CAPPED & UNCAPPED US NAVY AP SHOT & SHELL VS HARVEYIZED NI-STEEL ARMOR AT NORMAL OBLIQUITY (1894-97)
PLUS SEVERAL KRUPP KC (KC a/A) PLATE TESTS BY KRUPP

By NATHAN OKUN

(3rd REVISION USING FACEHARD 6.8 & Q(Armor) = 0.76 FOR NI-STEEL IN M79APCLC -- 1/11/2011)

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details

3" Plate (33-50% Cemented Face)

Carp. AP	4	25	1206	IP	<0.5	BB NB	Carn	No	Yes	NC.
Carp. AP	4	25	1357	IP	<0.5	BB NB	Carn	No	Yes	NC.
Carp. AP	4	25	1800	IP	<0.5	BB NB	Carn	No	Yes	NC.

=== NBL >> 1800

Soft-steel Johnson cylindrical nose-tip cap added (Body weight ~24 lb):

W-S. AP Shell	4	25	1700	CP	Thru	BB NB	Carn	No	Yes	All pieces in backing. No added cracks.

=== NBL <= 1700 (Close)

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 24 lb for capped projectile.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1325--> Way below NBL
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2019--> Possible
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1725--> 1.5% high if NBL = 1700
FACEHARD 6.8: 4" AP Shell: HBL = 1611 NBL = 1863 EBL = NEVER (Shatter only)--> Way below NBL
FACEHARD 6.8: 4" AP Shell: HBL = 1920 NBL = 2220 EBL = NEVER (Shatter + Max damage)--> Possible
FACEHARD 6.8: 4" APC Shell: HBL = 1482 NBL = 1714 EBL = 1904 (No shatter assumed)--> 0.8% high if NBL = 1700

DISCUSSION: Obviously, the homogeneous armor formula using 1890 Ni-Steel is not applicable here, even if Q(Armor) was raised considerably by the year 1897. The AP shattered and did little to the plate, so we have no "lid" on the NBL and cannot get a good value for it. The C.D. Formulae give results that are rather good for APC and possible for AP. My FACEHARD 6.8 is almost perfect for the APC shell and possible for the AP shell.

4" Plate (25-40% Cemented Face)

Carp. AP Shell	5	50	1977	PP	Thru	BB NB	Carn	No	Yes	~Half projectile in backing. Conical plug. NC.

=== NBL > 1977 (Close)

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 48 lb for capped projectile. Uncapped test only.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1357--> Way below NBL
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1980--> Very Good
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1717--> Way too low
FACEHARD 6.8: 5" AP Shell: HBL = 1705 NBL = 1921 EBL = NEVER (Shatter only)-->2.98% low if NBL = 1980
FACEHARD 6.8: 5" AP Shell: HBL = 1920 NBL = 2163 EBL = NEVER (Shatter + Max Damage)-->9.24% high "
FACEHARD 6.8: 5" APC Shell: HBL = 1515 NBL = 1707 EBL = 1897 (No shatter assumed)-->Way below NBL

DISCUSSION: Obviously, the homogeneous armor formula using 1890 Ni-Steel is not applicable here, even if Q(Armor) was raised considerably by the year 1897. The AP shattered and about half made through the plate, so we have an impact just a little below the NBL for that set of conditions. The C.D. Formulae give results that are extremely good for AP, but not for APC, which is to be expected here. My FACEHARD 6.8 formula straddles the shattered AP impact when non-shatter damage is applied in full or is not applied at all. In this case, the shell was not damaged as much by the impact as with most shattered shells, so it was in-between the two extremes, but closer to the full-damage-applied case, as I would think would be more common here. FACEHARD 6.8's APC calculation is not applicable here and is way off, as would be expected.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details

Experimental 5" Upper Flat/5-3.5" Lower Tapered Plate & Assumed ~4.25" (Average) @ Impacts (~23-37% Cemented Face)

W-S. AP Shell	4	25	?	IP	<0.5	BB NB	Carn	No	Yes	FC. *(4 impacts with same results.)*
Carp. AP Shell	4	25	?	IP	<0.5	BB NB	Carn	No	Yes	FC. *(4 impacts with same results.)*

=== NBL >> UNKNOWN

Soft-steel Johnson cylindrical nose-tip cap added (body weight ~24 lb):

W-S. AP Shell	4	25	1711	CP	Thru	BB NB	Carn	No	Yes	All proj. pieces in backing. No added cracks.

=== NBL =< 1711 (Close)

COMPARE RESULTS TO FORMULAE:

(Comparison not possible for uncapped results since striking velocities not given. All uncapped tests probably well above capped test velocity.) (Assume Body Weight 24 lb for capped projectile.)

Assume 5" at Impact:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1817--> Too high
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2961--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2596--> Way too high
FACEHARD 6.8: 4" AP Shell: HBL = 2240 NBL = 2459 EBL = NEVER (Shatter only)-->Way too high
FACEHARD 6.8: 4" AP Shell: HBL = 2671 NBL = 2932 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 4" APC Shell: HBL = 2158 NBL = 2369 EBL = 1897 (No shatter assumed)-->Way too high

Assume 4.25" at Impact:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1637--> Somewhat too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2621--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2280--> Way too high
FACEHARD 6.8: 4" AP Shell: HBL = 2023 NBL = 2264 EBL = NEVER (Shatter only)-->Way too high
FACEHARD 6.8: 4" AP Shell: HBL = 2411 NBL = 2698 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 4" APC Shell: HBL = 1915 NBL = 2143 EBL = 2381 (No shatter assumed)-->Way too high

Assume 3.5" at Impact:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1325--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2266--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1952--> Way too high
FACEHARD 6.8: 4" AP Shell: HBL = 1782 NBL = 2034 EBL = NEVER (Shatter only)-->Way too high
FACEHARD 6.8: 4" AP Shell: HBL = 2124 NBL = 2424 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 4" APC Shell: HBL = 1658 NBL = 1892 EBL = 2101 (No shatter assumed)-->11.29% high if NBL = 1700

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is only applicable here if the plate is slightly thicker than 4.25" where hit. The AP shattered and none of the shells did mote than scratch the plate's surface. The C.D. Formulae give results that are way too high no matter where the shell hit that plate. My FACEHARD 6.8 formula is also way too high for shattered projectiles but it straddles the unshattered, but badly broken up, APC impact between its HBL and NBL if the hit was at or near the lower edge where the plate was only 3.5" thick. If so, then this means that either the projectile was not quite as damaged as it usually is and its NBL and HBL went down or, conversely, it was broken into even smaller pieces than usual and more of them were able to get through the hole at the lower velocity, which is essentially the same thing here. This is why the NBL is of little consequence in this kind of impact, where the projectile is in pieces, since only the HBL really matters as to the amount of damage behind the plate. In this case, FACEHARD 6.8 predicts that a bunch of pieces will get through, since the impact is above its HBL, and this is indeed the case (how many to define the NBL is of minimal interest). Since we do not know where the APC shell hit, this is ambiguous, but FACEHARD does give results that are possible. Note also that this was an experimental plate and might not be of the same quality as standard plates to be used on a ship (which have to pass all of the standard tests). Finally, if the hit was near the lower edge, the plate is not as strong, since it can fold back away from the free edge. Most tests are restricted to be at least 3 calibers away from any hole or edge, but this may not have been the case here. Best we can do here.

