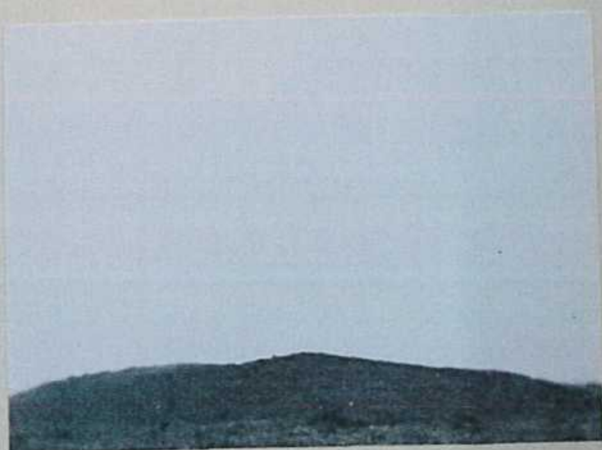
Height 5 ft. 8 in.

Approximate weight 180 tons.

Before Explosion

During Explosion

Maximum height of Eruption



After Explosion

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Note No. ARP 122/KLCF
December 1940

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Road Research Laboratory

REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS ON PROTECTIVE HELMET BODIES AND MATERIALS RECEIVED ON NOVEMBER 29TH 1940

SUMMARY

Penetration tests have been made on a number of protective helmet bodies and various materials suggested for use in their construction.

A civilian pattern steel helmet resisted a ½-in. diameter shrapnel ball striking at 450 ft./sec. and gave a dent similar to that produced in a 22 S.W.G. mild steel helmet previously tested. The resistance of two leather helmets compared favourably with that of mild steel and was superior, weight for weight, to any alternative materials so far tested. The minimum penetration velocity for "Pernax" was 550 ft./sec. which compares favourably with that of many other suitable materials previously tested but vulcanised fibre wood pulp pressboard and "Orobello" metallized plastic, weight for weight, compare unfavourably.

Penetration tests have been made on a number of protective helmet bodies and materials suggested for use in their construction. The tests were made in accordance with the procedure described in Note No. ARP/103.

A summary of the test results and details of the helmets are given in Table 1 and details of the sheet materials in Table 2. Details of the tests are given in Tables 3 and 4.

The dents formed in the civilian pattern steel helmet (Fig. 1), were similar in size to those formed by balls striking the 22 S.W.G. mild steel helmets previously tested and reported in Note No. D.2[illegible].

The resistance of both of the leather helmet bodies compared favourably, weight for weight, with that of mild steel and was superior to that of any other materials tested. The minimum penetration velocity for the pliable sheet material, "Pernax", was 550 ft./sec. and if this material could be obtained in slightly thinner sheets (say 0.2 in.)

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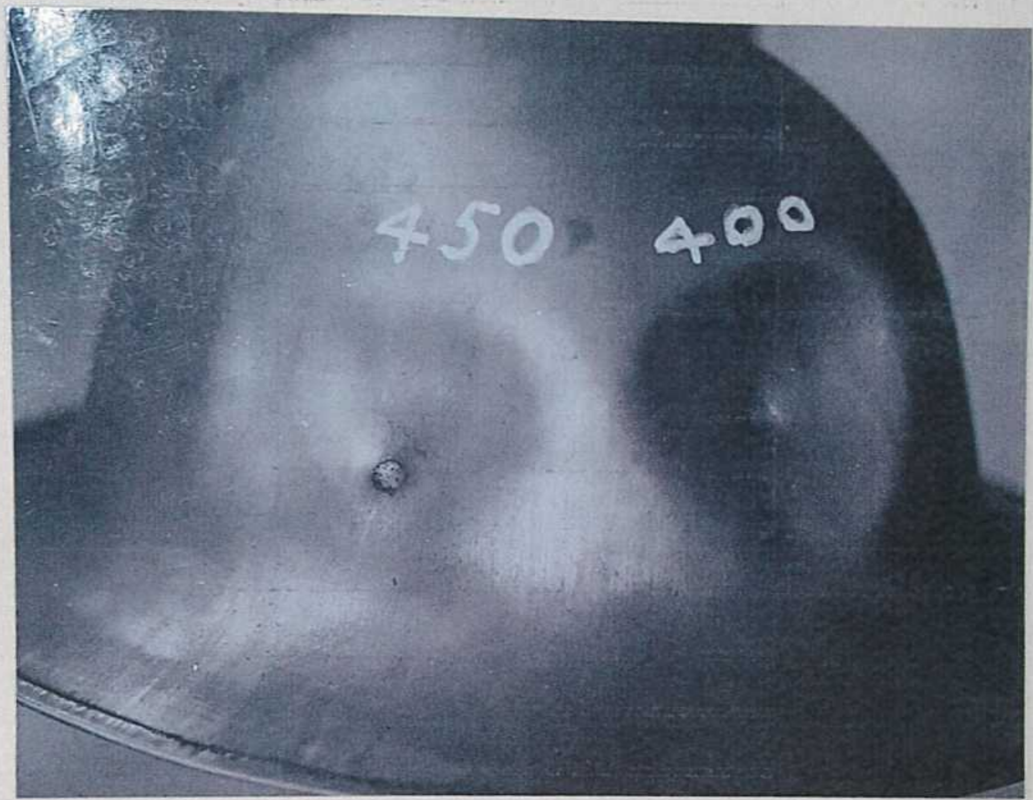

Fig. 1.

Results of tests with shrapnel balls of $\frac{1}{2}$-in. diameter fired at 400 and 450 ft./sec. at Civilian Pattern Steel Helmet.

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Note No. ARP.124/RFM.
December 1940.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Road Research Laboratory

REPORT FOR THE MINISTRY OF HOME SECURITY

THE EFFECT OF PENETRATION OF A CHARGE BENEATH THE REINFORCEMENT OF A CONCRETE SLAB.

SUMMARY

A doubly reinforced concrete slab 6 in. thick (which would withstand, without serious damage, the effect of a tamped 2 oz. charge of Polar Ammon gelignite in contact with the face) was cast with a hole $2\frac{1}{2}$ in. deep and $1\frac{1}{4}$ in. diameter in the centre of the front face. A tamped 2 oz. charge of Polar Ammon gelignite was placed in this hole and detonated. The tamping corresponded approximately to that experienced by a charge at a depth of 1 ft. 3 in. in earth. Very serious damage was caused to the slab; this damage was not greatly reduced in the case of an untamped charge placed at the same depth as the tamped charge.

The results indicate that it is necessary to give special consideration to the reinforcement of slabs intended to resist the destructive action of charges which penetrate the surface reinforcement.

The slabs tested were all 2 ft. 6 in. square and 6 in. thick. The reinforcement in each of them was arranged in the form of two mats consisting of a mesh of 12 S.W.G. steel wire forming squares of $\frac{7}{8}$ in. side in one mat and $1\frac{3}{4}$ in. side in the other. The $\frac{7}{8}$-in. mat was placed $\frac{1}{4}$ in. from, and parallel to, the rear face of the slab, whilst the $1\frac{3}{4}$-in. mat was $\frac{1}{4}$ in. from the front face.

Arrangement of Tests

Three sets of two slabs were tested and were subjected respectively to the following tests:-

(a) Tamped 2 oz. charge of Polar Ammon gelignite in contact with the centre of the front face.

(b) Tamped 2 oz. charge of Polar Ammon gelignite in a hole in the centre of the front face.

(c) Untamped 2 oz. charge of Polar Ammon gelignite in a hole in the centre of the front face.

