DEVELOPMENT AND PROOF SERVICES
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Authority: ORDMX-ECM
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Lt. Witt/lr

INVESTIGATION OF THE

VULNERABILITY TO BALLISTIC ATTACK OF OSCILLATING TANK TURRETS

FIRST REPORT ON PROJECT TT2-586

ARMOR TEST REPORT NO. AD-1186

DATES OF TEST: 13 May 1953 to 15 January 1954

OBJECT

To investigate six oscillating turrets on the basis of their vulnerability to various types of ballistic attack.

SUMMARY

Various types of ballistic attack have been conducted against most armor areas, clearances, the component parts of the trunnions and the top cover plate of oscillating turrets with a view towards determining the turret's vulnerability to attack and arriving at suggested methods of improving the protection afforded by this turret design.

CONCLUSIONS

The oscillating turret has both advantages and disadvantages as compared to the present American production models of one piece turrets of standard design and it will be a matter of compromise by the using forces as to whether the oscillating turret will be acceptable for their needs.

RECOMMENDATION

Thorough consideration be given to each of the changes in design which are suggested in this report.

I. INTRODUCTION

A. DISCUSSION

1. The oscillating turret was of interest because of certain desirable design features which should add to its effectiveness in combat. Fundamentally the principle of operation of the oscillating turret is that the oscillating turret section, which mounts the gun, moves up and down on two pins anchored to a ring surrounding the entire circumference of the oscillating section. The size of the turret is relatively small due to the fact that the gun moves with the turret and the recoil of the gun can be kept to a minimum since the gun will always recoil through the same space within the turret regardless of the elevation of the gun. These principles of operation of this particular turret make automatic loading possible. Most of the upper frontal armor areas of the oscillating turret present high obliquities to attacking projectiles, and gun shields which are heavy and subject to immobilization by ballistic attack are eliminated. A roof cover plate on this turret could be lifted up completely to facilitate easy loading of ammunition and equipment into the turret. These and other features made possible by the oscillating turret have added to the interest for investigation and study of this turret design. The tests covered by this report were for the purpose of providing information concerning weaknesses in the oscillating turret design as related to vulnerability to ballistic attack.

2. Six cast oscillating turrets for the 90mm Gun, which are the subject of this report, were submitted to Aberdeen Proving Ground by Rheem Manufacturing Company for the purpose of obtaining information as to the protection afforded against various types of ballistic attack. The entire turret or oscillating section elevates within a rotating ring, (sometimes referred to as the skirting ring) which constitutes the trunnion mounting assembly, and each turret body is designed so that the gun is an integral part of the turret. Since the oscillating design presents many new vulnerability problems as compared to the present American production models of one piece standard design turrets thorough consideration has been given to these problems in this report.

3. In addition to the testing of the turret armor surfaces, various tests were conducted to determine the possibility of fragments and blast entering the inside of the tank through the clearance between the oscillating section and the rotating ring. Arrangements for covering this clearance on the inside of the turret with layers of nylon cloth and a metal shield were each tested and are discussed in this report. Another investigation was made of the shock resistance of the trunnion bearings to various ballistic attacks and the effectiveness of a bullet-splash trap arrangement on the top cover plate of the turret. Detailed results of all these tests are included in this report and a chart showing the tests performed on each turret may be found in Appendix C.

4. Detailed firing data for these tests are included in Appendix D, and four Memorandum Reports submitted previous to this report are included in Appendix B. Photographs included in Appendix F, Sub-Appendix 1, show the general design of the turret and each numbered square refers to a thickness measurement taken in this area. A consecutive list of these areas with the thickness measurements may be found for each turret in the APG Physical Test Laboratory Reports. (See Appendix E).

B. REFERENCES

1. Letter, file DA 470.5/0CO (7 Jan 53) c, APG 451.6/6, ORDMX-ECM, with Indorsement 1, Subject: Ballistic Test of Oscillating Turrets.

2. Letter, file DA 470.5/APG (11 Mar 53)c, APG 451.6/16, ORDMX-ECCA, Subject: Ballistic Test of Oscillating Turrets.

3. Letter, file DA 412.5/APG (30 July 53), APG 412.5/291, ORDMX-ECCA, Subject: Link-Belt Self-Aligning Roller Bearings, DE-22320T.

4. Report, Aberdeen Proving Ground, Armor Test Report AD-1170.

5. Report, Link-Belt Company Laboratory Report No. 3220, Subject: Ballistic Testing of 90mm Oscillating Turret Mounting Two Link-Belt DE22320T Roller Bearings.

II. DESCRIPTION OF MATERIAL

A. MATERIAL TESTED

1. Cast Oscillating Turret for the 90mm Gun developed by Rheem Mfg. Co., Test Turret No. 1, Casting Serial No. 3, equipped with Link-Belt Bearings No. DE22320T with rubber and metal sleeve around the bearing.

2. Cast Oscillating Turret for the 90mm Gun developed by Rheem Mfg. Co., Test Turret No. 2, Casting Serial No. 5, equipped with Link-Belt Bearings No. DE22320T with rubber and metal sleeve around the bearing.

3. Cast Oscillating Turret for the 90mm Gun developed by Rheem Mfg. Co., Test Turret No. 4, Casting Serial No. 4, equipped with twenty layers of nylon cloth enclosed in a canvas cover over the inside clearance between the oscillating section and the rotating ring, and further equipped with Link-Belt Bearings No. DE22320T, and a top cover plate equipped with a double groove bullet splash trap. (See Photographs A90963-A90968, Appendix F, Sub-Appendix 4).

4. Cast Oscillating Turret for the 90mm Gun developed by Rheem Mfg. Co., Test Turret No. 5, Casting Serial No. 7, equipped with Link-Belt Bearings No. DE22320T with a solid metal sleeve around the bearing. (See Photograph A92658, Appendix F, Sub-Appendix 5).

5. Cast Oscillating Turret for the 90mm Gun developed by Rheem Mfg. Co., Test Turret No. 3, Casting Serial No. 8, equipped with Link-Belt Bearing No. DE22320T.

6. Cast Oscillating Turret for the 90mm Gun developed by Rheem Mfg. Co., Test Turret No. 6, Casting Serial No. 6, equipped with a metal shield arrangement over the inside clearance between the oscillating section and the rotating ring. Link-Belt Bearings No. DE22320T, and a top cover plate equipped with a double-groove, bullet-splash trap. (See Photographs A95237-A95242, Appendix F, Sub-Appendix 6).

B. GUNS AND TUBES USED

1. Gun, 90mm, T15E2, No. 112, w/Tube, 90mm, T15E2, No. 37260.
2. Gun, 76mm, T91E3, No. 477, w/Tube, 76mm, T91E3, No. 25232.
3. Gun, 57mm, M1, No. 11065, w/Tube, 57mm, M1, No. 6410.
4. Gun, 57mm, M1, No. 726, w/Tube, 57mm, M1, No. 24679.
5. Gun, 37mm, M3A1, No. 8649, w/Tube, 37mm, M3, No. 120006.
6. Gun, 37mm, M3, No. 13900, w/Tube, 37mm, M3A1, No. 110003.
7. Howitzer, 105mm, M2A1, No. 347, w/Tube, 105mm, M2A1, No. 19414.
8. Rifle, Accuracy, Mann Type, Caliber .50, No. 170 with Receiver No. 46.
9. Rifle, Accuracy, Mann Type, Caliber .30, M1903, Receiver No. 1512536.