5" Plate (20-30% Cemented Face)

W-S. AP	5	50	1712	IP	2	BB NB NSIP	Carn	No	No	Crack in back bulge. Corner broke off.

=== NBL > 1712 (probably between 1850 & 2000)

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 48 lb for capped projectile. Doing uncapped comparison only.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1558--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2341--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2053--> Somewhat high
FACEHARD 6.8: 5" AP Shell: HBL = 1965 NBL = 2157 EBL = NEVER (Shatter only)-->Somewhat high
FACEHARD 6.8: 5" AP Shell: HBL = 2210 NBL = 2427 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 5" APC Shell: HBL = 1786 NBL = 1961 EBL = 2179 (No shatter assumed)-->Possible

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is way too low. The C.D. formula for AP is way too high, given the cracked bulge and broken-off chunk at only 1712 ft/sec. The C.D. formula for APC is also somewhat high, but not as much. FACEHARD 6.8 for the AP with shatter only is well within the range for its HBL, though it

gives a too high NBL. The same result using all possible projectile damage is way too high. The FACEHARD 6.8 result with an APC gives a result "right on the money". This might indicate that the projectile suffered only a rather minor damage effect from the shatter of the nose -- perhaps only the tip of the nose initially broke due to shatter, with the rest of the damage being non-shatter breakup due to not penetrating. This would make the uncapped results and a capped result not too different. Either a weak plate or a stronger-than-normal shell would do it. That is why one shot is difficult to use in this kind of analysis. The fact that the shell could start putting pieces through at its HBL at perhaps 1965 ft/sec or not much higher than that, if it had hit at that velocity, even if below the rather fuzzy NBL, means that the damage to the target predicted by FACEHARD is within the range of possible results. Again, the best we can do.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details
6" Plates (15-25% Cemented Face)										
Carp. Special	6	100	2110	PP	Thru	BB NB	Carn	Yes	Yes	Nose stuck 18" into backing. NC.
Carp. Special	6	100	2030	PP	Thru	BB NB	Carn	Yes	No	One nose piece thru. NC.
Carp. Special	6	100	1800	IP	4	BB NB NSIP	Carn	Yes	No	One TC.
Carp. Special	6	100	1800	IP	2.7	BB NB	Carn	Yes	Yes	NC.
Carp. Special	6	100	2000	IP	4	BB NB	Carn	Yes	Yes	NC.
Carp. Special	6	100	2000	IP	4.5	BB NB	Carn	Yes	Yes	Back spall. NC.
W-S. Special	6	100	1800	IP	4	BB NB	Carn	Yes	Yes	NC.
W-S. Special	6	100	2100	Hole	Thru	BB NB	Carn	Yes	Yes	Projectile all in front. Old cracks widened.
W-S. AP	6	100	2100	PP	Thru	BB NB	Carn	No	No	NC. Tip of broken nose just thru plate.
Carp. AP	6	100	2100	IP	4	BB NB NSIP	Carn	No	No	One TC. Large back spall.
Carp. AP Shell	6	100	1859	IP	<4	BB NB NSIP	Carn	No	No	NC.
Carp. AP Shell	6	100	1957	IP	<4	BB NB NSIP	Carn	No	No	NC.
Carp. AP Shell	6	~115	1986	IP	<4	BB NB	Carn	No	No	Projectile cavity filled with steel plug. NC.
W-S. AP Shell	6	100	1986	IP	<4	BB NB NSIP	Carn	No	No	NC.
Carp. AP Shell	6	100	2050	CP	Thru	BB NB	Carn	No	No	One Piece of projectile base in front. NC.
Carp. AP Shell	6	100	2122	CP	Thru	BB NB	Carn	No	No	Projectile in many small pieces. NC.
=== NBL >= 2120 (Close)										
Copper contoured nose-tip cap added (Body weight ~100 lb):										
Carp. AP Shell	6	~100.5	1986	IP	<4	BB NB NSIP	Carn	No	No	1/16" thick cap. NC.
Carp. AP Shell	6	~101.5	1957	CP	Thru	BB NB	Carn	No	No	1/4" thick cap. NC.
Carp. AP Shell	6	~101.5	1825	IP	4.5	BB NB	Carn	No	No	1/4" thick cap. NC.
Carp. AP Shell	6	~103	1796	CP	Thru	BB NB	Carn	No	No	1/2" thick cap. Hole smooth. NC.
Carp. AP Shell	6	~103	1807	IP	<4	BB NB	Carn	No	No	1/2" thick cap. NC.
Carp. AP Shell	6	~103	1821	CP	Thru	BB NB	Carn	No	No	1/2" thick cap. NC.
=== NBL = ~1800 (Close)										
Soft steel 1"-thick contoured nose-tip cap added (French type?) (Body weight ~100 lb):										
Carp. AP Shell	6	~104	1784	CP	Thru	BB NB	Carn	No	No	NC.
=== NBL < 1784										
Soft-steel Johnson cylindrical nose-tip cap added (Body weight ~97.5 lb):										
Carp. AP Shell	6	100	1785	CP	Thru	BB NB	Carn	No	No	Projectile in medium & large pieces. NC.
Carp. AP Shell	6	100	1793	CP	Thru	BB NB	Carn	No	No	Projectile in few large pieces. NC.
Carp. AP Shell	6	100	1813	Hole	**??**	BB NB	Carn	No	No	Projectile in many small pieces in front. NC.
Carp. AP Shell	6	100	1821	PP	Thru	BB NB	Carn	No	No	~Half proj. pieces in back. Rough 7" hole.
Carp. AP Shell	6	100	1825	CP	Thru	BB NB	Carn	No	No	Projectile in large pieces. Smooth hole. NC.
Carp. AP Shell	6	100	1986	CP	Thru	BB NB	Carn	No	No	Projectile in large pieces. Smooth hole. NC.
=== NBL = ~1800 (Close)										

COMPARE RESULTS TO FORMULAE:

6" Uncapped & Capped AP (Total Weight 100 lb and Body Weight ~97.5 lb):

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1443--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2079--> 1.94% low if NBL = 2120
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1840--> 2.22% high if NBL = 1800
FACEHARD 6.8: 6" AP Shell: HBL = 1698 NBL = 1819 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 6" AP Shell: HBL = 2051 NBL = 2197 EBL = NEVER (Shatter + Max Damage)-->3.63% high if NBL = 2120
FACEHARD 6.8: 6" APC Shell: HBL = 1698 NBL = 1819 EBL = 2021 (No shatter assumed)-->1.06% high if NBL = 1800