The slabs tested as at (b) and (c) each had a hole $2\frac{1}{2}$ in. deep and $1\frac{1}{4}$ in. diameter cast in the centre of their front faces during manufacture; this hole was of such a size that all of the charge could be placed just beneath the reinforcement near the front face.

The methods of support of the slab and tamping of the charge were as described in Note No. ARP.84/RFM. The method of tamping, with sand and weights, gave results corresponding to those produced by a

/charge

Fig.1.

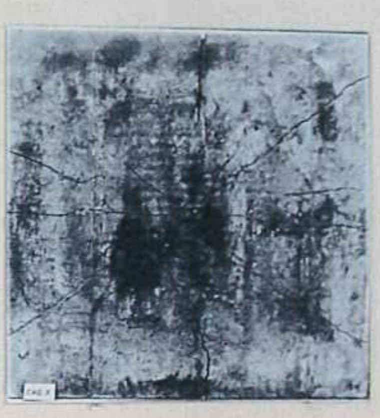

Fig.2.

Tamped Charge on Surface.

Fig.3.

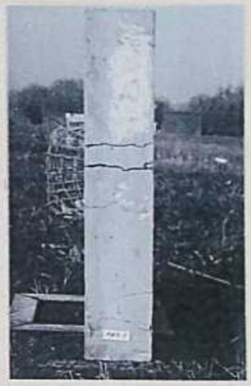

Fig.4.

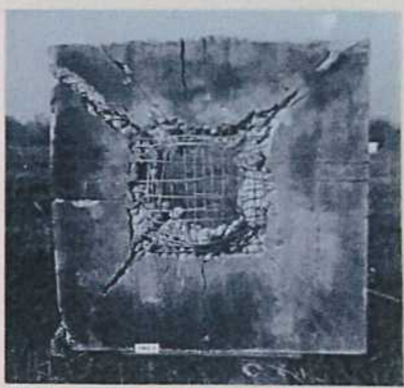

Fig.5.

Tamped Charge under Reinforcement.

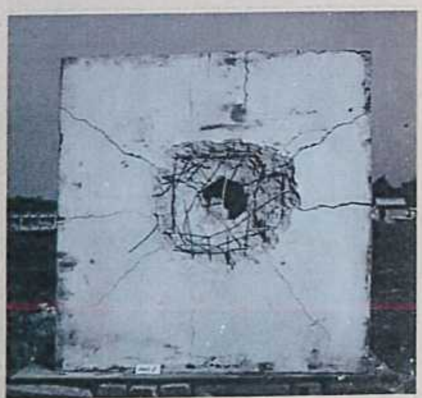

Fig.6.

Fig.7.

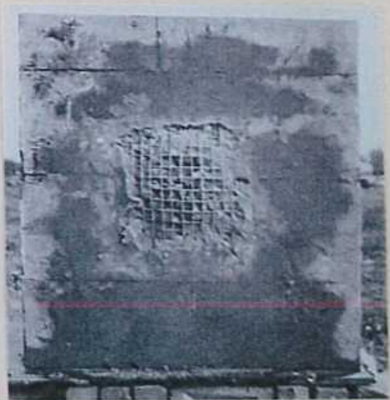

Fig.8.

Untamped Charge under Reinforcement.

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Note No. ARP/126/NSB
December, 1940

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Road Research Laboratory

REPORT FOR THE MINISTRY OF HOME SECURITY

THE RESISTANCE OF CELLOPHANE AND OF SERVICE RESPIRATORS TO PENETRATION BY SMALL HIGH VELOCITY FRAGMENTS

SUMMARY

Tests have been made on the resistance to penetration of a Service respirator in its haversack against $^{3}/_{32}$-in. steel balls striking at high velocities. In some tests additional protection was given by cellophane pads about 5 mm. thick placed in the respirator case. Standard particles, penetrating only the haversack and respirator face-piece, did not perforate until the velocity exceeded 1600 ft./sec., whilst particles of much higher velocity failed to perforate when they struck the canister. The protection given by the face-piece was much increased when a cellophane pad was placed in the haversack behind the respirator. When the pads were separately tested the specimen B made from 100 sheets (5 mm.) of "600-substance" cellophane gave the best result; the combination of the face-piece with this pad resisted attack by standard particles striking at rather less than 2950 ft./sec. A 10 mm. pad of the "300-substance" material placed behind the face-piece just resisted a standard particle striking at 3800 ft./sec. The weights of these additional protective pads covering about 75 sq.in. were 0.8 and 1.6 lb. respectively (20% and 40% respectively of the weight of the respirator). No tests were made on the resistance of the cellophane to damp.

Penetration tests have been made on the resistance to penetration of a Service respirator in its haversack when struck by standard projectiles - steel balls, $^{3}/_{32}$ in. in diameter, and weighing 53 milligrams - fired from the micro-fragment gun at various velocities. Further tests were made when various types of cellophane pads were placed in the haversack and other tests were made on the pads themselves.

The tests were made to investigate the degree of protection afforded to personnel by the Service respirator against small bomb-fragments and to study what additional protection could be provided by the use of cellophane pads inside the haversack. Cellophane pad A1 consisted of 204 sheets of "300-substance" cellophane laid together and rivetted at the four corners and the centre. The pad was 5.1 mm. thick, and weighed 0.75 g./sq.cm. Specimen A2 consisted of the pad A1 folded double. Pad B consisted of 110 sheets of "600-substance" cellophane, laid together and riveted at 9 points. Pad B was 4.95 mm. thick, and weighed 0.73 g./sq.cm. Specimen C was prepared from a seocnd pad of "300-substance" cellophane sheets, identical with specimen A1, by heating under pressure for about an hour. A rigid board was thereby obtained. Specimen D was similarly prepared from a pad of "600-substance" cellophane sheets.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS WITH THE 3/32-IN. MICRO-FRAGMENT GUN ON ANIMAL HIDES AND PROTECTIVE WAISTCOATS (DECEMBER 7TH 1940)

SUMMARY

This note describes penetration tests with the 3/32 in. micro-fragment gun on a number of tanned animal hides and several types of body-armour. All these materials except hippopotamus hide, which was 23 mm. thick, were perforated when the ball struck at a velocity of 3800 ft./sec. Several of the targets were satisfactory at a velocity of 2950 ft./sec. including the chrome steel body-armour and one of the protective waistcoats.

Penetration tests were conducted on a number of tanned animal hides, a sample of chrome steel body-armour, and two protective waistcoats. These samples were supplied by Professor Zuckermann. The projectile - a 3/32-in. steel ball-was fired from the micro-fragment gun at various velocities at the target. (Note No. ARP./125/NSB.JI).

Details of the animal hides are given with the results of the tests in Table 1. The specimen of chrome steel body-armour was similar to that employed in the U.S.A. and consisted of two sheets of steel, each 0.62 mm. thick, separated by a sheet of rubber 1.3 mm. thick. Waistcoat A was from an ordinary suit, and was lined with two layers of small cellophane pads, 2 in. square. Each pad comprised 200 sheets of "300-substance" cellophane, packed closely together without an adhesive. The thickness of each pad was 5 mm., the total thickness of the cellophane lining thus being 10 mm. Waistcoat B (of the 'Saleeby' type) was of a thin cotton fabric very loosely padded with sheet cellophane, the thickness when uncompressed being about 2 cm. The projectiles were fired at the fabric side in both cases.

Waistcoat A was found to be much superior to waistcoat B, and was capable of withstanding a standard projectile striking with a velocity of 2950 ft./sec.