C. AMMUNITION

1. Projectile, Plate Proofing, 105mm, M1004
2. Shot, AP, 90mm, T33 w/Windshield, Lot LS-SR-55
3. Shot, HVAP, 90mm, M304 w/Windshield, w/Core, Lot YEM-3-4
4. Shot, AP, 76mm, T128E6, w/Windshield, Lot NSC-5-2, Lot NSC-5-1
5. Shot, AP, 57mm, M70, w/Rotating Band, Lot Unknown
6. Shell, High Explosive, 37mm, M54, Lot Unknown
7. Bullet, Ball, Caliber .50, M2
8. Bullet, AP, Caliber .50, M2
9. Bullet, Ball, Caliber .30, M2, Lot FA-No
10. Bullet, AP, Caliber .30, M2

III. DETAILS OF TEST

A. PROCEDURE

1. Prior to all testing, the six oscillating turrets were measured for thickness by means of a supersonic reflectoscope. The turrets were marked off in approximately 10" x 10" sections and numbered. (See APG Photographs A88717-A88728 inclusive Appendix F, Sub-Appendix 1). A smooth spot was ground as close to the center of each section as surface conditions would permit so all measurements could be taken

with the reflectoscope. One measurement was obtained in each block and a list of the measurements for these blocks may be found for each turret in the APG Physical Test Laboratory Reports included in Appendix E. It will be noted that there are no photographs showing the thickness measurement locations on five of the turrets. However, all turrets were marked off in squares identical to those of Test Turret No. 1 shown in Photographs A88717-A88728 inclusive (Appendix F, Sub-Appendix 1). These photographs should be referred to for a reference to measurement locations for all turrets included in these tests. Measurements 134 to 163 inclusive, are located on the rotating ring, and due to the shape of it, exact maximum thickness measurements could not be obtained. Thicknesses in these locations should be considered as approximate.

2. To conduct the ballistic tests of these turrets, each turret was in turn placed on a turntable in such a position as to permit the desired type of attack. Since a variety of tests were conducted on each turret, a detailed explanation of the test procedure for each turret is included below:

a. Test Turret No. 1, Casting Serial No. 3.

(1) The frontal and side areas of Test Turret No. 1 were subjected to a direct frontal attack and to a 30° flank attack, 30° off the longitudinal axis of the turret with 90mm, AP, T33 projectiles. In addition to the frontal attacks, the turret was subjected to a direct (90°) flank attack on the left side and a 60° flank attack on the right side with the 76mm, AP, T128E6 projectile. Levels of protection against the various ballistic attacks were established insofar as the turret design would allow.

(2) To determine the effect of shock on the trunnion bearings and component parts, one 90mm AP, T33 projectile was fired against the right trunnion and one 76mm, T128E6 projectile was fired against the left trunnion. Both impacts were placed at locations near the trunnion which would subject the bearings to a high level of shock.

(3) After all firing had been completed the turret was completely disassembled in order to examine the bearings and the component parts of the trunnion. The outer race and the bearings were inspected for damage resulting from shock, as well as damage from penetration of fragments to the surfaces of the inner and outer bearing race.

b. Test Turret No. 2, Casting Serial No. 5.

(1) The frontal and side areas of Test Turret No. 2 were subjected to a direct frontal attack and to a 30° flank attack, 30° off the longitudinal axis of the turret, with 90mm, HVAP, M304 projectiles. In addition to the frontal attacks, the turret was subjected to a direct (90°) flank attack on the right side and a 60° flank attack on the left side with the 57mm, AP, M70 projectile. Levels of protection against the various ballistic attacks were established insofar as the turret design would allow.

(2) Again, as on Test Turret No. 1, to determine the effect of shock on the trunnion bearings and component parts, one 90mm, AP, T33 projectile was fired from direct flank against both the right and left trunnions to strike directly on the trunnions. Previous tests conducted on the first turret in which impacts were placed near the trunnions indicated that the attacks used would not damage the bearings excessively, therefore it was felt that a more severe test was needed in order to make an evaluation. This more severe test was obtained by impacting the trunnions directly.

c. Test Turret No. 4, Casting Serial No. 4.

(1) This turret was equipped with twenty layers of nylon cloth inclosed in a canvas cover over the inside clearance which would normally be inside of a tank between the oscillating section and the rotating ring. This covering was designed to protect the inside of the turret and hull against fragments and bullet splash. (See APG Photographs A90963-A90968 inclusive, Appendix F, Sub-Appendix 4). Also, this turret was equipped with a top cover plate which was designed with a double-groove, bullet-splash trap around the perimeter of the turret cover plate. (See Sketch 1, Third Memorandum Report, Appendix B).

(2) The frontal and side clearances between the oscillating section and the rotating ring of Test Turret No. 4 were subjected to direct frontal attacks with Caliber .30, Ball M2, Caliber .50, Ball M2, and Caliber .50, AP, M2, small arms projectiles to evaluate the protection afforded by the twenty layers of nylon cloth. In addition to the testing conducted with the small arms projectile, fragmentation grenades, MK-2, were statically detonated along the outside of the clearance on the front and back of the turret and two 37mm, HE, M54 projectiles were fired against the front of the turret near the clearance. When all testing of the cloth was completed the cloth was removed from the turret for a detailed examination.

(3) To determine the effectiveness of the double-groove splash trap around the perimeter of the turret cover plate against small arms projectiles, nine Caliber .50, Ball M2 projectiles were fired against the small clearance between the cover plate and the oscillating section. Examining the top cover plate it was felt that shock against the upper side of the turret bustle might pin the top cover plate to the turret, therefore, one 105mm Proof Projectiles M1004 was fired at each side of the turret at approximately 1150 fps to determine if it would be possible to develop enough of a bulge to cause this condition.

d. Test Turret No. 5 Casting Serial No. 7.

(1) Test Turret No. 5 was equipped with a solid metal sleeve over the outside of the trunnion bearings instead of the rubber and metal combination sleeve which was used on the turrets previously tested. The frontal and side areas of the turret were subjected to a direct frontal attack and to a 30° flank attack, 30° off the longitudinal axis of the turret, with 90mm, AP, T33 projectiles. In addition to the frontal attacks the side bustle areas were subjected to both a direct (90°) flank attack and a 60° flank attack on the left side with 76mm, AP, T128E6 projectiles and on the right side with 57mm, AP, M70 projectiles. Levels of protection against the various ballistic attacks used were again established, as was mentioned on other turrets, insofar as the turret design would allow.

(2) To determine the effect of shock on the trunnion bearings and component parts, one 90mm, AP, T33 projectiles was fired against both the right and left trunnions from a 30° flank attack. Both impacts were placed at locations near the trunnions which would subject the bearings to the greatest amount of shock. The shock tests of the trunnions on this turret were conducted similarly to the tests conducted on Test Turret No. 1 in order to make a comparison of the effects of shock on the two different types of trunnion bearing sleeves used. After all firing had been completed, the turret was completely disassembled from the rotating ring in order to examine the bearings and the component parts of the trunnion.

e. Test Turret No. 3, Casting Serial No. 8.