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is way too low. The C.D. formula for AP and APC are close, which implies Ensign Davis used this as one of his major data points in deriving his equations, as did I for FACEHARD 6.8. There is quite a spread of incomplete and complete penetrations, both with AP and APC projectiles, indicating a rather wide spread in plate and/or projectile quality from test to test. If you use the HBL-to-NBL range as the range of possible minimum velocity hits that can punch a hole through the plate and send chunks of the projectile through afterwards, then FACEHARD 6.8 is giving perfect results, as close as the plate and projectile quality variations allow. Note that no projectile penetrated intact here or even close to intact, capped or not. Note all that FACEHARD 6.8 gives the SAME results for shatter of an AP shell with no other damage as it does for no shatter for an APC shell, but all other damage applied (at least at right angles). In other

words, shatter is not doing anything to the projectile that the other nose damage effects are with this thin face (15-25%) -- to wit, breaking the shell apart under all conditions, penetrating or not. Only when shatter is ADDED to the other damage does the effects get worse, which is usually the case for these weak projectiles. US tests of the post-WWI Bethlehem Thin Chill (BTC) Class "A" (face-hardened) armor, with only a 20% face, showed that it was having rather little effect on the better APC shells then in use unless the obliquity of impact was raised to 40 degrees. It seems that with a face this thin as a percentage of the total face thickness, nose breakage from any cause gives similar results and the difference between shatter and other breakage effects is decreasing (at low obliquity, at least); shatter merely starts the damage here, and the later effects of trying to force its way through the plate causes most of the negative results on the ability of the nose to penetrate in a broken condition. This makes some sense because the thin face is the only thing that makes this armor different from homogeneous Ni-Steel armor and this thin face will be smashed in whether the projectile shatters on the surface or breaks it nose after penetrating a small amount into the plate, the result is the same. Only when a thick face is used (thinner Harvey armor or most KC-type armors), does the shatter on the surface or deeper into the face have a significantly different effect on penetration results, since the closer to the surface the damage is, the more the deeper face can amplify the breakage and further reduce the penetration ability of the projectile. The ductile Ni-Steel behind the face has minimal effects in increasing the damage to the nose, once the nose damage at and near the surface has set in from whatever the cause may be.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details
7" Plates (14.25-21.5% Cemented Face)										
John. AP Shot	6	103	2100	IP	3.75	BB NB NSIP	Carn	Yes	No	One TC. Face flaked.
John. AP Shot	6	103	2100	IP	~4.5	BB NB NSIP	Carn	Yes	No	One TC. Face flaked.
W-S. AP	6	100	2100	IP	5.4	BB NB NSIP	Carn	Yes	No	Several TC. Face flaked.
W-S. AP Shell	6	100	1816	IP	3	BB NB	Carn	Yes	Yes	NC.
Carp. AP Shell	6	100	1620	IP	2	BB NB	Carn	Yes	Yes	NC.
=== NBL >> 2100										
Soft-steel Johnson cylindrical nose-tip cap added (body weight ~97.5 lb):										
John. AP Shot	6	100	2100	CP	Thru	NB -- Tip	Carn	Yes	Yes	Through everything. Smooth hole. NC.
John. AP Shot	6	100	2100	CP	Thru	NB	Carn	Yes	Yes	Through everything. Smooth hole. NC.
John. AP Shot	6	100	858	IP	<0.5	BB NB	Carn	Yes	Yes	NC.
=== NBL << 2100										
Aluminum-bronze alloy Johnson cylindrical nose-tip cap added (body weight ~97.5 lb):										
John. AP Shot	6	100	2100	CP	Thru	NU	Carn	Yes	Yes	Through everything. Smooth hole. Many TC.
=== NBL << 2100										
Soft-steel Johnson cylindrical nose-tip cap added (body weight ~97.5 lb) **AT 21 DEGREES OBLIQUITY**:										
John. AP Shot	6	100	2100	Hole	5	BB NB	Carn	Yes	Yes	All projectile pieces in front. Plug thrown & imbedded in backing. One TC.
=== NBL > 2100										

COMPARE RESULTS TO FORMULAE:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1583--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2334--> Possible, but high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2081--> Too high
FACEHARD 6.8: 6" AP Shell: HBL = 1846 NBL = 1929 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 6" AP Shell: HBL = 2230 NBL = 2331 EBL = NEVER (Shatter + Max Damage)-->Possible, but high
FACEHARD 6.8: 6" APC Shell: HBL = 1891 NBL = 1977 EBL = 2197 (No shatter assumed)-->Quite possible

Capped 6" AP* at 21 Degrees Obliquity:

FACEHARD 6.8: 6" AP Shell: HBL = 1968 NBL = 2057 EBL = NEVER (Shatter only)-->Too low
FACEHARD 6.8: 6" AP Shell: HBL = 2379 NBL = 2486 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 6" APC Shell: HBL = 2267 NBL = 2369 EBL = ~2369 (No shatter assumed)-->Possible, but high

****This projectile acts like it was capped and the cap worked at 21 degrees (1 degree beyond regular soft cap functioning range with a KC plate). Thin face may allow cap to work since it only needs to work for a very short time before thin cemented surface is cracked around the nose tip, so cap pull-off occurs AFTER cap has performed its function for these plates. Even so, I would not expect a soft cap to work much over 20 degrees against this armor.***

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is way too low. The C.D. formula for AP is quite possible, though it seems slightly high, while the result for APC is much too low, given the holes in the plate. There is no "lid" for the AP tests, since none of them completely penetrate and the deepest was only about 3/4th through the plate. I would give the NBL at around 2200-2250 ft/sec based on this small sample. The APC tests have essentially no "bottom" in that 858 ft/sec is obviously way below the HBL. The NBL could be as far down as 1500 ft/sec or so, though from the 6" plate tests (assuming these 7" plates are of similar quality), the HBL is going to be closer to 1900-2000 ft/sec. FACEHARD 6.8 with no shatter gives a perfect fit. As with the 6" plate, shatter with no other damage is obviously not happening, since these values imply that such a situation gives BETTER penetration than if no shatter occurs, which may be true at high obliquity, where shatter inhibits ricochet, but cannot possibly be correct at a right angles impact. If you add all possible damage, the effects seem to be somewhat high -- though, interestingly, the AP shell NBL results for FACEHARD 6.8 and the C.D. formula are almost identical. These shattered AP shell NBL values may be correct, as there is no information contradicting them. For the 21-degree obliquity test, the single impact punched a hole -- there is nothing to

