3” (76.2mm) FLAT-NOSED (CYLINDRICAL) HARDENED STEEL SHOT

VERSUS SPECIAL TREATMENT STEEL (STS) ARMOR PLATE

MADE BY THE CARNEGIE-ILLINOIS STEEL CORPORATION

**(Tested at the US Naval Proving Ground, Dahlgren, Virginia, in 1942)**

**By Nathan Okun (22 July 2011)**

# SOURCE

The data was obtained from the U.S. Naval Proving Ground (NPG), Dahlgren, Virginia, U.S.A., Armor and Projectile Laboratory, headed by Dr. Allen V. Hershey during World War II. I was given this data and much other such WWII armor test data by Dr. Hershey on his retirement in 1981 from the U.S. Naval Weapons Laboratory, which was the new name at the time for the NPG--its name is now Dahlgren Division of the U.S. Naval Surface Warfare Center, Naval Sea Systems Command (NSWC/DD of NAVSEA). There are many formal test reports and Dr. Hershey's personal 3"x5" annotated index card test file, which contain thousands of test results and which I now possess.

# PROJECTILES

The projectiles used were of two general types. The first (TYPE 1 here) was a 15-pound (6.8 kg) U.S. Army 3” M79 Armor-Piercing (AP) Monobloc Shot projectile (which was a solid block of steel with a small pit in the base for a tracer element and a narrow copper driving band near the base) that had its ogival nose sawed off flat reducing its weight to 10.7 pounds (4.85 kg) and length to 5.35” (13.59 cm), while the second (TYPE 2) were specially-made 3”-wide hardened steel cylinders of varying length with a similar narrow copper driving band (these latter were made by the U.S. Army Frankford Arsenal especially for this test series). They were all fired from standard U.S. Navy 3”/50 guns at the Plate Battery experimental armor test area at the NPG. All were made of hardened chromium-nickel steel with a density of 0.283 pounds/cubic inch (7.83 grams/cubic centimeter). The projectile’s weight was determined by adjusting its length, which never exceeded 2.5 calibers. Both projectile types were of high hardness and did not deform, shatter, or break up until plate thickness exceeded 0.4-caliber, above which various forms of deformation and, finally, shatter set in gradually. The projectiles were:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Test Projectile** | | **Weight** | | **Length** |
| **ID** | **Type** | **(lb)** | **(kg)** | **(CAL)** |
|  |  |  |  |  |
| A | 2 | 7.4 | 3.36 | 1.23 |
| B | 2 | 8.5 | 3.86 | 1.42 |
| C | 1 | 10.7 | 4.85 | 1.78 |
| D | 2 | 10.7 | 4.85 | 1.78 |
| E | 2 | 15.0 | 6.80 | 2.50 |

# PLATES

The armor plates used were Special Treatment Steel made by the Carnegie-Illinois Steel Corporation (later called U.S. Steel Corporation) for the U.S. Navy Bureau of Ships during WWII. This steel, as with similar U.S. Navy Bureau of Ordnance Class “B” (homogeneous, ductile) armor, was a rolled ductile chromium-nickel alloy steel somewhat similar in composition and metallurgy to later U.S. Navy HY-80 and HY-100 high-tensile construction steels and to U.S. Army Rolled Homogeneous Armor (though usually softer than the latter metal, in the 200-230 Brinell Hardness Number range). The differences between HY-80/100 and STS were: (1) No copper, molybdenum, cobalt, or vanadium alloys were specified in STS; (2) the ~2% chromium content of STS was similar to HY-80; (3) the ~3.5% nickel content of STS was similar to HY-100; (4) the 0.25-0.35% carbon content of STS was higher than in HY-80/100; (5) the 80-95 kpsi (56.24-63.28 kg/sq.mm) typical yield strength of STS was similar to HY-80; and (6) the typical 110-120 kpsi (77.34-84.37 kg/sq.mm) tensile strength of STS was similar to HY-100. The STS plates were especially heat treated to several hardness values and tensile strengths, which varied over a large range. Plate thicknesses ranged from 0.618” (1.57 cm) to 2.439” (6.2 cm) -- a single 3.21" (8.15 cm) plate test shattered a 15-lb projectile (no hole) -- and the plates were tilted so that the impact obliquity ranged from 0° (normal) through 60°, with most tests 0-~30°.

# TEST DATA TAKEN

In some cases, a series of firings was done against a single plate at a single obliquity by a single projectile type to get a value for the complete penetration ballistic limit (also called the “base through” or “U.S. Navy” Ballistic Limit (NBL, for short)) in which the projectile entirely passes through the plate with the minimum possible remaining velocity (which may be greater than zero at high obliquity since ricochet rather than stopping the projectile is the major method of resistance here). In some cases the remaining velocities on complete penetration were measured and plotted to get a good value of the NBL by extrapolating the plot back to zero (only useful for normal or low obliquity impacts, however). An NPG Report was created that used some, but not all, of the data I have, illustrating this remaining velocity method of NBL computation.

Other firings were simply one shot at a given plate by a given projectile at a given obliquity with the results documented, so many of such trials had to be carefully analyzed to give a reasonable picture of the trends.