(1) Since testing had been conducted on one turret (Test Turret No. 4) which was equipped with a covering over the inside clearance between the oscillating section and the rotating ring, it was felt that testing should be done using similar test procedures on a turret which had no covering over the clearance to make an accurate evaluation of the protection offered. In order to carry out this plan, the frontal and side clearances between the oscillating section and the rotating ring of Test Turret No. 3 were subjected to direct frontal attacks on the outside with Caliber .30 Ball, M2, Caliber .50, Ball M2, and Caliber .50, AP, M2 small arms projectiles. The clearance between the oscillating section and the rotating ring on this turret was covered at the lower edge of the turret, which would normally be on the inside of a tank, with a screen of 24 ST. Aluminum (.025" thick), referred to as Dural in this report, on the front and with Kraft paper on the sides and back. These screens of paper or Dural provided a means of determining the extent to which bullet splash and fragments were entering the clearance between the oscillating section and the rotating ring, thereby entering what would be the inside of a tank.

By determining the extent to which bullet splash and fragments were entering this clearance a more complete evaluation of the effectiveness of placing twenty layers of nylon cloth on the inside of this clearance could be made.

(2) In addition to the testing conducted with the small arms projectiles, fragmentation hand grenades, MK-2, were statically detonated along the outside of the clearance on the front of the turret (See Sketch 2, Fourth Memorandum Report, Appendix B) and one 37mm, HE, M54 projectile was fired against the front of the turret near this clearance. The setup using a screen of paper or Dural on the inside of the clearance to determine how many fragments were entering the clearance was the same as that described for the small arms attacks in the preceding paragraph.

f. Test Turret No. 6, Casting Serial No. 6.

(1) Test Turret No. 6 was equipped with a metal shield arrangement (See APG Photographs A95237-A95242, Appendix F, Sub-Appendix 6) over the inside clearance which would normally be inside of a tank between the oscillating section and the rotating ring. As was the case with the nylon cloth on Test Turret No. 4, this covering was designed to protect the inside of the turret and hull against fragments and bullet splash.

(2) The frontal and side clearances between the oscillating section and the rotating ring of the turret were subjected to direct frontal attacks with Caliber .30, Ball M2, Caliber .50, Ball M2 and Caliber .50 AP, M2 small arms projectiles to evaulate the protection afforded by the metal shield arrangement. In addition to the small arms tests, fragmentation grenades, MK-2, were statically detonated along the outside of the clearance on the front of the turret and two 37mm HE, M54 projectiles were fired against the front of the turret near this clearance. Since the metal shield arrangement had a small opening on the inside of the turret, this clearance was covered on the inside with a screen of 24 ST Aluminum (.025" thick) or Kraft paper in each test to determine how many fragments and how much blast was penetrating this opening. This testing on the clearance completed three phases of tests which were conducted to determine what could be done to stop fragments and blast from entering the tank. One turret was tested with no covering, another had a twenty layer nylon cover and still a third turret had a metal shield arrangement cover over the inside clearance between the oscillating section and the rotating ring.

B. RESULTS AND OBSERVATIONS

1. The complete round-by-round results for each turret tested may be found in Appendix D and should be referred to for a more detailed discussion than is presented here. It will be noted in the detailed results and the Memorandum Reports (Appendix B) that in many cases due to the limited area over which a uniform obliquity and thickness existed, ballistic limits could not be obtained in evaluating the protection offered. Detailed results of the laboratory tests may be found in the APG Physical Test Reports included in Appendix E. Results of the tests performed on each turret are included below:

a. Test Turret No. 1, Casting Serial No. 3.

(1) From the results of the tests with the 90mm AP, T33 projectile it appears that the protection afforded by this oscillating turret is very good in the highly sloped areas to the right and left of the gun. The area under the gun and the adjacent areas which have almost 0° obliquity do not offer a very high level of protection against this projectile. (See APG Photographs A89569-A89571 Appendix F, Sub-Appendix 1).

(2) Direct flank and 60° flank attacks on the bustle side areas of the turret with 76mm AP, T128E6 projectiles indicate that these attacks could not be defeated at ranges less than 4,000 yards and possibley even at somewhat greater ranges. Both side areas of the turret bustle have very little obliquity. The ballistic limits for the 76mm AP, T128E6 were 1458 fps on 2.75" of armor from direct flank on the left side and 1718 fps on 2.45" of armor from 60° flank attack on the right side (In APG Photographs A89569-A89576, Appendix F, Sub-Appendix 1).

(3) One 90mm AP, T33 projectile hit under the gun near the rotating ring and produced face petalling of the armor which pinned the oscillating turret section to the rotating ring and prevented further elevation and depression of the turret. It is felt that much smaller projectiles could produce the same results if they remained in the armor after impact or produced large enough petals on the surface. (See APG Photograph A89570 Appendix F, Sub-Appendix 1).

(4) One 90mm AP, T33 projectile against the right trunnion (see Round 15, APG Photograph A89571, Appendix F, Sub-Appendix 1) and one 76mm T128E6 projectile against the left trunnion (see Round 18, APG Photograph A89572, Appendix F, Sub-Appendix 1) did some damage to the bearings. Both bearings, however, would roll after the turret was disassembled from the skirt. The bearings could not be checked before removal because the oscillating turret section was locked in place by armor petalled out against the skirt section. For a detailed view of the damage done to each bearing refer to APG Photographs A89978-A89979, A93215-A93222, Appendix F, Sub-Appendix 1. Considerable difficulty was encountered in disassembling the oscillating section from the rotating ring due to

the warping of the bearing retainer caused by the shock of the impacts near the trunnions. Metal chips were found inside the bearings and the inner and outer rear surfaces were scarred by fragments in several places as is shown by the photographs mentioned above.

b. Test Turret No. 2, Casting Serial No. 5.

(1) Results of the tests with the 90mm,HVAP,M304 projectile against the oscillating Turret No. 2 indicate that the protection afforded is good in the highly sloped area to the left of the gun against direct frontal attack. As was indicated on Test Turret No. 1 above, the area under the gun and adjacent areas which have almost 0° obliquity do not offer a high level of protection against either the 90mm AP, T33 or the 90mm HVAP, M304 projectiles. Results of these tests indicate that attacks with the 90mm,HVAP,M304 projectiles at the area under the gun when the turret is elevated can not be defeated at any range less than 4000 yards and possibly even somewhat greater ranges. (See APG Photographs A90762, A90763, Appendix F, Sub-Appendix 2).

(2) Five impacts with the 90mm HVAP M304 projectile from a 30° frontal flank on the area to the right of the gun gave protection complete penetrations ranging in velocity from 1929 fps in a low obliquity area to 3453 fps in a high obliquity area. (See APG Photograph A90764, Appendix F, Sub-Appendix 2). Direct flank and 60° flank attacks on the bustle side areas of this turret with the 57mm AP M70 projectile indicate a poorer level of protection than a turret of this class should normally be expected to maintain. As was mentioned in the results of Test Turret No. 1 above, the design of the oscillating turret bustle is such that the side areas present very little obliquity. The ballistic limits for the 57mm,AP,M70 were 1850 fps on 2.55" of armor from direct flank on the right side and 2486 fps on 2.60" of armor from 60° flank attack on the left side. (See APG Photographs A90766, A90768, A90771, A90772, Appendix F, Sub-Appendix 2).