state it was big enough to comply with the HBL requirement, though -- but no pieces went through whatsoever, so it seems that this impact was significantly below the HBL, since from my other data, SOME pieces of the projectile should go through the plate at the HBL if the projectile nose is broken into small pieces, as seems to be the case here. The depth of the pit in the face indicated that the projectile nose only made it 5" into the plate before rebounding like a cue-ball after hitting another ball on a pool table. This rebound effect on the nose is one of the main reasons that there is such a gap between the HBL and the NBL; a mass of the nose material equal in weight to the ejected plug is thrown backward into the projectile body at the HBL at the same speed and must be stopped and re-accelerated forward by the remaining mass of the shell, which slows the whole shell down noticeably on top of the energy lost to the plate in making the hole and plug in the first place and requires extra velocity (energy) to be able to finish the hole in the plate and still have some energy available to get the whole projectile itself through at the NBL (it does not matter if the nose stays attached to the body or not, the laws of physics are the same). Here, it seems that the cap worked and allowed a hole to be punched in the plate, but it did not prevent the projectile from being completely broken up in the process, which used up so much energy that there was nothing left for even a few small pieces to get through the plate. The FACEHARD 6.8 values for no shatter and shatter with all other damage seem to be high, but, again, nothing contradicts them, so they can be used without any real challenge, as of now. FACEHARD uses the shattered-with-full-other-damage effects in its predictions, which is the worst case scenario.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details

8" Upper Flat/8-4" Lower Tapered Plate & UNKNOWN THICKNESS @ Impact

Holt. AP	6	100	2149	IP	7	BB NB NSIP	Carn	No	No	NC.

=== NBL > 2149

COMPARE RESULTS TO FORMULAE:

6" Uncapped AP (100 lb) ***(Assume body weight of 97.5 lb for capped projectile. Doing uncapped comparison only.)*:**

TRIAL #1: Assumed hit at 8" thickness (12.5-19% Cemented Face)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1724--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2580--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2316--> Possible, but high
FACEHARD 6.8: 6" AP Shell: HBL = 1911 NBL = 1951 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 6" AP Shell: HBL = 2309 NBL = 2357 EBL = NEVER (Shatter + Max Damage)-->Quite possible, but high
FACEHARD 6.8: 6" APC Shell: HBL = 2009 NBL = 2051 EBL = 2279 (No shatter assumed)-->Too low

TRIAL #2: Assumed hit at 7" thickness (14.25-21.5% Cemented Face)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1583--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2334--> Possible, but high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2081--> Too low
FACEHARD 6.8: 6" AP Shell: HBL = 1846 NBL = 1929 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 6" AP Shell: HBL = 2230 NBL = 2331 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 6" APC Shell: HBL = 1891 NBL = 1977 EBL = 2197 (No shatter assumed)-->Way too low

TRIAL #3: Assumed hit at 6" thickness (15-25% Cemented Face)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1443--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2079--> Way too low
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1840--> Way too low
FACEHARD 6.8: 6" AP Shell: HBL = 1698 NBL = 1819 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 6" AP Shell: HBL = 2051 NBL = 2197 EBL = NEVER (Shatter + Max Damage)-->Too low
FACEHARD 6.8: 6" APC Shell: HBL = 1698 NBL = 1819 EBL = 2021 (No shatter assumed)-->Way too low
NOTE: 6" is barely thin enough so that the back would not have cracked open when it bulged; no thinner.

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is way too low. The C.D. formula for AP is way too high, while the result for APC is possible, if somewhat high, given the deep penetration into the plate. There is no "lid" for the AP test, since no complete penetration test is given and the hole is nearly through the plate (it may be entirely through the original plate volume, being only stopped by the backward bulge of the ductile main plate body). I would give the HBL at around 2200-2250 ft/sec based on this test, with the NBL somewhat higher. A plate thickness between 7" and 8" seems to give results that match FACEHARD 6.8 computations closest.

8" Plates (12.5-19% Cemented Face)

Whlr. AP	8	250	1701	IP	3.5	BB NB NSIP	Carn	No	No	Projectile pulverized. Plate dished 0.5". NC.
Midv. AP Exprmntl	8	250	1689	IP	7	BC NB NSIP	Carn	No	No	Projectile body cracked lengthwise. 4"x15" back bulge. Face flaked. One FC & one TC.
Midv. AP Exprmntl	8	250	1799	IP	8.5	BU NB - Tip	Carn	No	No	Proj, 6.5" shorter. 3.5"x21" back bulge, split open 9" wide. Face flaked. No new cracks.

NOTE: ***These projectiles are the beginning of the development that led to the 1916 'MIDVALE UNBREAKABLE' shells.***

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details
Carp. AP Shell	8	250	1700	IP	4	BB NB NSIP	Carn	No	No	Projectile in 10 pieces. 2.25"x~8" back bulge. Face dish 1" x 48". Several FC.
Carp. AP	8	250	1900	CP	Thru	BB NB	Carn	No	No	No more cracks.
Carp. AP	8	250	1800	IP	6	BB NB NSIP	Carn	No	No	Projectile pulverized. Two TC.
Whlr. AP	8	251	1800	IP	8	BB NB NSIP	Carn	No	No	Projectile pulverized. Several TC.
Whlr. AP	8	251	1900	IP	7	BB NB NSIP	Carn	No	No	Projectile pulverized. Several TC.
W-S. AP	8	252	1900	CP	Thru	NB -- Tip	Carn	No	No	NC.
W-S. AP	8	251	1900	CP	Thru	BsB	Carn	No	No	Projectile broke across at driving band. NC.
W-S. AP	8	251	1900	CP	Thru	None	Carn	No	No	NC.
W-S. AP Hvy Expr	8	260	2057	CP	Thru	BB NB	Carn	No	No	Broken plug 17" wide thrown. No other cracks.
W-S. AP Exprmntl	8	250	1900	CP	Thru	BB NB	Carn	No	No	Projectile pulverized. Many TC.
Carp. AP	8	250	1900	CP	Thru	BC NC	Carn	No	No	Plate broke in two through hole.
Carp. AP	8	250	1900	CP	Thru	BB NB	Carn	No	No	Projectile pulverized. No more cracks.
Carp. AP	8	250	1900	CP	Thru	BB NB	Carn	No	No	Projectile in 15 pieces. Broken plug thrown. Face flaked.
Carp. AP	8	250	1900	CP	Thru	BB NB	Carn	No	No	Projectile pulverized but all through. NC.