The difference is probably due to the different packing of the cellophane in the two cases, waistcoat B, with the cellophane loosely packed, being the inferior sample.

The chrome steel body-armour was also found to resist a projectile striking at 2950 ft./sec., although it was completely perforated at 3800 ft./sec.

/Table 1

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REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS ON THE "CLARK-CRETE" SAFETY LIGHT.

SUMMARY

The "Clark-Crete" safety light consists of four thicknesses of plate glass of nominal thickness $\frac{7}{8}$-in. spaced at 3 in. intervals and held in a body of reinforced concrete. Penetration tests were made on a set of these plates held in wooden frames. It was found that, when plates 15/16 in. thick were used, a $1\frac{1}{4}$-oz. cylinder fired at 4950 ft./sec. perforated three plates and damaged the fourth. When the tests were repeated with actual $\frac{7}{8}$-in. plates, four plates were perforated but a fifth was not damaged. A 0.303 in. armour-piercing bullet fired at 2450 ft./sec. perforated two of the plates in a set and did not harm the third. It was concluded that the "Clark-Crete" four-plate arrangement does not wholly withstand projectiles of the "splinter gun" type, but a five-plate arrangement does. The four-plate arrangement resisted 0.303 in armour-piercing bullets.

Introduction

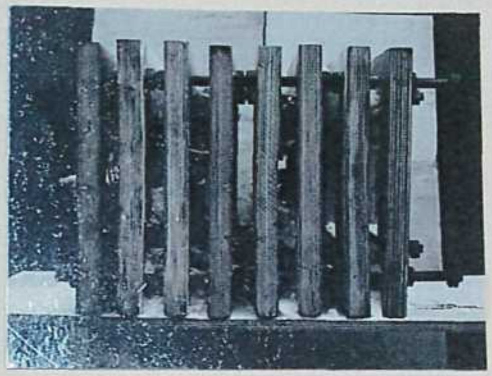
The "Clark-Crete" safety light consists of four sections of plate glass, each having a nominal thickness of $\frac{7}{8}$ in., spaced at 3 in. intervals in a body of strong reinforced concrete. The glass plates are square and graded in size so that the housing tapers from approxmately 10 in. square to 17 in. square in a length of 16 in., the narrower portion being external. It is claimed by the manufacturer that this arrangement is bullet and splinter-proof.

The concrete housing was not employed in the tests described in this report, but a set of wooden frames was used instead. The frames consisted of pieces of plywood, 1 in. thick and 12 in. square held together by four lengths of screwed rod of $\frac{1}{2}$ in. diameter. Each piece of wood had a central square aperture of $5\frac{3}{4}$ in. side. Each of the glass plates was $7\frac{1}{2}$ in. square and was held between two of the wooden frames and bolted as tightly as possible, the spacing of 3 in. between the plates being carefully measured. The test arrangement is shown in Fig. 1. During the test, a 75 lb. weight was placed on top of the arrangement, and another similar weight at the rear, to stop the frames from moving. This set-up should be equivalent to the reinforced concrete housing used in practice.

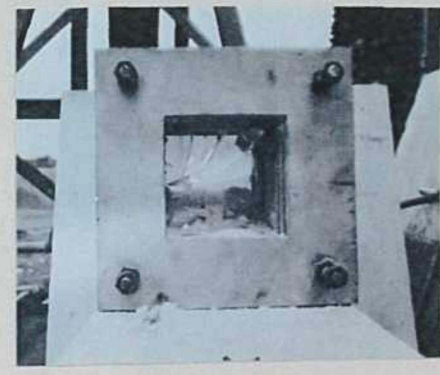
Results

The first set of tests was made with plates which had an actual thickness of 15/16 in. A set of four plates was tested with the "splinter gun", which fired a $1\frac{1}{4}$ oz. cylindrical projectile at a

/striking



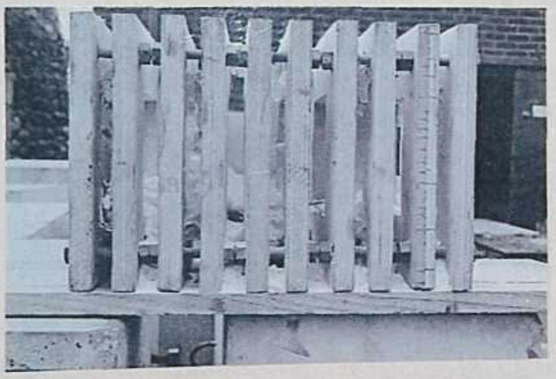
(a) Side view showing broken rear plate on left hand side.



(b) View from front

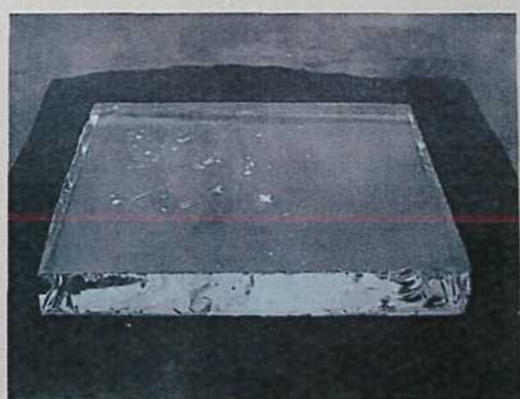
Fig.1.

Result of splinter gun test ($1\frac{1}{4}$ oz. at 4950 ft./sec.) on four layers of 15/16 in. glass plate spaced at 3 in. intervals. The fourth plate was smashed but not perforated.



(a) Side view - front of target shown on right hand side.

(b) View from front



(c) Fifth plate after test showing scratches.

Fig.2.

Result of splinter gun test on five layers of $\frac{7}{8}$ in. glass plate spaced at 3 in. intervals. The fifth plate was not perforated or broken.

striking velocity of 4950 ft./sec. The first three plates were perforated and the fourth was chipped and scratched by the glass fragments and, possibly, the projectile.

The "splinter gun" test was repeated with a new set of plates and, once again, the first three plates were perforated. The fourth plate was found broken, but not perforated. The result of the test can be seen from Fig.1. The projectile did not pass through the fourth plate, but much glass powder and fragments had passed through, and it appeared that this material might be as dangerous as the actual splinter. In both tests, a large quantity of powdered glass resulted from the smashing of the plates by the projectile.

In view of the fact that the four-plate arrangement had not proved entirely satisfactory, a further set of plates was obtained from the manufacturer. These were found to be $\frac{7}{8}$ in. thick as compared with 15/16 in. for the first set. A five-plate target with 3 in. spacing was arranged and tested with the "splinter gun". The projectile perforated the first four plates and the glass fragments chipped and scratched the fifth plate. The result of the test can be seen from Fig.2. Again, much powdered glass and many fragments resulted from the impact of the projectile. A repeat test was made and gave an exactly similar result. The difference between these results and those of the first set was due to the difference in thickness of the plates.

It appears, therefore, that a four-plate arrangement of $\frac{7}{8}$ in. glass plates spaced at 3 in. intervals will not withstand a projectile of the "splinter gun" type, but that a five-plate arrangement, with similar spacing, will do so.

When a set of the 15/16 in. glass plates was tested with a 0.303 in. armour-piercing bullet fired from the Service rifle at 38 ft. range to give a striking velocity of 2450 ft./sec., the bullet perforated the first two plates but did not damage the third.

Conclusions

(1) The "Clark-Crete" safety light consisting of four $\frac{7}{8}$ in. glass plates arranged at 3 in. intervals will not resist a projectile of the "splinter gun" type.