(3) The turret was elevated approximately 15° and several 90mm,HVAP, M304 projectiles were fired so that the impacts would strike the turret in the area beneath the gun and just above the turret skirt. Enough bulge was produced on the face of the armor around the impact area to prevent depression of the turret. (See Rounds 13,29, and 6, APG Photograph A90763, Appendix F, Sub-Appendix 2).

(4) One 90mm, AP, T33 projectile fired from direct flank against each trunnion completely displaced the trunnion pin, bearing, housing sleeve, and component parts from the turret. For a complete assembly diagram of the trunnion parts see the Drawing in Appendix C. The impact locations are shown in APG Photographs A90765 and A90767 Appendix F, Sub-Appendix 2. The attack against the left trunnion pushed the trunnion pin bearing, sleeve, and bearing cover plate from the housing. The bearing retainer remained in the turret

and the outer race of the bearing was broken into two pieces. (See APG Photograph A91495, Appendix F, Sub-Appendix 2). The attack against the right trunnion completely displaced the trunnion pin and the bearing from the housing, and the bearing itself was completely demolished. (See APG Photograph A91496, Appendix F, Sub-Appendix 2).

(5) Both attacks against the trunnions of this turret represent possibly the severest attacks that these areas would be subjected to under combat conditions. It is felt that one direct flank attack with a 90mm, AP, T33 projectile against either trunnion at a striking velocity of approximately 2000 fps would cause serious damage to the turret assembly and possibly prevent further oscillation. In addition to the damage which would be done to the turret proper, all personnel in the tank would be exposed to being struck by the trunnion parts which were displaced. The trunnion pin is the axis of oscillation of the turret which supports all the trunnion components. (See Drawing Appendix C). This pin is anchored to the skirting ring with bolts and the failure of these bolts by the shock of 90mm, AP, T33 projectiles caused the entire trunnion pin, bearing, and component parts to be displaced inside the tank.

c. Test Turret No. 4, Casting Serial No. 4.

(1) The tests conducted on Test Turret No. 4 with Caliber .30 Ball, M2 ammunition to determine the effectiveness of placing nylon cloth over the clearance between the oscillating section and the rotating ring did not cause any complete penetrations of the nylon cloth by fragments or bullet splash. Similar tests with Caliber .50 Ball, M2 ammunition did not cause any complete penetration either, but several fires were started by the fragments from these projectiles on the canvas covering which was placed over the twenty layer pad of nylon cloth. Six rounds of Caliber .50 AP, M2 ammunition were fired against the same clearances and none of these rounds produced fragments which gave complete penetrations of the nylon cloth.

(2) Since almost complete protection was offered by the nylon cloth against fragments produced by small arms, eight fragmentation grenades were statically detonated along the clearance to make a more complete evaluation of the protection afforded. From the detonation of these grenades only one fragment completely penetrated the nylon cloth and canvas covering. Evidence that many fragments did enter the clearance and strike the nylon cloth was found when the turret was disassembled after the test was completed and these fragments were noted lying on the top layer of cloth. The blast from the fragmentation grenades was severe enough to pull the cloth away from the oscillating sections or the rotating ring in several areas where it was fastened.

(3) Results of the test conducted on this turret by firing two 37mm HE, M54 projectiles under the gun near the clearance between the rotating ring and the oscillating section indicated that the blast was severe enough to tear the cloth from the oscillating section and the rotating ring. Approximately fourteen small fragments completely penetrated the twenty layers of nylon cloth and the canvas covering. Examining the cloth after testing was completed indicated that about four times the number of fragments which went through all twenty layers of the nylon cloth penetrated the first ten layers. Although the sizes of these fragments which completely penetrated the nylon cloth cannot be determined, examination of the holes produced in the cloth indicate that only one fragment approached a limit of 3/4" in diameter. Again as was mentioned in the test conducted using fragmentation grenades many of the smaller fragments which penetrated the twenty layers of nylon cloth had insufficient velocity to penetrate the canvas covering. It must be realized that although some fragments did completely penetrate the nylon cloth in this test, most of them after traveling through the clearance, the nylon cloth, and the covering would probably have insufficient velocity to cause casualties among personnel or damage to components inside the tank. For photographs of the nylon cloth after it was removed from the turret. (See APG Photographs A91633-A91637, Appendix F, Sub-Appendix 4). (It will be noted that the 37mm, HE, M54 projectile was the largest HE projectile used in this test and it can be expected that larger HE projectiles if fired would produce more blast and larger fragments resulting in more complete penetrations of the nylon cloth).

(4) Results of the test conducted to determine the effectiveness of a double-groove splash trap around the perimeter of the turret top cover plate against fragments and bullet splash indicate that one splash trap alone would be sufficient to stop these missiles. Several rounds hit directly in the crack between the top cover plate and the section of the turret which holds the top plate but no fragments went beyond the first splash trap. (See Sketch 1, Third Memorandum Report, Appendix B).

(5) The test conducted to determine if shock against the top side section of the bustle could bulge this area enough to key the top cover plate to the turret side did not give any indication that such a condition would occur under the test conditions with a 105mm Proof Projectile M1,004. It was found, however, that the four bolts which held this particular top cover plate to the turret would be sheared in almost every case and the top cover plate would probably be knocked off.

d. Test Turret No. 5, Casting Serial No. 7.

(1) From the results of the tests with the 90mm, AP, T33 projectiles on Test Turret No. 5 it appears that the protection afforded by this oscillating turret is good in the highly sloped areas to the right and left of the gun as was discussed in the testing done on Test Turret No. 1 above. The area under the gun and the adjacent areas which have almost 0° obliquity still offer a poor level of protection against the 90mm, AP, T33 projectile. (See APG Photographs A92452-A92453, A92455, Appendix F, Sub-Appendix 5).

(2) The armor of this turret was inferior to the armor of turrets previously tested. After firing approximately eight rounds against the front of the turret at both direct frontal and 30° flank attacks a forty-five inch horizontal crack developed across the upper front of the turret casting above the opening for the gun. (See APG Photograph A92453, Appendix F, Sub-Appendix 5). Another crack, thirty-eight inches long, started under the opening for the gun and ran into the forty-five inch crack. In addition to this excessive crack which developed there was cratering and spalling of the armor in several places from impacts with the 90mm, AP, T33 projectile.

(3) Direct flank and 60° flank attacks on the right side bustle area with 57mm, AP, M70 projectiles and on the left side bustle area with 76mm, AP, T128E6 projectiles indicate that the ballistic limits obtained from these attacks would compare very closely with the ballistic limits obtained from previous tests conducted under similar conditions. Although the protection ballistic limits compared very closely with the tests conducted on previous turrets, the armor of this turret developed more spalling and cracks than the previous turrets tested. (See APG Photographs A92449, A92454, A92456, Appendix F, Sub-Appendix 5).

(4) One 90mm, AP, T33 projectile against the left and right trunnions near the bearings and trunnion assembly from a 30° flank attack damaged both bearings. These bearings were equipped with a solid metal sleeve around the bearings whereas previous turrets tested under these conditions were equipped with a metal and rubber sleeve. The attack of the right trunnion with the 90mm, AP, T33 projectile completely demolished the bearing and component parts of the trunnion assembly. A similar attack on the left trunnion sheared one bolt on the cover plate but the bearing remained in the turret. The bearing was disassembled from the turret after the test was completed. Metal chips were found inside the bearing and the inner and outer races were brinelled in several places. (See APG Photographs A92450-A92451, A92457, A92657, A92658, Appendix F, Sub-Appendix 5).