=== NBL =< 1875 (Close)

COMPARE RESULTS TO FORMULAE:

8" Uncapped AP (250 lb) ***(Assume body weight of 244 lb for capped projectile. Doing uncapped comparison only.)*****:**

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1396--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1884--> 0.48% high if NBL = 1875
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1691--> Way too low
FACEHARD 6.8: 8" AP Shell: HBL = 1491 NBL = 1522 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 8" AP Shell: HBL = 1804 NBL = 1841 EBL = NEVER (Shatter + Max Damage)-->1.81% low if NBL = 1875
FACEHARD 6.8: 8" APC Shell: HBL = 1602 NBL = 1569 EBL = 1780 (No shatter assumed)-->Way too low

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is way too low. The C.D. formula for AP is perfect, while the result for APC is way too low. The FACEHARD 6.8 prediction is very slightly low, but well within the possible error in the NBL result. I assume that this was also one of the test results Ensign Davis used to calibrate his formula for AP impacts. Note that the Midvale projectiles deformed and cracked, but did not break up or shatter, though this did not make them act as penetrators any better than the more brittle shells.

10" Plates (10-15% Cemented Face)

Holt. AP	8	250	2076	IP	10	BB NB NSIP	Beth	Yes	No	Shallow dish. Face flaked. NC.
Holt. AP	8	251	1950	IP	~6.5	BB NB NSIP	Carn	No	No	Shallow dish. Face flaked. One TC.
W-S. AP	8	251	2080	IP	~7.3	BB NB NSIP	Carn	No	No	Projectile pulverized. Face flaked. One TC.
Carp. AP	8	250	2064	IP	~7.3	BB NB NSIP	Carn	No	No	One TC.
Carp. AP Shell	8	250	2064	IP	<4	BB NB	Carn	No	Yes	Projectile pulverized. One TC.

=== NBL > 2100

Soft-steel Johnson cylindrical nose-tip cap added (body weight ~97.5 lb):

John. AP Shot	6	100	2100	IP	7	BU NB NSIP	Carn	No	Yes	Proj. shortened. Old cracks widened; none new.
John. AP Shot	6	100	2505	CP	Thru	BsB BC	Carn	No	Yes	Through everything. Projectile body slightly distorted. Base broke diagonally to driving band. Smooth hole. No new cracks.

=== NBL > 2100 & << 2500

COMPARE RESULTS TO FORMULAE:

8" Uncapped AP (250 lb) ***(Assume body weight of 244 lb for capped projectile. Doing uncapped comparison only.)*****:**

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1443--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2227--> Possible & close to limit
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2022--> Way too low
FACEHARD 6.8: 8" AP Shell: HBL = 1727 NBL = 1763 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 8" AP Shell: HBL = 2089 NBL = 2132 EBL = NEVER (Shatter + Max Damage)-->Slightly low but possible
FACEHARD 6.8: 8" APC Shell: HBL = 1817 NBL = 1855 EBL = 2060 (No shatter assumed)-->Way too low

6" Capped AP (Total weight 100 lb and body weight ~97.5 lb) ***(Doing capped comparison only.)*****:**

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1989--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 3049--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2768--> Way too high
FACEHARD 6.8: 6" AP Shell: HBL = 2213 NBL = 2259 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 6" AP Shell: HBL = 2673 NBL = 2728 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 6" APC Shell: HBL = 2326 NBL = 2374 EBL = 2638 (No shatter assumed)-->Quite possible

DISCUSSION: The homogeneous armor formula using 1890 Ni-Steel is way too low for either projectile. The C.D. formula for the 8" AP is good, though a little high, while the result for 6" APC is way too low. The FACEHARD 6.8 prediction for the 8" AP is a little low, but well within the possible error in the NBL result, while for the 6" APC, the FACEHARD 6.8 unshattered penetration result is very reasonable.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details

18" Upper Flat/18-8" Lower Tapered Plates & ~11" at Impact (9-13.7% Cemented Face)

W-S. AP	13	1100	1942	CP	Thru	BB NB	Carn	No	Yes	Through everything. Right side of plate broken up; backing crushed. All bolts bent.

=== NBL << 1942

COMPARE RESULTS TO FORMULAE:

(Assume body weight of 1075 lb for capped projectile. Doing uncapped comparison only.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1149--> Somewhat low but possible
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1454--> Quite possible
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1326--> Somewhat low but possible
FACEHARD 6.8: 13" AP Shell: HBL = 1214 NBL = 1239 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 13" AP Shell: HBL = 1468 NBL = 1498 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 13" APC Shell: HBL = 1277 NBL = 1304 EBL = 1448 (No shatter assumed)-->Low but possible

DISCUSSION: There is no bottom to this single test result and the shell broke up, but went through everything at a high speed. Thus, all results here are possible, though some are rather low. This is the best we can do here.

12" Upper Flat/12-7" Lower Tapered Plate & UNKNOWN THICKNESS @ Impact

Carp. AP	13	1100	1473	IP	~9	BB NB NSIP	Beth	No	No	Projectile pulverized. Left side broken off plate through hole. Many TC. Face flaked.
Carp. AP	13	1100	1650	IP	~8	BB NB NSIP	Beth	No	No	Projectile pulverized. Plate left upper corner broke off thru hole. Many TC. Face flaked.
Carp. AP	13	1100	1810	CP	Thru	None	Beth	No	No	Dish 2" x (?). One TC.

=== NBL > 1650 & < 1810 (= ~1750 would be close)

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 1075 lb for capped projectile. Doing uncapped comparison only.)

TRIAL #1: Assumed hit at 12" thickness (8-12.5% Cemented Face)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1213--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1552--> Way too low
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1421--> Way too low
FACEHARD 6.8: 13" AP Shell: HBL = 1277 NBL = 1304 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 13" AP Shell: HBL = 1546 NBL = 1578 EBL = NEVER (Shatter + Max Damage)-->9.82% low if NBL = 1750
FACEHARD 6.8: 13" APC Shell: HBL = 1345 NBL = 1373 EBL = 1525 (No shatter assumed)-->Way too low

TRIAL #2: Assumed hit at 11" thickness (9-13.8% Cemented Face)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1149--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1454--> Way too low
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1326--> Way too low
FACEHARD 6.8: 13" AP Shell: HBL = 1214 NBL = 1239 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 13" AP Shell: HBL = 1468 NBL = 1498 EBL = NEVER (Shatter + Max Damage)-->Way too low
FACEHARD 6.8: 13" APC Shell: HBL = 1277 NBL = 1304 EBL = 1448 (No shatter assumed)-->Way too low

DISCUSSION: These results from all formulae are too low even for the maximum 12" plate thickness, but FACEHARD 6.8 with shatter-and-all-other-damage comes closest for the 12" thickness. Either these 13" AP projectiles were inferior to the average in damage resistance or the plate was stronger than average (or both, perhaps).