In the following table, I summarize the descriptions on Dr. Hershey's index cards for these flat-nose tests. Tests against each single plate are grouped together with a blank line between plates in each test group.

Dr. Hershey’s index cards use the following abbreviations for plate and projectile results of a given test or tests:

**DAMAGE TO PLATE:**

“CP” = Complete penetration (impacts at or over NBL)

“IP” = Incomplete penetration (below NBL) (holes may or may not be made in the plates)

“PP” = Partial penetration (holes were made and the projectiles broke up, with part of projectiles passing through the holes) (below NBL)

“SIP” = Projectile imbedded in plate (holes were always made in the plates) (impact is barely below NBL)

“L” = Lamination(s) -- which are abrupt internal defects or cracks parallel to plate face -- noted in hole made in plate (CP is always implied here)

In this case, a hole was always accompanied by a caliber-diameter circular (low obliquity) or caliber-minimum-width elliptical (medium or high obliquity) plug of armor cut out of the plate’s full thickness, usually intact, though always bent at oblique impact.

**DAMAGE TO PROJECTILE:**

“E” = Projectile completely undamaged (“excellent”)

“X” = Projectile shattered into several pieces

“NX” = Projectile nose (upper end) shattered, but most of projectile body more-or-less intact

“NB” = Nose broken by some other mechanism than shatter, but most of projectile body most-or-less intact

“NO” = Nose offset (bent sideways)

“NU” = Nose upset (compressed and widened more-or-less symmetrically)

“NC” = Nose cracked but otherwise intact

“BF” = Base flattened on one side due to “slap” against plate during oblique impact

Damage given is the most important damage noted if more than one kind happened simultaneously.

Plate thicknesses given in calibers are exact thicknesses at center of impact areas for each shot, so they vary slightly even on a single plate hit by several projectiles. For multiple hits determining the NBL, the thickness is the average of all areas hit on that plate by those shots.

Question marks mean the data was not supplied, but in some cases I can make a reasonable guess as to the correct data to be used there, although I keep the question mark to indicate that the data point is possibly incorrect.

The “Error” column only has meaning when the question "NBL?" is answered "Y" (= "YES") and shows roughly how close the given NBL value (the numbers in the “Striking Velocity” column for these rows) is to the true value (i.e., gives the length of error bars on a graph; I think the error given is to one “standard deviation”).  It usually means an average of several tests straddling the velocity where the projectile barely makes it through the plate.  These rows are the critical data in the table for creating my penetration program.   In the rows where "NBL?" is "N" (= "NO") where there no number in the “ERROR” column, the “Striking Velocity” is just that: The velocity used in the test (or average if more than one shell fired) and of no other significance, used to indicate the damage that the projectiles suffered, which is needed when studying that part of the penetration problem (my computer program assumes a “quasi-ideal” projectile with no damage at all or pure shatter with no other kind of damage -- not really true in real life, as the various results in this table show).

**TABLE NOTES:**

A single group of tests using various yawed (nose tilted away from the projectile direction of motion) projectiles were included in these test firings. Yaw angle is given in degrees.

“TS” means plate tensile strength (slow pull test to test article being torn in two) in kpsi (multiply this number by 0.70308 to get kg/sq.mm). A number in parenthesis indicates that all table tests with that number were against the same plate.

The ORIGINAL and REHEATED entry is for a single plate that was re-manufactured and then tested again in an attempt to see how plate strength affected the results.  This was only done once here because the plate was going to be re-manufactured anyway for some other reason, so why not try to get some test information “for free”?  (Here the change in tensile strength increased the NBL by 9.2%. In modern WELDOX high-tensile steel tests (460E, 700E, and 900E) using 20mm (0.7874") 196.8 kg (0.4343 lb) hardened projectiles with various nose shapes, including flat, the three plate types had huge differences in hardness and tensile strength, but the NBL results at right-angles for the 0.6-caliber (0.47244") plate thickness used for most of these tests (when restricted to unbroken projectiles) only varied by 1-4%, depending on nose shape, from plate to plate.  This is rather strange, since for STS and both flat-nose and M79 medium-point projectiles, the NBL variation with strength, while gradual, was, as shown here, significantly larger than that.  One of several things that I do not understand about WELDOX steel!)

58 Rc = 58 Rockwell “C” (for high-strength steel) hardness test result, which is significantly harder than the 51-53 Rc used for most of these projectiles.  I usually use Brinell Hardness (there are also Vickers and Shore hardness scales).  I have a chart that approximately converts one to the other (but beware, different charts vary slightly!!).