(5) The test performed on Test Turret No. 5 duplicated tests conducted on Test Turrets Nos. 1 and 2 and was a check on the evaluation of the protection offered by these turrets. A comparison

of Protection Ballistic Limits obtained on the different turrets has been included in tabulated form in Chart 3, Appendix C. Where ballistic limits were not given for a particular area refer to the Detailed Test Data in Appendix D for each turret. Due to the limited area, in certain locations of the turret, which had a uniform obliquity and thickness, protection ballistic limits could not always be obtained.

e. Test Turret No. 3, Casting Serial No. 8.

(1) The tests conducted with Caliber .30, Ball, M2 ammunition to determine how much bullet splash and fragments were entering the clearance between the oscillating section and the rotating ring when no protective covering was used on Test Turret No. 3 caused complete penetrations of the Dural and Kraft paper. All fair rounds of the Caliber .30 Ball, M2 projectiles produced complete penetrations of the Dural and/or paper. Many of the fragments entering the front clearance followed the clearance around the perimeter of the turret and caused complete penetrations of the Kraft paper over the back clearance. Similar tests conducted with the Caliber .50, Ball, M2 projectile caused complete penetrations of the Dural and Kraft paper in almost every instance where the round was a fair one. Although the Caliber .50, AP, M2 projectiles which hit near the clearance did not cause complete penetrations of the Kraft paper and Dural, cratering around the impact area produced fragments which entered the clearance and caused complete penetrations.

(2) Using the same test setup as was used in the small arms test, three MK-2, fragmentation, hand grenades were statically detonated at three different places along the clearance on the front of the turret (See sketch 2, Fourth Memorandum Report, Appendix B). From the detonation of these fragmentation hand grenades, fragments completely penetrated the Dural in all three tests and the paper completely disintegrated. The fragments from one grenade tore the Dural approximately fourteen inches and there were more than fifty small complete penetrations of the Dural. (See APG Photographs A92605 and A92607 for test setup, Appendix F, Sub-Appendix 3).

(3) Results of the test conducted by firing one 37mm, HE, M54 projectile under the gun near the clearance between the rotating ring and the oscillating section indicate that enough blast and fragments were produced by this projectile to severely penetrate and tear the Dural which was placed under the entire inside front clearance of this turret. The Kraft paper over the inside back and side clearance was completely torn up by the blast and fragments. (See APG Photographs A92604 and A92606, Appendix F, Sub-Appendix 3).

f. Test Turret No. 6, Casting Serial No. 6.

(1) The tests conducted on Test Turret No. 6 with Caliber .30 Ball, M2 ammunition to determine the effectiveness of placing a metal covering over the clearance between the oscillating section and the rotating ring caused several small fragments less than 1/4" diameter to penetrate the Kraft paper under the clearance. Similar tests with Caliber .50 Ball, M2 ammunition caused several complete penetrations of the paper. Six rounds of Caliber .50 AP, M2 ammunition were fired against the same clearance and one fragment produced a complete penetration of the Kraft paper.

(2) Four fragmentation hand greandes, MK-2, were statically detonated along the clearance with only one fragment penetrating the Dural. (See APG Photograph A95241, Appendix F, Sub-Appendix 6). Results of the test conducted on this turret by firing two 37mm, HE, M54 projectiles under the gun near the clearance between the rotating ring and the oscillating section indicated that if the projectile detonated on the oscillating section the blast was severe enough from one round to completely tear up the Kraft paper under the back of the turret and cause many complete penetrations of the Dural under the front clearance. Nine complete penetrations of the .025 Dural sheet were larger than 1/2" in diameter and forty-six penetrations were less than 1/2" diameter. (See APG Photograph, A95239, Appendix F, Sub-Appendix 6). It will be noted that there were no tears of large areas of the Dural as was the case of Test Turret No. 3 where no covering was placed over this clearance under similar test conditions. (Refer to APG Photographs. A92604, Appendix F, Sub-Appendix 3).

IV. CONCLUSIONS

A. Based on the results obtained from the tests conducted and explained in this report it is concluded that:

1. The highly sloped armor areas to either side of the gun afford a higher level of protection against attacks from direct front with the 90mm, AP, T33 and 90mm, HVAP, M304 projectiles than does the T48 turret of standard design.

2. The armor area under the gun, against attack from direct front with the 90mm, AP, T33 and 90mm, HVAP, M304, can be defeated at ranges much greater than is normally experienced in tank combat.

3. One impact from the 90mm, AP, T33 projectile, or the 90mm, HVAP, M304 projectile or possibly even a smaller caliber projectile, could prevent elevation or depression of the gun if the impact is placed just above the rotating skirt ring and produces face petalling and/or a bulge; or if a projectile penetrates through the rotating ring into the oscillating turret section and keeps the two components together.

4. The area on the bustle sides, against attacks from direct flank and 60° flank with either the 57mm, AP, M70 projectile or the 76mm, AP, T128E6 projectile, can be defeated at ranges much greater than is normal for a tank turret of this class.

5. A direct flank attack on the trunnion assembly with the 90mm, AP, T33 projectile at velocities of approximately 2000 fps, will cause serious damage to the trunnion bearing and component parts which will in turn prevent further elevation and depression of the gun.

6. A direct flank attack with a 76mm, AP, T128E6 projectile and a 30° flank attack with a 90mm, AP, T33 projectile near the trunnion assembly on the rotating ring indicated that the bearings would withstand the shock under either condition without being excessively damaged, although considerable difficulty might be encountered in disassembling the trunnion parts. In addition, the grease seals under the bearing cover plate would not retain fluid lubricants.

7. Trunnion bearings equipped with a solid metal sleeve around the bearing do not offer as much resistance to shock under attack from a 30° flank with 90mm, AP, T33 projectiles as do bearings equipped with a rubber and metal sleeve around the bearing when subjected to the same attack conditions.

8. Fragments and/or blast from small arms, fragmentation grenades, and 37mm HE projectiles will enter the inside of a tank equipped with an oscillating turret through the clearance between the oscillating section and the rotating ring with sufficient velocity to endanger the equipment and personnel inside the tank unless some protective covering is provided for the clearance.

9. Twenty layers of nylon cloth over the inside clearance between the oscillating section and the rotating ring of an oscillating turret was effective in preventing the entrance of the great majority of fragments produced by attacks from small arms, fragmentation grenades and 57mm, HE projectiles.

10. A metal shield arrangement over the inside clearance between the oscillating section and the rotating ring of an oscillating turret was only partially effective in preventing fragments produced by small arms, fragmentation grenades and 37mm, HE projectiles from entering the inside of the turret.

11. The double-groove splash trap around the perimeter of the top cover plate on a turret of the oscillating design was effective in stopping fragments and bullet splash from small arms projectiles.

V. RECOMMENDATIONS

A. It is recommended that:

1. Serious consideration be given to bringing about changes in design which will provide improved protection in the armor area below the gun on the turret oscillating section.

2. More obliquity be given to the bustle side areas in order to provide a higher level of protection in these areas.

3. The clearance between the rotating skirt ring and the oscillating turret section be increased to prevent keying of the two components when projectiles produce petalling or bulging on the face of the armor.