12" Plates (8-12.5% Cemented Face)

Whlr. AP	12	850	1769	CP	Thru	None	Beth	No	No	Corner broken off plate. Many TC.
Whlr. AP	12	850	1787	CP	Thru	BB NB	Beth	No	No	Projectile broke into 6 pieces. Corner broken off plate. Many TC.
Carp. AP	12	850	1800	CP	Thru	BB NB	Beth	No	No	Projectile pulverized. Plate right half broke apart; held on by bolts. Several TC.
Whlr. AP	12	850	1800	CP	Thru	BB NB	Carn	No	No	Projectile pulverized & only 6 tiny pieces in front. Corner broken off plate. Several TC.
Carp. AP	12	850	1800	CP	Thru	BB NB	Carn	No	No	SAME AS ABOVE. More pieces broken off plate.
Carp. AP	12	850	1800	CP	Thru	BB NB	Carn	No	No	Projectile pulverized. Plate broke apart; held on by bolts.
Whlr. AP	12	850	1800	CP	Thru	BB NB	Carn	No	No	SAME AS ABOVE.
Holt. AP	12	850	1811	PP	Thru	BB NB	Carn	No	Yes	Projectile pulverized & most in front. Dished 0.75" x (?). Cylindrical plug thrown, but remained in backing. NC.
W-S. AP	12	850	1769	CP	Thru	BB NB	Carn	No	Yes	Projectile pulverized & little in front. NC.

=== NBL < 1769 (Close)

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details
Soft-steel Johnson cylindrical nose-tip cap added (body weight ~487 lb):										
John. AP Shot	10	500	1600	IP	9	BB NB	Carn	No	Yes	Plate broke apart; held on by bolts.
=== NBL >> 1600										

COMPARE RESULTS TO FORMULAE:

12" Uncapped AP (Weight 850 lb)*(Assume Body Weight 829 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1307--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1696--> Possible but slightly low
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1554--> Too low
FACEHARD 6.8: 12" AP Shell: HBL = 1372 NBL = 1401 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1660 NBL = 1694 EBL = NEVER (Shatter + Max Damage)-->3.2% low if NBL = 1750
FACEHARD 6.8: 12" APC Shell: HBL = 1444 NBL = 1474 EBL = 1638 (No shatter assumed)-->Way too low

10" Capped AP (Total Weight 500 lb and Body Weight ~487 lb) *(Doing capped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1494--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2019--> Too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1849--> Quite possible
FACEHARD 6.8: 10" AP Shell: HBL = 1599 NBL = 1632 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 10" AP Shell: HBL = 1930 NBL = 1970 EBL = NEVER (Shatter + Max Damage)-->Possible but high
FACEHARD 6.8: 10" APC Shell: HBL = 1679 NBL = 1714 EBL = 1904 (No shatter assumed)-->Quite possible

DISCUSSION: The 12" AP results match FACEHARD 6.8 shatter-with-all-other-damage close enough to be possible due to test-to-test spread, they are also almost exactly what the C.D. AP formula gives, too. The 10" APC results from FACEHARD 6.8 are well within the possible values range, though there is no lid to this test to give the maximum that the NBL could be, as is the C.D. APC results, though they differ considerably.

12.5" Plate (8-12% Cemented Face)

Carp. AP	12	850	1932	Hole	10.5	BB NB	Carn	Yes	Yes	Projectile pulverized; all pieces in front. Conical plug thrown into backing. Plate broken into 3 pieces through hole.
=== NBL > 1950										

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 829 lb for capped projectile. Doing uncapped comparison only.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1334--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1749--> Way too low
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1605--> Way too low
FACEHARD 6.8: 12" AP Shell: HBL = 1405 NBL = 1434 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1699 NBL = 1734 EBL = NEVER (Shatter + Max Damage)-->Way too low
FACEHARD 6.8: 12" APC Shell: HBL = 1478 NBL = 1509 EBL = 1676 (No shatter assumed)-->Way too low

DISCUSSION: All formulae are well below the NBL for this plate against this AP projectile. Even the HBL is probably above any of the values given here. This plate seems to be extra-strong or the single projectile used was inferior to most. This is about the best we can do here.

13" Plates (7.5-11.5% Cemented Face)

W-S. AP	12	850	1800	CP	Thru	BB NB	Carn	No	No	Projectile pulverized. Conical plug thrown. Upper right corner broken off plate.
W-S. AP	12	850	1800	CP	Thru	None	Carn	No	No	Several TC. Lower right corner broken off plate.
Carp. AP	12	844.5	1800	CP	Thru	BB NB	Carn	No	No	Projectile pulverized. Right half of plate broken apart.
Whlr. AP	12	850	1800	CP	Thru	BB NB	Carn	No	No	Projectile pulverized. Many TC. Pieces broken off plate.
Whlr. AP	12	850	1800	CP	Thru	None	Carn	No	No	Plate broken into several pieces.
=== NBL < 1800										

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 829 lb for capped projectile. Doing uncapped comparison only.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1368--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1801--> High
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1515--> Possible but low
FACEHARD 6.8: 12" AP Shell: HBL = 1436 NBL = 1466 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1736 NBL = 1772 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 12" APC Shell: HBL = 1511 NBL = 1542 EBL = 1713 (No shatter assumed)-->Possible but low

DISCUSSION: The AP results from FACEHARD 6.8 shatter-with-all-other-damage is reasonable, though there is no bottom to the tests to limit how low the NBL might be. The C.D. AP result is somewhat higher than the NBL has to be. All other values are from too low to way to low. This is about the best we can do here.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details
14" Plates (7-11% Cemented Face)										
Carp. AP	10	500	1930	IP	~9.5	BB NB NSIP	Carn No	No		Face flaked over 24" diameter area. NC.
=== NBL >> 1930										
+++										
W-S. AP	12	850	1858	CP	Thru	NB -- Tip	Carn No	No		Face flaked slightly. Hole smooth. NC.
Carp. AP	12	850	1858	CP	Thru	BB NB	Carn No	No		Rough hole 14.5" wide. One TC.
W-S. AP	12	850	2037	CP	Thru	BB NB	Carn No	No		Hole smooth. NC.
W-S. AP	12	850	2000	CP	Thru	BB NB	Carn No	Yes		Several TC.
W-S. AP	12	850	1800	Hole	17	BB NSIP	Carn No	Yes		Near NBL. Proj. nose intact. One TC. Many FC.
=== NBL = ~1825										
+++										
W-S. AP	13	1100	1800	CP	Thru	NB -- Tip	Carn No	Yes		NC.
=== NBL < 1800										

COMPARE RESULTS TO FORMULAE:

10" Uncapped AP (Weight 500 lb)*(Assume Body Weight 487 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1649--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2266--> Quite possible
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2092--> Quite possible
FACEHARD 6.8: 10" AP Shell: HBL = 1732 NBL = 1768 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 10" AP Shell: HBL = 2092 NBL = 2135 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 10" APC Shell: HBL = 1820 NBL = 1858 EBL = 2064 (No shatter assumed)-->Way too low