(2) Satisfactory resistance to this type of projectile is offered by five glass plates similarly arranged.

(3) A 0.303 in. armour-piercing bullet fired at 2450 ft./sec. will perforate two plates of the "Clark-Crete" arrangement.

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December 1940.

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Note No. ARP.130/KLCF,JI.
December 1940.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Road Research Laboratory

REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS ON FIBRE BOARD PROTECTIVE HELMET SUPPLIED BY MESSRS. BABCOCK & WILCOX

SUMMARY

Penetration tests have been made on a protective helmet supplied by Messrs. Babcock & Wilcox. The helmet body was made of "vulcanised" fibre reinforced at the crown with steel sheet. The minimum velocity of penetration of ½-in. shrapnel balls through the crown was 500 ft./sec. The vulcanised fibre vizor, sides and neck shield withstood the shrapnel ball striking at 250 ft./sec.

Penetration tests have been made for the Ministry of Home Security, on a "vulcanised" fibre protective helmet of rivetted construction designed by Messrs. Babcock & Wilcox and marked RE.30/12/8. The conical top of this helmet consisted of two thicknesses of "vulcanised" fibre with a sheet of 32 S.W.G. steel between; the helmet sides and the neck shield consisted of a single thickness of the fibre. The tests were made in accordance with the procedure described in Note No. ARP.103. The behaviour of the fibre was a little uncertain and perforation at the limiting velocity was accompanied by more or less extensive cracking and tearing, the holes not being clean.

Details of the helmet are given in Table 1 and details of the tests in Table 2.

Table 1

Particulars of Helmet

Material	Thickness	Weight including light head harness (g.)	Weight including light head harness (lb.)	Min. penetration velocity of ½-in. dia. shrapnel balls (ft./sec.)
"Vulcanised" fibre. (Top reinforced with thin steel.)	Top: Fibre (2 thicknesses) 0.13 in.	595	1.31	500
	Sides: Fibre 0.07 in.			250

/Table 2.

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Note No. ARP 131/TL
December 1940

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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REPORT FOR THE MINISTRY OF HOME SECURITY

THE IGNITION OF PETROL VAPOUR BY SPLINTERS

SUMMARY

A series of experiments was made to test the inflammability of petrol vapour - air mixtures and of petrol and ether soaked rags when struck by A.P. bullets or splinters, previously made hot by being fired through one or more steel plates. None of the arrangements tried fired the rags. A petrol vapour - air mixture was, however, ignited by a high velocity splinter.

Introduction.

Petrol fires occurring after the explosion of H.E. bombs have been thought to be due to hot splinters. This note describes attempts to produce this type of ignition in the laboratory with petrol in tins and with petrol and ether-soaked rags.

Details of experiments and results obtained.

The details of the experiments made and of the results obtained are tabulated below.

No. of Experiment	Conditions of Experiment	Result
	Petrol soaked rags etc.	
1	0.303 A.P. bullet, initial velocity 2450 ft./sec. fired into petrol-soaked rags through two $\frac{1}{8}$ in. steel plates 4 in. apart (3 experiments)	No ignition. Shower of sparks were produced between the two steel plates.
2	As 1, but petrol-soaked rags between plates to catch sparks (1 experiment).	No ignition.
3	As 1, but 5/16 in. plates substituted for $\frac{1}{8}$ in. plates (1 experiment).	No ignition, bullet passed through both plates shower of sparks behind plates.
4	As 3, but large bundle of petrol-soaked rags placed 2 ft. 6 in. from rear plate in line of bullet (1 experiment).	Bullet went through rags. No ignition.

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Note No. ARP./132/TL.
December, 1940.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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REPORT FOR THE MINISTRY OF HOME SECURITY

THE IGNITION OF INFLAMMABLE MATERIALS BY SPLINTERS FROM A GERMAN BOMB

SUMMARY

After a 50 kg. German bomb had been exploded near a bundle of rags 15 ft. from the bomb and covered with a ¼ in. steel plate, the bundle was found to be smouldering and the rags showed many small scorch marks about ¼ in. across. Numerous scorch marks were found on a similarly covered bundle at 19 ft., but uncovered bundles at 21 ft., 27 ft. and 31 ft. showed only a few marks. At 18 ft. from the bomb strips of blanket and canvas soaked in lubricating oil were extensively damaged but showed no signs of ignition.

Introduction

In air raids, fires are apparently caused by the ignition of materials by H.E. bombs in the absence of damage to gas pipes or electrical circuits. The present experiment with a 50 kg. German bomb was designed to obtain preliminary information, prior to a test with a larger 250 kg. bomb, as to (a) the position of test samples which should be as near as possible to the bomb consistent with their survival (b) the effect of interposing a steel plate between the inflammable material and the bomb.

Description of Experiment

(a) Test specimens. The various specimens were placed in butts situated around the bomb, which was placed on the ground in open country. Each test specimen consisted of 30 lb. of rags loosely packed in a wood and wire cage to make a bundle 2 ft. 6 in. by 2 ft. 6 in. by 8 in. Each bundle was wrapped in waterproof paper and held in a sandbag butt against a ½ in. steel plate resting on the rear wall of the butt, the 2 ft. 6 in. by 2 ft. 6 in. side of the bundle facing the bomb. Two of the specimens had a further ½ in. steel plate interposed between them and the bomb. Immediately before firing, the waterproof paper was torn from the rags and the specimen was sprinkled in patches with about 400 ccs. of paint in turpentine substitute, so as to simulate rags used in painting.

In addition, strips of oiled blanket and oiled canvas stretched between posts were exposed facing and edge on to the bomb.

/(b)

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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REPORT FOR THE MINISTRY OF HOME SECURITY

BLAST TUNNEL TESTS ON PERFORATED ASBESTOS CEMENT SHEET MADE BY MESSRS. ROWNSON, DREW AND CLYDESDALE.

SUMMARY

Blast tests have been made on a sample of perforated asbestos cement sheet with the holes covered with viscose film. It was found that the resistance of the sheet to blast pressure was not greater than that of unperforated material of the same type. Both the perforated and plain sheets were stronger than 24 oz. glass.

Details of Tests

Tests have been made on samples of asbestos sheet, submitted by Messrs. Rownson, Drew and Clydesdale, to determine their relative resistance to blast from explosions.

The specimens consisted of sheets of $\frac{1}{4}$ in. asbestos cement, 27 in. square, one of which was perforated with eight 3 in. diameter holes covered with viscose film of 300 substance. The second specimen was plain sheet of the same material.

The specimens were mounted as for normal window tests at one end of the blast tunnel, together with a square of 24 oz. sheet glass for comparison purposes. By firing balloons filled with a mixture of hydrogen and oxygen at various distances from the other end of the tunnel, it was possible to subject the specimens to waves of blast pressure of varying intensity, approximating to those due to a full size bomb. The blast waves in the tunnel were of shorter duration than those of a full scale bomb and on this account the test was somewhat arbitrary. It is known, however, that the behaviour of materials in the tunnel is similar to that observed in practice.

Balloons were fired at progressively shorter distances, in steps of 2.5 ft., until the fracture of one or other of the specimens occurred. The broken sample was then replaced with plywood and the test contined. The results are shown in Table 1.

/Table 1

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS ON LAMINATED COMPRESSED WOOD PROTECTIVE HELMET

SUMMARY

The minimum penetration velocity of ½ in. shrapnel balls on a laminated compressed wood protective helmet was 200 ft./sec.