4. Some additional means other than bolts be considered for fastening the trunnion pins to the rotating ring and some non-fluid lubricant be used in lubricating the bearing.

5. The metal and rubber combination sleeve around the trunnion bearings be used in preference to the solid metal sleeve since the combination sleeve offers more resistance to shock.

6. Some means of covering the inside clearance between the rotating ring and the oscillating section be used if fragments and/or blast from small arms, fragmentation grenades and 37mm, HE projectiles are to be stopped from entering the tank.

7. The twenty layers of nylon cloth over the inside clearance between the oscillating section and the rotating ring be used instead of the metal shield arrangement if protection against blast and fragments from relatively small caliber projectiles is to be provided.

8. Changes be brought about in the method of fastening the nylon cloth between the oscillating section and the rotating ring of oscillating turrets to reduce the possibility of pulling the cloth from these parts by blast from high explosives.

9. Some fire resistant material be used as a cover for the nylon cloth other than canvas in order to cut down the fires that could be started by fragments striking such materials and by white phosphorous and by jellied gasoline.

10. When definite methods of fastening the top cover plate to the oscillating turret have been devised, it is suggested that an investigation be conducted to determine the possibility of keying the top cover plate to the turret and/or displacing the top cover plate from the turret by projectile impacts on the turret side walls.

WEP D. H. Witt
D. H. WITT
1st Lt., Ord Corps
Proof Officer

APPROVED:

for Em Lee, Ass't
T. F. COLLERAN
Director,
Development & Proof Services

Benjamin S. Goodwin
BENJAMIN S. GOODWIN
Chief,
Arms & Ammunition Div.

LABORATORY SERVICE DIVISION
PHYSICAL TEST LABORATORY REPORT

ORDBG-DPS-LS

TEST OF:

Oscillating Tank Turret No. 3.

OBJECT OF TEST:

To obtain the wall thickness of the above turret before test at A.P.G.

TEST PROCEDURE:

1. Instrumentation: Reflectoscope.

2. Procedure:

a. The turret was marked off in approximately 10" x 10" sections and numbered (see APG Photographs A88717-A88728, inclusive, Appendix II).

b. A smooth spot was ground as close to the center of each section as surface conditions would permit so all measurements could be taken with the reflectoscope. One (1) measurement was obtained in each block.

c. Sections 134 to 163, inclusive, are located on the skirt, and due to the shape of it, exact maximum thickness measurements could not be obtained. Thicknesses in these locations should be considered as approximate.

RESULTS:

1. For data see Appendix I.

2. For photographs see Appendix II.

Report No. 53-L-146

Sheet 1 of 1

Date of Test 24 April 1953

Report Complete 8 May 1953

Conducted for A & A Division

Mr. W. Pless

Project No. TT2-586

Work Order No. 2013-513-0

References None

2 Incl
Appendix I
Appendix II

Approved: _____
J. M. McKinley,
Chief,
Physical Test Laboratory.

Signed: _____
D. Lee Seagle,
Measurements Section.

ORDBG-DPS-LS

Report No. 53-L-146

Thickness Measurements of Oscillating Tank Turret, No. 3, with Skirt, No. 4

Section No.	Thickness	Section No.	Thickness	Section No.	Thickness
1	3.75"	41	2.25"	81	3.10"
2	4.25	42	5.50	82	5.25
3	2.10	43	5.50	83	2.15
4	2.00	44	4.10	84	3.00
5	1.50	45	4.20	85	1.00
6	1.90	46	4.20	86	1.00
7	2.90	47	3.95	87	1.00
8	3.50	48	1.60	88	1.00
9	3.50	49	1.80	89	1.00
10	4.25	50	1.75	90	1.00
11	3.50	51	3.50	91	1.00
12	3.10	52	3.75	92	1.00
13	2.05	53	2.40	93	1.00
14	1.70	54	1.80	94	1.00
15	2.25	55	1.75	95	1.00
16	4.25	56	1.75	96	1.00
17	4.25	57	2.00	97	1.00
18	4.50	58	3.10	98	1.00
19	5.45	59	3.00	99	1.10
20	5.50	60	3.00	100	1.90
21	6.00	61	2.75	101	1.90
22	3.75	62	2.60	102	1.90
23	1.80	63	2.60	103	2.00
24	3.00	64	2.25	104	1.90
25	5.50	65	2.60	105	1.90
26	5.25	66	2.50	106	1.75
27	4.75	67	2.40	107	1.60
28	4.25	68	2.25	108	1.60
29	5.00	69	2.60	109	1.75
30	7.00	70	2.10	110	1.60
31	4.50	71	2.00	111	1.60
32	3.50	72	1.50	112	1.50
33	4.75	73	1.80	113	1.50
34	6.00	74	1.90	114	1.00
35	4.75	75	2.00	115	1.00
36	4.00	76	1.75	116	1.00
37	2.25	77	4.50	117	1.50
38	2.25	78	2.00	118	1.50
39	2.50	79	2.50	119	2.75
40	2.75	80	3.00	120	2.70

Thickness Measurements of Oscillating Tank Turret, No. 3, with Skirt, No. 4

Section No.	Thickness	Section No.	Thickness
121	2.60"	161	2.50"
122	3.10	162	2.50
123	3.10	163	3.25
124	3.05		
125	2.50		
126	2.30		
127	2.50		
128	2.50		
129	2.45		
130	2.60		
131	2.10		
132	1.80		
133	2.10		
134	1.75		
135	2.75		
136	3.25		
137	3.00		
138	2.50		
139	2.55		
140	3.00		
141	3.00		
142	3.00		
143	3.00		
144	4.00		
145	3.50		
146	3.00		
147	3.00		
148	1.75		
149	1.00		
150	1.00		
151	3.00		
152	1.10		
153	1.10		
154	1.50		
155	2.60		
156	2.50		
157	3.00		
158	2.50		
159	2.40		
160	2.50		

Thickness Measurements of Oscillating Tank Turret, No. 8, with Skirt, No. 3

Section No.	Thickness	Section No.	Thickness	Section No.	Thickness
1	4.30"	41	2.65"	81	2.90"
2	4.60	42	5.75	82	5.75
3	2.40	43	5.50	83	2.50
4	2.40	44	4.30	84	3.50
5	1.50	45	4.75	85	1.25
6	2.00	46	4.45	86	1.10
7	2.95	47	4.00	87	1.10
8	3.95	48	1.80	88	1.00
9	4.05	49	1.90	89	1.25
10	5.25	50	2.20	90	1.25
11	3.75	51	3.75	91	1.10
12	2.55	52	3.95	92	1.05
13	2.55	53	2.50	93	1.05
14	1.60	54	1.90	94	1.25
15	3.00	55	1.75	95	1.25
16	4.60	56	1.75	96	1.00
17	4.90	57	2.80	97	1.10
18	4.50	58	3.25	98	1.00
19	5.40	59	3.25	99	1.00
20	6.00	60	3.00	100	1.00
21	5.25	61	2.90	101	2.00
22	2.50	62	2.75	102	1.90
23	1.60	63	3.10	103	1.80
24	3.25	64	3.00	104	1.75
25	5.75	65	3.00	105	1.75
26	6.05	66	2.85	106	1.60
27	5.25	67	2.90	107	1.60
28	4.10	68	2.90	108	1.60
29	5.50	69	2.50	109	1.60
30	6.50	70	2.30	110	1.60
31	4.75	71	2.30	111	1.65
32	3.45	72	1.75	112	1.60
33	4.20	73	1.95	113	1.60
34	5.80	74	2.00	114	1.25
35	4.60	75	2.55	115	1.00
36	4.50	76	2.25	116	1.00
37	2.70	77	2.50	117	1.50
38	2.25	78	2.50	118	1.50
39	3.00	79	3.00	119	3.00
40	2.45	80	3.00	120	2.50