12" Uncapped AP (Weight 850 lb)*(Assume Body Weight 829 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1434--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1904--> Too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1558--> Way too low
FACEHARD 6.8: 12" AP Shell: HBL = 1491 NBL = 1522 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1804 NBL = 1841 EBL = NEVER (Shatter + Max Damage)-->0.88% high if NBL = 1825
FACEHARD 6.8: 12" APC Shell: HBL = 1569 NBL = 1602 EBL = 1780 (No shatter assumed)-->Way too low

13" Uncapped AP (Weight 1100 lb) *(Assume Body Wt. 1075 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1330--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1742--> Quite possible
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1608--> Possible but low
FACEHARD 6.8: 13" AP Shell: HBL = 1392 NBL = 1421 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 13" AP Shell: HBL = 1683 NBL = 1718 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 13" APC Shell: HBL = 1465 NBL = 1495 EBL = 1661 (No shatter assumed)-->Possible but very low

DISCUSSION: The FACEHARD 6.8 results for the 10", 12", and 13" AP shells are quite reasonable, while only the C.D. 10" and 13" AP results are in agreement with the single impact in each case. While the 12" AP results are rather solid, the 10" and 13" AP shell results are only based on a single impact each, so they are not the most reliable data. This is about the best we can do here.

18" Upper Flat /18-8" Lower Tapered Plate & 14.4" @ Impact (6.8-10.5% Cemented Face)										
Carp. AP	13	1100	1800	CP	Thru	BB NB	Beth No	Yes		Pieces buried in sand butte. Several TC.
Carp. AP	13	1100	1800	CP	Thru	BB NB	Beth No	Yes		SAME AS ABOVE.
=== NBL << 1800										

COMPARE RESULTS TO FORMULAE:

(Assume Body Weight 1075 lb for capped projectile. Doing uncapped comparison only.)

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1354--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1779--> Too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1645--> Quite possible
FACEHARD 6.8: 13" AP Shell: HBL = 1413 NBL = 1442 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 13" AP Shell: HBL = 1708 NBL = 1743 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 13" APC Shell: HBL = 1486 NBL = 1517 EBL = 1685 (No shatter assumed)-->Possible but low

DISCUSSION: The FACEHARD 6.8 AP result for shatter-and-all-other-damage is quite reasonable, as is the C.D. AP result, since we do not have bottom on this test series to limit how low the NBL might be. This is about the best we can do here.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details

15" Plate (6.5-10% Cemented Face)

Carp. AP Shell	10	500	1539	IP	3	BB NB	Beth	Yes	Yes	Projectile pulverized. NC.
Carp. AP Shell	10	500	1940	IP	5	BB NB	Beth	Yes	Yes	SAME AS ABOVE.
=== NBL >> 1940										
+++										
W-S. AP	12	850	1701	IP	11.5	BB NB	Beth	Yes	Yes	One TC.
=== NBL > 1750										
Soft-steel Johnson cylindrical nose-tip cap added (body weight ~829 lb):										
W-S. AP Shell	12	850	2000	CP	Thru	BB NB	Beth	Yes	Yes	Through everything. Several TC.
=== NBL << 2000										
Soft-steel Johnson cylindrical nose-tip cap added (body weight ~829 lb) ***AT 21 DEGREES OBLIQUITY***:										
John. AP Shot	12	850	2000	CP	Thru	BB NB	Beth	Yes	Yes	Through everything. Smooth 12" x 12.25" oval hole. Many TC.
== NBL << 2000										

COMPARE RESULTS TO FORMULAE:

10" Uncapped AP (Weight 500 lb)*(Assume Body Weight 487 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1723--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2386--> Possible but high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2211--> Quite possible
FACEHARD 6.8: 10" AP Shell: HBL = 1795 NBL = 1832 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 10" AP Shell: HBL = 2165 NBL = 2210 EBL = NEVER (Shatter + Max Damage)-->Quite possible
FACEHARD 6.8: 10" APC Shell: HBL = 1884 NBL = 1923 EBL = 2137 (No shatter assumed)-->Way too low

12" Uncapped & Capped AP (Total Weight 850 lb and Capped Projectile Body Weight ~829):

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1499--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2005--> Quite possible for AP
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 1857--> Quite possible for both
FACEHARD 6.8: 12" AP Shell: HBL = 1545 NBL = 1577 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1867 NBL = 1906 EBL = NEVER (Shatter + Max Damage)-->Quite possible for AP
FACEHARD 6.8: 12" APC Shell: HBL = 1625 NBL = 1659 EBL = 1843 (No shatter assumed)-->Quite possible for APC

12" Capped* at 21 Degrees Obliquity:

FACEHARD 6.8: 12" AP Shell: HBL = 1647 NBL = 1681 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1991 NBL = 2032 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 12" APC Shell: HBL = 1923 NBL = 1963 EBL = ~1963 (No shatter assumed)-->Possible but high

****This projectile acts like it was capped and the cap worked at 21 degrees (1 degree beyond regular soft cap functioning range with a KC plate). Thin face may allow cap to work since it only needs to work for a very short time before thin cemented surface is cracked around the nose tip, so cap pull-off occurs AFTER cap has performed its function for these plates. Even so, I would not expect a soft cap to work much over 20 degrees.***

DISCUSSION: The FACEHARD 6.8 AP and APC results for all of the tests are reasonable, as is the C.D. AP and APC results for the applicable shells. We do not have bottom or top values for any of these test series to box in the results, so this has to be guessed at. The 21-degree APC test acted as if the AP cap worked perfectly, and the projectile seems to have broken up, but penetrated the plate as if it was intact. This implies that these soft AP caps are working fine even at slightly higher obliquities than they work for KC-type armors. The caps do not have to work very long here; just long enough to crack the thin cemented surface layer. If the projectiles are shattering at 21 degrees, it does not seem to be affecting their penetration much! This is about the best we can do here.

18" Upper Flat/18-8" Lower Tapered Plate & 16" at Impact (6.4-9.5% Cemented Face)

W-S. Common*	13	1100	1942	IP	~7	BB NB NSIP	Carn	Yes	No	Projectile pulverized. Plate broken in 4 pieces through impact and fell to ground.
=== NBL >> 2000										

****This projectile did not have a chilled (hardened) nose and it had a large cavity (~4-6% filler weight).***

COMPARE RESULTS TO FORMULAE:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1448--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 1925--> Way too low
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = ***NOT APPLICABLE HERE***
FACEHARD 6.8: 13" AP Shell: HBL = 1849 NBL = 1887 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 13" AP Shell: HBL = 2232 NBL = 2278 EBL = NEVER (Shatter + Max Damage)-->Possible but low
FACEHARD 6.8: 13" APC Shell: HBL = 1942 NBL = 1982 EBL = 2202 (No shatter assumed)-->***NOT APPLICABLE HERE***

DISCUSSION: The C.D. shattered AP shell result is way too low. The FACEHARD 6.8 shatter-with-all-other-damage result for AP is possible, though probably too low due to the fragility of the shell. Note how the collapse of the shell delivered such a wide-spread, violent punch that it cracked the plate apart, but didn't penetrate.