Penetration tests have been made on a pressed laminated wood helmet supplied to the Ministry of Home Security by Messrs. Moulded Components (Jablo) Ltd. The helmet, which was comparatively heavy, was tested with ½ in. diameter shrapnel balls fired at velocities from 150 ft./sec. upwards. Resistance was poor as compared with that of pressboard and other samples previously tested. Experimental results are tabulated below. There is a well defined minimum penetration velocity.

Table 1

Results of Penetration Tests on Compressed Laminated Wood Helmet.

Reference Mark	Composition and Surface.	Weight		Thickness		Minimum Penetration Velocity. (ft./sec.)
		g.	lb.	cm.	in.	
None	Compressed laminated wood - surface painted grey.	746	1.64	0.59	0.231	200

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REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS ON MOULDED PLYWOOD MADE BY MESSRS. MERRON LTD.

SUMMARY

Penetration tests have been made on a protective helmet body made from gaboon veneers bonded with hot cured u./f. (urea-formaldehyde) resin.

The minimum penetration velocity of $\frac{1}{2}$ in. diameter shrapnel balls was 250 ft./sec.

Penetration tests have been made on a protective helmet body made by Messrs. Merron Ltd. from a material described as "8 laminations of 1 mm. gaboon veneers bonded by hot cured u./f. resin." The tests were made in accordance with the procedure outlined in Note No. ARP.103/KLCF.

Details of the helmet are given in Table 1 and of the penetration tests in Table 2.

The resistance of this helmet was slightly greater, weight for weight, than that of Die Moulded Improved Wood (Jablo) Helmet reported in Note No. ARP.134/JI, but the damage to the inner surface was more extensive.

Table 1

Particulars of Helmet

Material	Thickness (in.)	Weight		Approximate min. penetration velocity of $\frac{1}{2}$ in. dia. balls. (ft./sec.)
		(g.)	(lb.)	
Gaboon veneers bonded with hot cured u./f. resin.	0.28	522	1.15	250

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Note No. ARP/143/ACW.
January, 1941.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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REPORT FOR THE MINISTRY OF HOME SECURITY

PENETRATION TESTS ON SUBSTITUTE MATERIALS - I - SUPERSULPHATED CEMENT.

SUMMARY

Splinter gun tests in which cylindrical projectiles weighing $1\frac{1}{2}$ oz. were fired at 4950 ft./sec. at walls of Fletton bricks built with mortar consisting of sand and supersulphated cement show that the substitute material was as good as Portland cement. When used to make thick concrete slabs, supersulphated cement was found to be slightly inferior to Portland cement and required 15 in. as compared with 12 in. to resist satisfactorily projectiles of the splinter gun type. Concrete made with supersulphated cement was slightly better than that made with Portland cement in resisting perforation and rear spalling by 0.303-in. rifle bullets, but was more brittle and apt to crack.

Penetration tests have been made with supersulphated cement (Resistacrete) supplied by Messrs. Imperial Chemical Industries, Limited. The tests were:-

(a) "splinter gun" tests on walls of Fletton bricks made with 3:1 sand:supersulphated cement mortar.

(b) tests with the "splinter gun" on thick concrete slabs of 1:2:4 mixture of supersulphated cement, $\frac{1}{8}$-in. Ham River sand, and $\frac{3}{4}$-3/16-in. Ham River ballast, water/cement ratio = 0.60.

(c) tests with an 0.303-in. Service rifle to determine the critical thickness of thin concrete slabs of varying thickness.

The concrete and the mortar were 28 days old at the time of test. Tests of mechanical strength were made on brick samples constructed from the mortar with which the walls were built (see Table 1). Six 4-in. cubes and three 16-in. x 4-in. x 4-in. beams were made with each of the concrete slabs, and were tested to determine the compressive and tensile strengths of the concrete (see Table 2).

Results of tests - brick walls. The results of the penetration tests on the walls of Fletton bricks are given in detail in Table 1. Cracking occurred at the rear of the cavity wall and of the solid 9-in. wall as a result of the impact of the $1\frac{1}{2}$ oz. cylindrical projectile fired from the splinter gun at 4950 ft./sec. The damage done to the 9-in. wall can be seen from Fig. 1, and, for purposes of comparison, Fig. 2 shows the rear

/of

(a) Entry crater

(b) Rear of wall showing cracks

Fig. 1 - Result of splinter gun test on 9 in. wall of Fletton bricks built with 3:1 sand:supersulphated-cement mortar.

(a) Front of wall showing entry crater.

(b) Rear of wall showing cracks.

Fig. 2 - Result of splinter gun test on 9 in. wall of Fletton bricks built with 3:1 sand:Portland-cement mortar.

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Note No. ARP/145/HJHS.
January 1941.

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REPORT FOR THE MINISTRY OF HOME SECURITY

BOMB EXPLOSION TEST ON AN OPEN TRENCH AT ASHLEY WALK, SEPTEMBER 1940. (SAND SOIL)

SUMMARY

A 250 lb. A.S. bomb, with its centre of mass 10 ft. deep in sand soil, was exploded at a distance of 25 ft. from an open, unlined trench, semi-circular in plan, 5 ft. wide at the top, 7 ft. deep and 2 ft. 6 in. wide at the bottom. Measurements of the earth movement in the vicinity of the bomb are recorded.

The subsoil at Ashley Walk consisted of a topsoil of porous, dark red sand about 1 ft. deep overlying a layer of red loamy sand about 3 ft. thick; below this was hard yellow sand.

An open, unlined trench, semi-circular in plan and of 25 ft. radius was excavated in this subsoil (Fig.1.) The nominal dimensions of the trench were 5 ft. wide at the top, 7 ft. deep and 3 ft. wide at the bottom.

A 250 lb. A.S. bomb was exploded at the centre of the semi-circle with its centre of mass 10 ft. deep in the ground.

The main object of the experiment was to determine the earth movement in the vicinity of the bomb on the sides near to, and remote from, the trench. The following measurements were made:-

(1) Permanent horizontal and vertical earth movements at various distances from the bomb as revealed by pegs.

(2) Maximum horizontal earth movement at various distances from the bomb, as observed by inertia-type displacement meters.

(3) Ground disturbance at a distance of about 100 yds. from the bomb, recorded by a horizontal vibrograph.

(4) Dimensions of the crater and a survey of the trench before and after the explosion.

Results

Permanent horizontal and vertical earth movements

The results obtained are shown in Fig.2. The earth movement between the bomb and the trench was much greater than that on the side of the bomb remote from the trench. The earth movement readings obtained in the ground on the trench side suggested that the whole mass of the earth between the bomb and the trench had suffered a bodily displacement of about 7 in. away from the bomb. The appropriate curve in

/Fig.2

Fig.2 shows that there was little difference in movement at distances of 15 to 25 ft. from the bomb; at distances less than 15 ft., i.e., very near to the crater, the movements were greater.

In the ground on the side of the bomb remote from the trench, the horizontal earth movement (permanent and maximum) decreased rapidly with distance from the bomb, in a manner suggestive of the earth movement in undisturbed ground.

The vertical earth movement near the bomb was much smaller than the corresponding horizontal movement. Between the bomb and the trench the vertical movement was approximately constant except very near the trench, where it was somewhat greater. On the side remote from the trench the vertical movement decreased with distance from the bomb in a manner suggestive of that in undisturbed ground.

On the far side of the trench no permanent movement was recorded but, at a distance of 1 ft. from the edge of the trench, a maximum horizontal movement of $\frac{1}{8}$ in. was recorded. It is clear that the trench afforded almost perfect protection against earth movement.