ORDBG-DPS-LS

Report No. 53-L-164

Thickness Measurements of Oscillating Tank Turret, No. 8, with Skirt, No. 3

Section No.	Thickness	Section No.	Thickness
121	2.75"	161	2.00"
122	2.75	162	2.50
123	3.10	163	2.20
124	3.10		
125	2.75		
126	2.75		
127	2.95		
128	2.90		
129	2.90		
130	3.00		
131	3.50		
132	2.00		
133	2.25		
134	1.45		
135	3.00		
136	3.10		
137	2.50		
138	2.45		
139	2.50		
140	2.90		
141	3.00		
142	3.00		
143	3.05		
144	3.50		
145	2.50		
146	3.50		
147	2.05		
148	1.75		
149	2.55		
150	1.60		
151	2.25		
152	2.50		
153	2.00		
154	3.60		
155	3.05		
156	3.10		
157	3.00		
158	2.95		
159	2.30		
160	2.50		

Measurements 134-163 taken on skirt.

CONFIDENTIAL

A88717 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3.
Top view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88718 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3.
Rear view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88719 CONFIDENTIAL ABERDEEN PROVING GROUND 20 April 1953
Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3.
Rear view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88720 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter right front view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88721 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

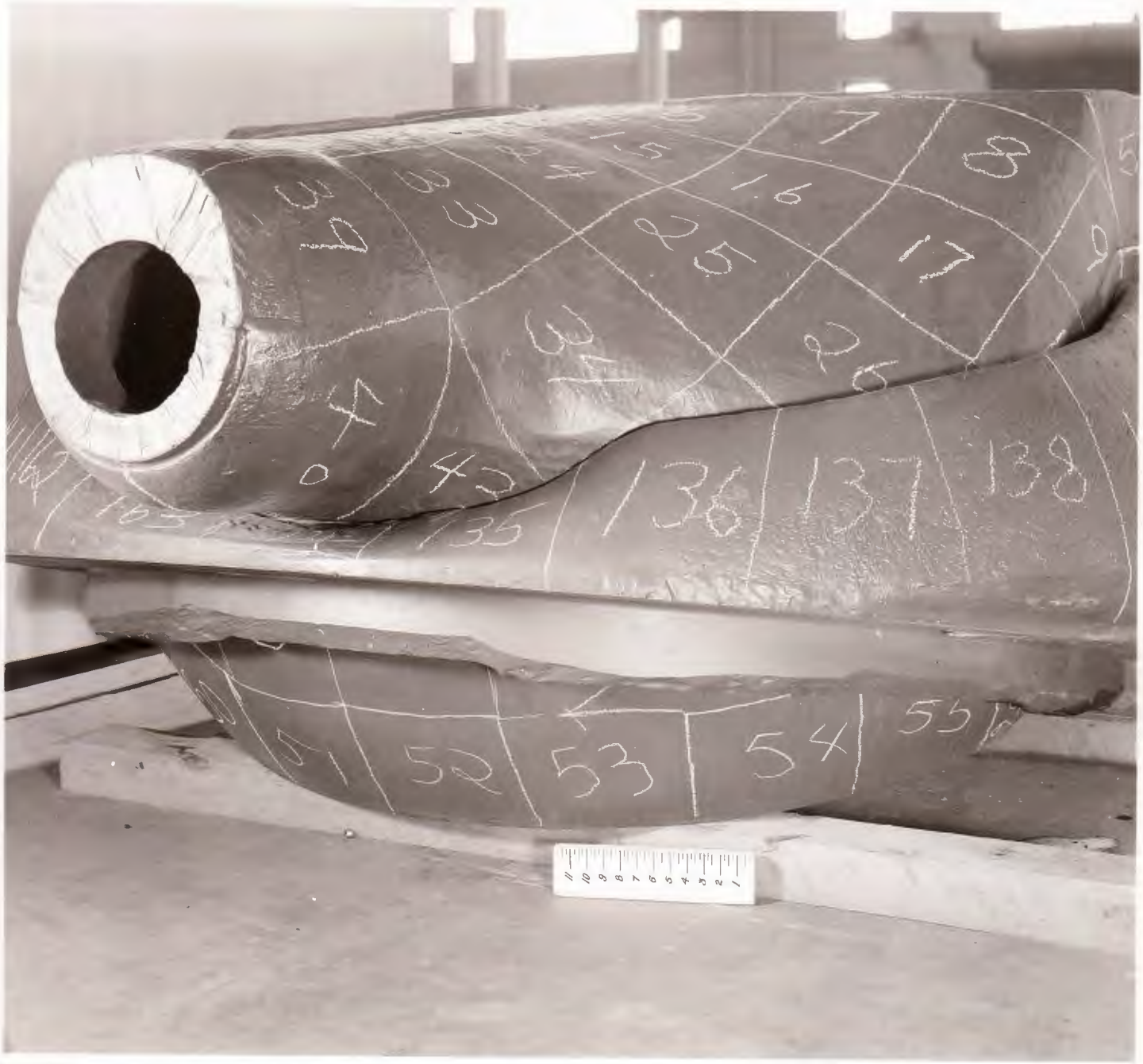
Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter right front view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88722 CONFIDENTIAL ABERDEEN PROVING GROUND 20 April 1953