| **Test ID** | **Thickness** | **Obliquity** | **Striking Velocity** | | **NBL?** | **Error** | **Number of Shots** | **Damage Caused** | **Notes** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **(Cal)** | **(°)** | **(ft/s)** | **(m/s)** | **(Y/N)** | **(%)** |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| A | 0.457 | 5.0 | 1,027 | 313.0 | Y | 3.0 | 3 | L-NC | TS=120(1) |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| B | 0.462 | 30.5 | 1,068 | 325.5 | N | --- | 1 | IP-NU | (1) |
|  |  |  |  |  |  |  |  |  |  |
| B | 0.810 | 30.0 | 1,775 | 541.0 | Y | 1.11 | ? | ? | TS=112 |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| C | 0.65 | 3.0 | 1,366 | 416.4 | N | --- | 1 | IP-X | TS=130(2) |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| D | 0.244 | 3.0 | 670 | 204.2 | Y | 1.41 | ? | E? |  |
|  |  |  |  |  |  |  |  |  |  |
| D | 0.429 | 0.0 | 689 | 210.0 | N | --- | 1 | SIP-NU | No yaw(3) |
| D | 0.431 | 0.5 | 664 | 202.4 | N | --- | 1 | IP-E | 5° yaw(3) |
| D | 0.429 | 0.5 | 709 | 216.1 | N | --- | 1 | IP-NU | 10° yaw(3) |
| D | 0.430 | 29.8 | 917 | 279.5 | N | --- | 3 | IP-NB | (3) |
|  |  |  |  |  |  |  |  |  |  |
| D | 0.453 | 0.0 | 1,150 | 350.5 | N | --- | 1 | CP-NU | (1) |
| D | 0.454 | 3.0 | 845 | 257.6 | N | --- | 1 | CP-NU | (1) |
| D | 0.454 | 3.0 | 781 | 238.0 | Y | 1.65 | 7 | L-NU | (1) |
| D | 0.455 | 5.0 | 767 | 233.8 | N | --- | 1 | IP-E | (1) |
| D | 0.454 | 30.0 | 918 | 279.8 | N | --- | 1 | SIP-E | (1) |
| D | 0.456 | 30.0 | 930 | 283.5 | N | --- | 1 | CP-E | (1) |
| D | 0.456 | 30.0 | 918 | 279.8 | Y | 0.65 | ? | E? | (1) |
|  |  |  |  |  |  |  |  |  |  |
| D | 0.651 | 0.0 | 1,686 | 513.9 | N | --- | 1 | IP-X | (2) |
| D | 0.649 | 1.0 | 963 | 293.5 | N | --- | 1 | IP-NU | (2) |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.207 | 0.0 | 514 | 156.7 | Y | 0.57 | ? | E? | TS=118(4) |
| E | 0.206 | 45.0 | 484 | 147.5 | Y | 0.85 | ? | E?? | (4) |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.247 | 60.0 | 675 | 205.7 | Y | 3.81 | ? | L-NU |  |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.459 | 1.0 | 586 | 178.6 | Y | 1.87 | 5 | L-NU | (1) |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.488 | 1.0 | 644 | 196.3 | Y | 0.7 | ? | L-NU | TS=120(5) |
| E | 0.488 | 30.0 | 793 | 241.7 | Y | 1.64 | ? | L-NO | (5) |
| E | 0.495 | 30.0 | 911 | 277.7 | N | --- | 1 | SIP-BF | (5) |
| E | 0.495 | 30.0 | 819 | 249.6 | N | --- | 1 | CP-E | (5) |
| E | 0.495 | 30.0 | 911 | 277.7 | Y | 0.29 | 2 | L-E | (5) |
| E | 0.496 | 45.0 | 1,045 | 318.5 | Y | 0.61 | ? | E? | (5) |
| E | 0.494 | 60.0 | 1,447 | 441.0 | Y | 5.66 | ? | E? | (5) |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.503 | 0.0 | 1,196 | 364.5 | Y | ? | 2 | L-NX | TS=117(6) |
| E | 0.501 | 30.2 | 800 | 243.8 | Y | ? | ? | E? | (6) |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.502 | 30.0 | 772 | 235.3 | Y | 0.68 | ? | E? | TS=87(Original 7) |
| E | 0.501 | 30.0 | 843 | 256.9 | Y | 0.62 | ? | L-NU | TS=113 (Reheat 7) |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.502 | 30.0 | 893 | 272.2 | Y | 0.88 | ? | L-NU |  |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.648 | 32.0 | 1,037 | 316.1 | N | --- | 1 | IP-NB |  |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.657 | 30.0 | 1,305 | 397.8 | N | --- | 1 | IP-X | TS=119 |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.662 | 30.0 | 1,432 | 436.5 | N | --- | 1 | IP-X | (8) |
| E | 0.662 | 30.0 | 1,244 | 379.2 | Y | 0.73 | ? | L-NO | (8) |
| E | 0.662 | 40.0 | 1,626 | 495.6 | N | --- | 1 | SIP-NU | (8) |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.673 | 1.0 | 769 | 234.4 | Y | 3.45 | ? | E? | TS=123 |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.793 | 29.5 | 1,618 | 493.2 | N | --- | 1 | IP-X | TS=119 & 58Rc nose |
|  |  |  |  |  |  |  |  |  |  |
| E | 0.813 | 0.0 | 1,142 | 348.8 | N | --- | 1 | SIP-NX | TS=125(9) |
| E | 0.813 | 0.0 | 1,386 | 422.5 | N | --- | 1 | CP-NU | (9) |
|  |  |  |  |  |  |  |  |  |  |
| E | 1.07 | 0.0 | 1,407 | 428.9 | N | --- | 1 | IP-X |  |