In some later tests on the same site, a 250 lb. A.S. bomb was exploded at a depth of 10 ft. in undisturbed ground. The permanent horizontal and vertical earth movements near this bomb were greater than those recorded in the ground on the side of the bomb remote from the trench (Fig.3). This difference suggested that the trench offered some relief to the earth pressure on the side of the bomb remote from the trench, at the expense of considerable movement between the bomb and the trench.

Ground disturbance at 275 ft. from the bomb

A horizontal vibrograph situated 275 ft. from the bomb on the side remote from the trench gave a record shown in Fig.4. The wave form is comparatively simple and appears to consist of a short wave train with an apparent frequency of about 9.5 per second, which may, however, be due to the superposition of two frequencies, followed by one of larger amplitude with a frequency of about 6.7 per second and finally by one with a frequency of 9.5 per second.

The ground shock at 250 ft. from the bomb was feeble compared with that experienced at the same distance from a similar bomb buried 10 ft. deep in clay soil.

Dimensions of the crater and survey of trench after explosion

Fig. 5 shows the crater produced by the explosion, as well as a profile of the trench before and after the explosion.

The crater dimensions, measured at and below ground level were:-

Mean diameter	20 ft.
" depth	4 ft. 6 in.

The shape of the crater was uniform and well-defined.

The effects of the explosion on the trench and the ground surrounding it are shown in Figs. 1 and 5. The whole of the inner wall of the trench had moved bodily towards the outer wall by about 7 in. (probably a little more half-way down the trench). There were several deep fissures in the top 3 ft. of earth but in only two places had earth broken away from the wall. On the surface between the bomb and the trench there were several deep fissures extending most of the way round the inner wall of the trench (Fig. 1). The outer wall of the trench was intact. The effect of the support given by relatively undisturbed earth at the ends of the trench is also shown in Fig.1.

Road Research Laboratory
January 1941.
D.

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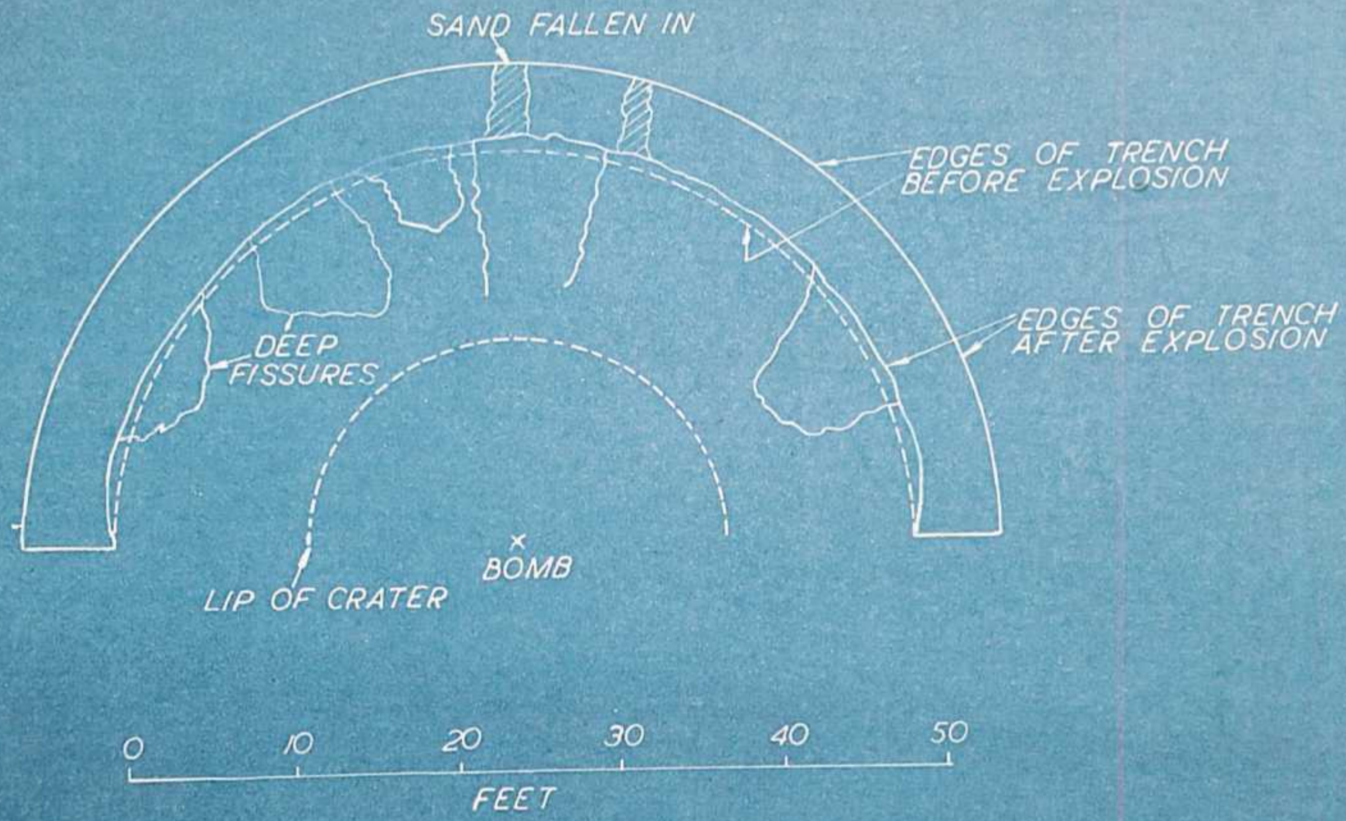
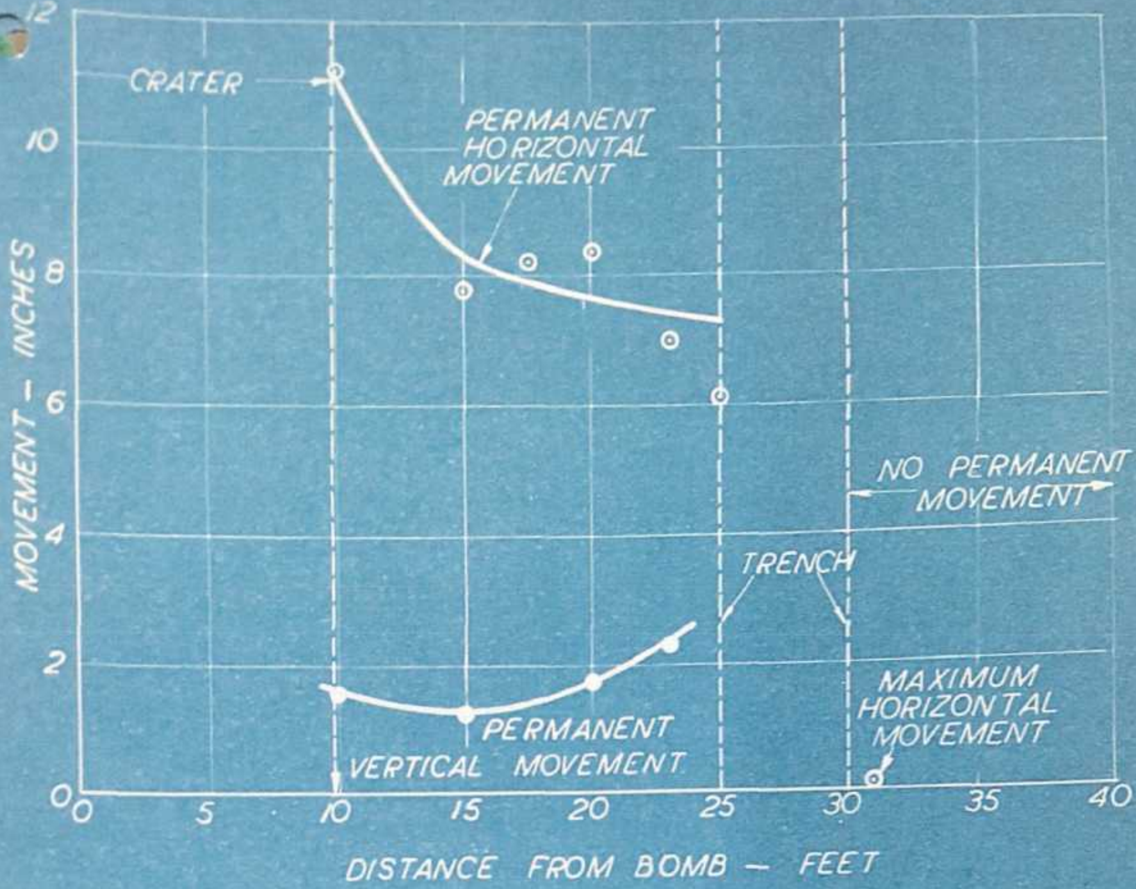
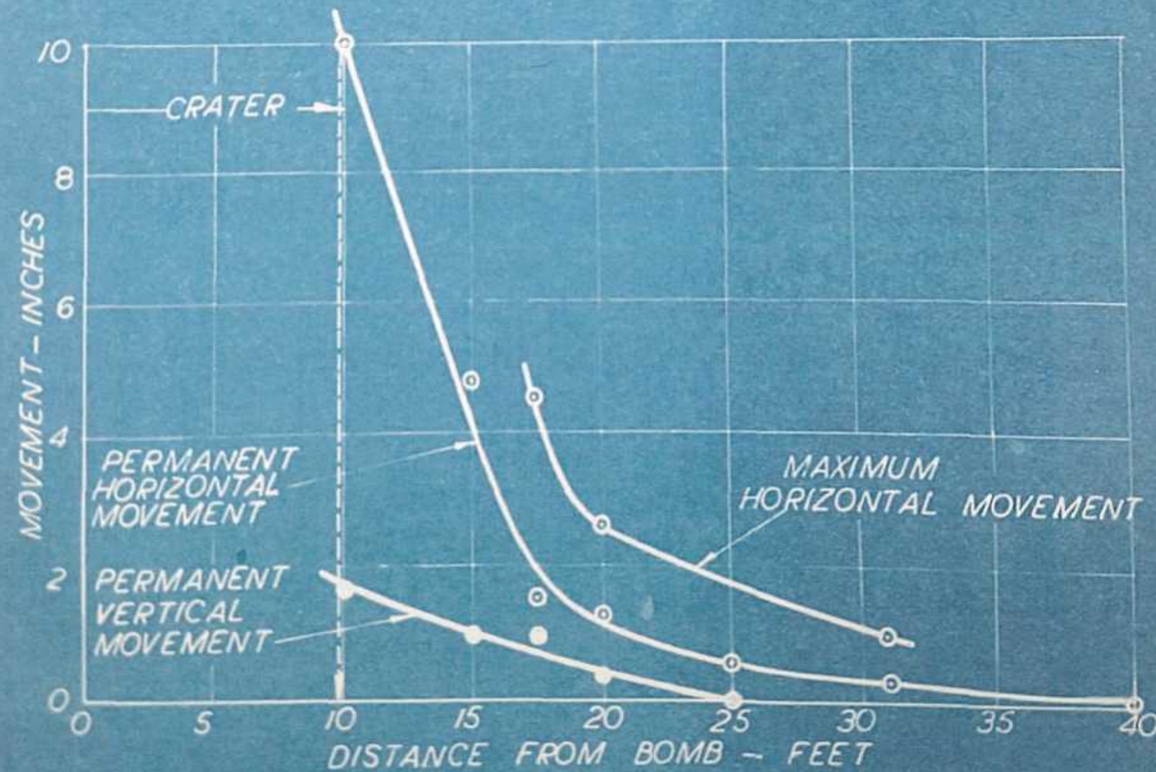