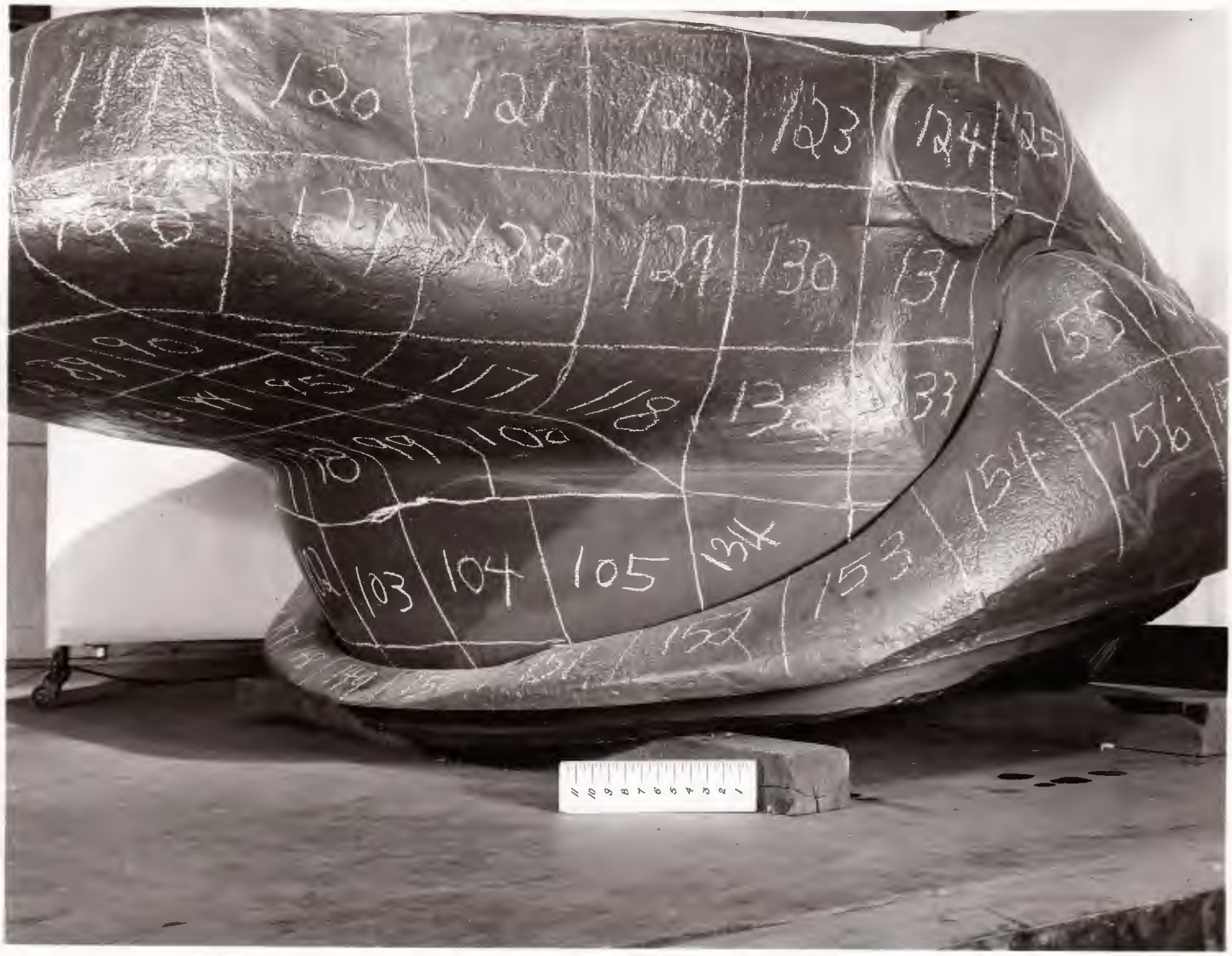
Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter left front view showing thickness measurement locations before test at APG.

CONFIDENTIAL



A88723 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter left front view showing thickness measurement locations before test at APG.



A88724 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter right rear view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88725 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

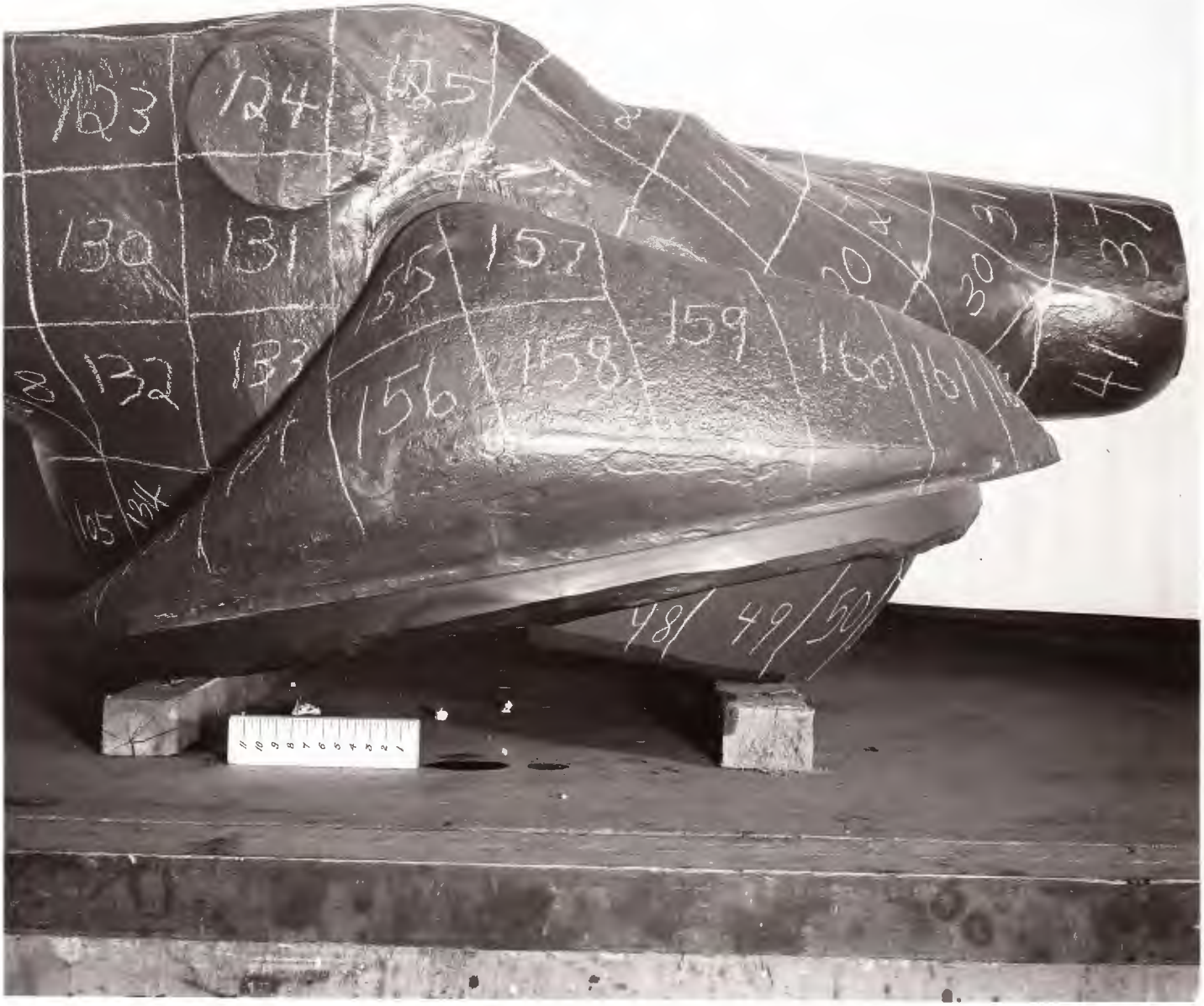
Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter right rear view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A88726 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Three-quarter left rear view showing thickness measurement locations before test at APG.

CONFIDENTIAL



A88727 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 April 1953

Project No. TT2-586. Tank, Turret, Oscillating, Serial No. 3. Right side view showing thickness measurement locations before test at APG.

CONFIDENTIAL

A89569 CONFIDENTIAL ABERDEEN PROVING GROUND 20 May 1953

Project No. TT2-586. Ballistic Test of Oscillating Turrets. Direct frontal attack with the 90mm, AP, T33, projectile w/windshield. Rounds 1, 2, 3, 4, 8, 9, 10.

CONFIDENTIAL

A89570 CONFIDENTIAL § ABERDEEN PROVING GROUND § 20 May 1953

Project No. TT2-586. Ballistic Test of Oscillating Turrets. Direct frontal attack with the 90mm, AP, T33, projectile w/windshield. Rounds 5, 6, 7. Gun elevated approximately 13°.