FIG. 1. PLAN OF SEMI-CIRCULAR TRENCH BEFORE AND AFTER THE EXPLOSION OF A 250 LB. A.S. BOMB 10 FT. DEEP IN SAND SOIL — ASHLEY WALK, SEP. 1940



IN GROUND ON TRENCH SIDE OF BOMB



IN GROUND ON SIDE OF BOMB REMOTE FROM TRENCH

FIG. 2. EARTH MOVEMENT NEAR 250 LB. A.S. BOMB EXPLODED 10 FT. DEEP IN SAND SOIL OPPOSITE A SEMI-CIRCULAR TRENCH

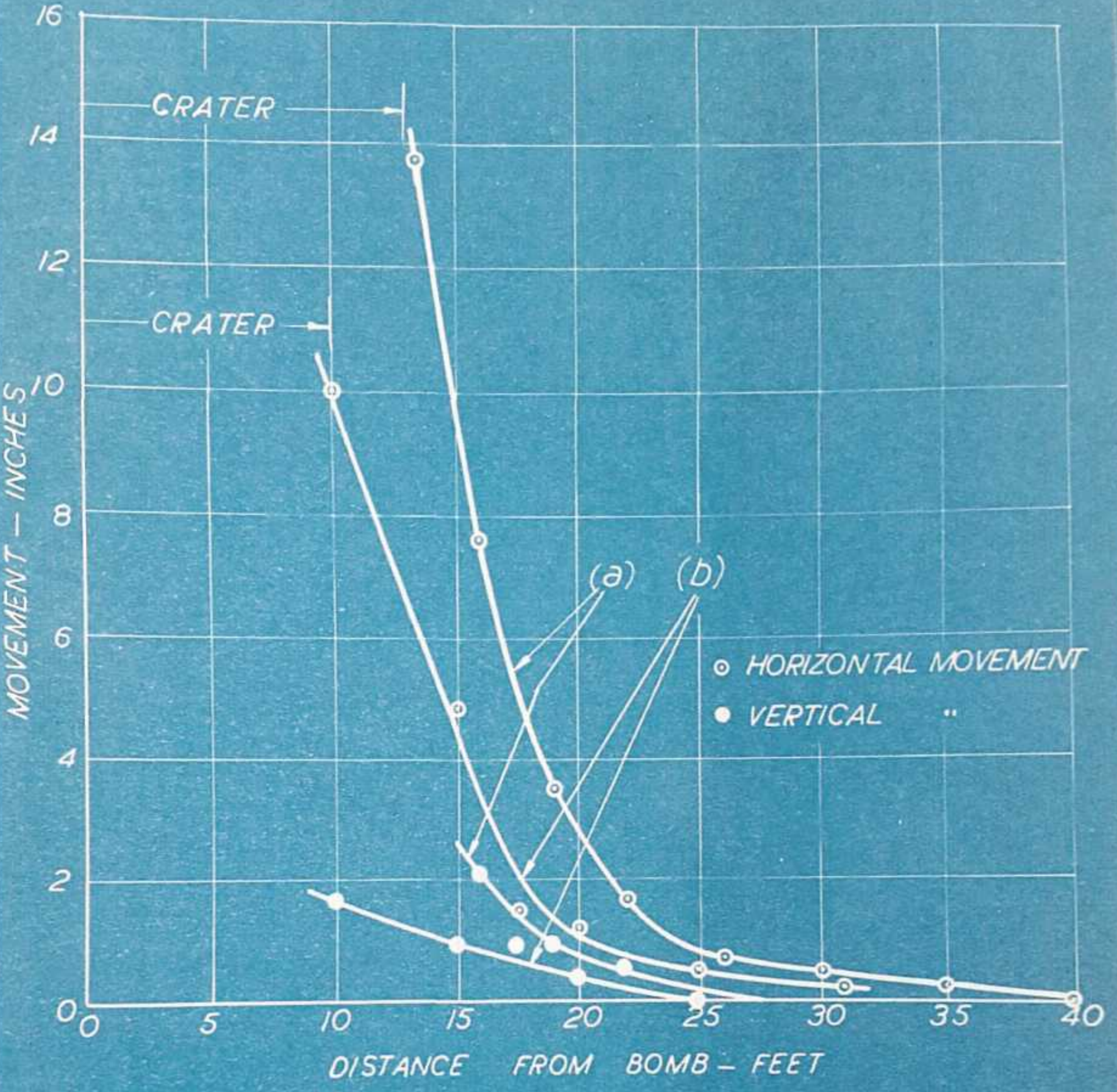


FIG. 3. PERMANENT EARTH MOVEMENT DUE TO THE EXPLOSION OF 250 LB BOMBS BURIED 10 FT DEEP IN SAND SOIL.

(a) IN UNDISTURBED GROUND

(b) IN GROUND ON OPPOSITE SIDE OF BOMB TO TRENCH

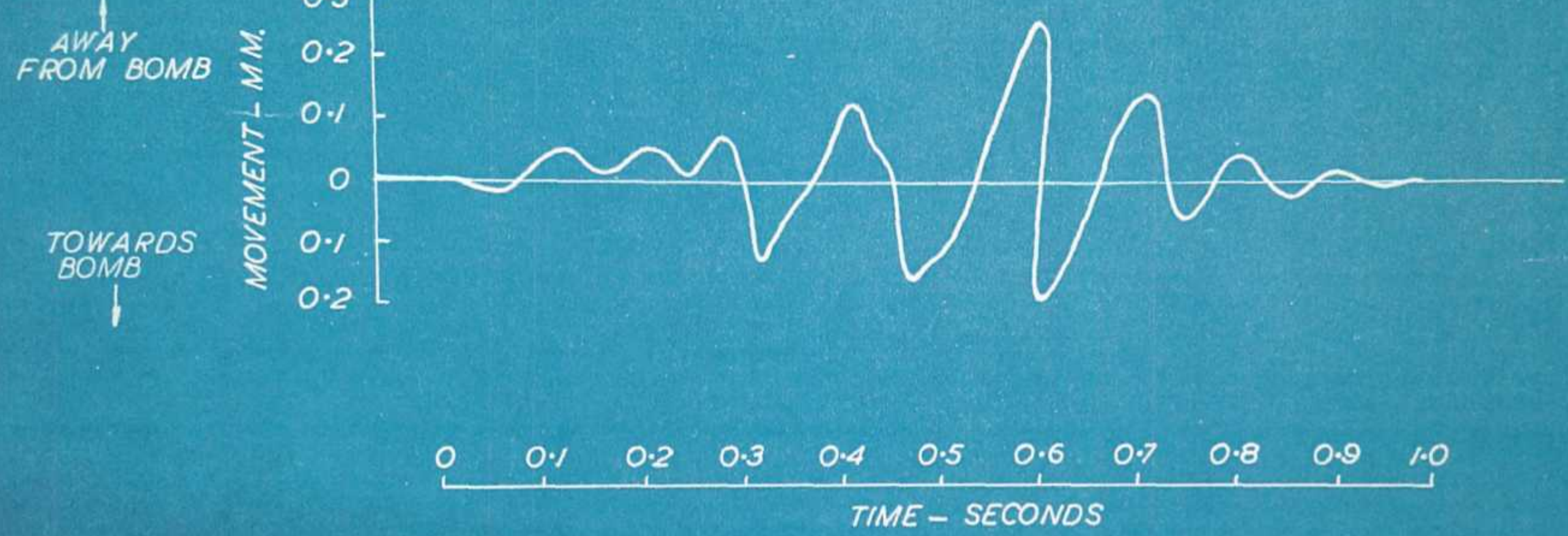


FIG. 4. HORIZONTAL EARTH MOVEMENT AT 275 FEET FROM A 250 LB. A.S. BOMB 10 FT. DEEP IN SAND SOIL.

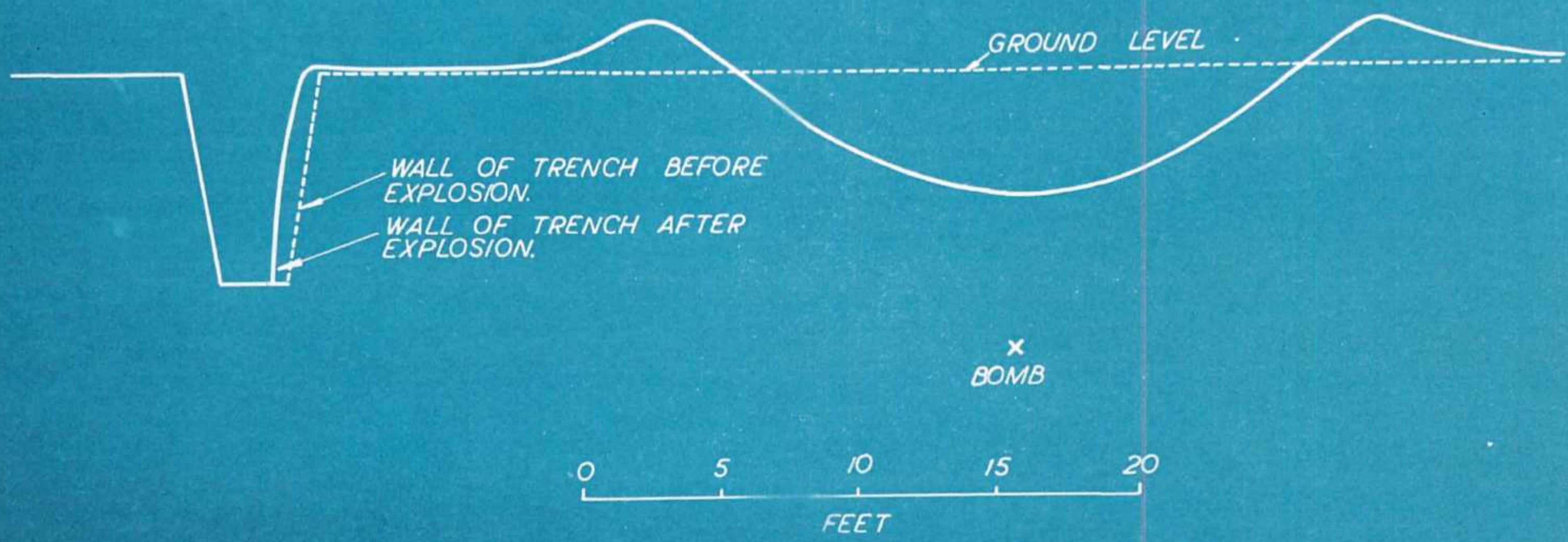


FIG. 5. PROFILE OF CRATER AND TRENCH AFTER EXPLOSION OF A 250 LB. A.S. BOMB 10 FT. DEEP IN SAND SOIL — ASHLEY WALK, SEP. 1940

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