Projectile ID	Dm	Weight	Vel.	Pen	Dpth	Proj Damage	Man.	Cv?	Bk?	Damage Details

17" Plates (5.8-9% Cemented Face)

Midv. AP Shell	10	500	1983	IP	20	BU NU	Carn	Yes	Yes	Projectile shortened. Several TC.
Midv. AP Shell	10	500	1983	IP	12.5	BO BU NU	Carn	Yes	Yes	Projectile bent & shortened. More TC.

NOTE: ***These projectiles are the beginning of the development that led to the 1916 'MIDVALE UNBREAKABLE' shells. Deformed MIDVALE 10" AP acts like broken non-Midvale APC here; neither shatter.***

=== NBL >= 2000 (Close)

+++

Carp. AP Shell	12	850	1410	IP	15	None	Carn	Yes	Yes	NC.
W-S. AP Shell	12	850	1858	CP	Thru	None	Carn	Yes	Yes	Through everything. NC.
Carp. AP Shell	12	850	1858	IP	20	BB NB	Carn	Yes	Yes	One TC.
Carp. AP Shell	12	850	1858	IP	19	BB NB	Carn	Yes	Yes	Opened up existing TC.
W-S. AP	12	850	1858	CP	Thru	None	Carn	Yes	Yes	NC.
W-S. AP	12	850	1858	IP	9.5	BB NB	Carn	Yes	Yes	Two TC.
Carp. AP	12	850	1858	IP	9.5	BB NB	Carn	Yes	Yes	One more TC.
Carp. AP	12	850	1838	IP	15	BB NB	Beth	Yes	Yes	One TC.

=== NBL >= 1600 (if no proj. damage) & = ~1875 (if proj. broken)

Soft-steel Johnson cylindrical nose-tip cap added (body weight ~475 lb):

John. AP Shot	10	500	1983	Hole	20	BsB SIP	Carn	Yes	Yes	Near NBL. Widened existing TC.

=== NBL = ~2000

COMPARE RESULTS TO FORMULAE:

10" Uncapped & Capped AP(Total Weight 500 lb & Capped Body Weight ~487 lb)*(For capped only; no shatter data.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1867--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2621--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2443--> Way too high
FACEHARD 6.8: 10" AP Shell: HBL = 1898 NBL = 1937 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 10" AP Shell: HBL = 2290 NBL = 2337 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 10" APC Shell: HBL = 1993 NBL = 2034 EBL = 2250 (No shatter assumed)-->1.7% high if NBL = 2000

12" Uncapped AP (Weight 850 lb)*(Assume Body Weight 829 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1624--> Quite possible w/o shatter
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2202--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2053--> Way too high
FACEHARD 6.8: 12" AP Shell: HBL = 1633 NBL = 1667 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 1975 NBL = 2016 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 12" APC Shell: HBL = 1718 NBL = 1754 EBL = 1949 (No shatter assumed)-->Halfway between intact & shattered shells

DISCUSSION: The C.D. values are all way too high. The FACEHARD 6.8 12" AP value for no shatter is right in the middle between the shatter case with the NBL about 1875 ft/sec and the unshattered case at about 1600 ft/sec. It seems that with the face this thin compared to the plate size, shatter only happens about half the time even without an AP cap on the projectile. FACEHARD handles this by splitting the difference between them -- actually, each should be given and the user flip a coin for each hit to see which to use. The 10" test results show this too: The Midvale AP shells are deforming, but act exactly like they had an AP cap, in that they match the Johnson capped AP Shot as to NBL exactly. Harvey armor is getting rather weak in the face at this thickness. Note that the M79APCLC result works for the non-shatter 12" AP shell (50% chance), indicating that the Ni-Steel under the thin face is the strength as the 1890 Ni-Steel used to create the DeMarre Formula, not any improved kind of steel.

18" Upper Flat/18-8" Lower Tapered Plate & 18" at Impact (5.5-8.5% Cemented Face)

John. AP Shot	12	845	1926	IP	~9	BB NB NSIP	Beth	Yes	Yes	Several TC.
Carp. AP Shell	12	850	1465	IP	11	BB NB	Beth	Yes	Yes	NC.
Carp. AP Shell	12	850	1926	IP	17	BB NB NSIP	Beth	Yes	No	One TC.
W-S. AP Shell	12	850	1926	IP	15	BB NB NSIP	Beth	Yes	No	Several TC.

=== NBL > 1950 (= 2000-2025 would be close)

Soft-steel Johnson cylindrical nose-tip cap added (body weight ~475 lb):

John. AP Shot	10	500	1983	IP	15.6	BB NB	Carn	Yes	Yes	Projectile broken into 5 undistorted pieces. Pieces broken off plate.

=== NBL > 2000 (= ~2100 would be close)

COMPARE RESULTS TO FORMULAE:

10" Capped AP (Total Weight 500 lb and Body Weight ~487 lb) (*Doing capped comparison only.*):

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1936--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2736--> Way too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2558--> Way too high
FACEHARD 6.8: 10" AP Shell: HBL = 1941 NBL = 1981 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 10" AP Shell: HBL = 2342 NBL = 2390 EBL = NEVER (Shatter + Max Damage)-->Way too high
FACEHARD 6.8: 10" APC Shell: HBL = 2038 NBL = 2080 EBL = 2311 (No shatter assumed)-->0.95% low if NBL = 2100

12" Uncapped AP (Weight 850 lb)*(Assume Body Weight 829 lb for capped projectile. Doing uncapped comparison only.)*:

M79APCLC w/Q(Armor)= 0.76 & % El.= 20 (Ni-Steel & no projectile damage): NBL = 1684--> Way too low
Cleland Davis Uncapped AP Versus Harveyized Ni-Steel: NBL = 2299--> Too high
Cleland Davis Capped AP Versus Harveyized Ni-Steel: NBL = 2149--> Possible but rather high
FACEHARD 6.8: 12" AP Shell: HBL = 1670 NBL = 1705 EBL = NEVER (Shatter only)--><Not applicable>
FACEHARD 6.8: 12" AP Shell: HBL = 2020 NBL = 2062 EBL = NEVER (Shatter + Max Damage)-->1.83% high if NBL = 2025
FACEHARD 6.8: 12" APC Shell: HBL = 1758 NBL = 1794 EBL = 1993 (No shatter assumed)-->Way too low

DISCUSSION: The C.D. values are all too high. The FACEHARD 6.8 12" AP value for shatter-with-all-other-damage is "right on the money". Ditto for the FACEHARD 6.8 10" APC value for no shatter.

END OF HARVEYIZED Ni-STEEL ARMOR DATA

SOME KRUPP CEMENTED (KC a/A) ARMOR TEST RESULTS
VERSUS GERMAN KRUPP AP SHOT/SHELL & FRENCH ST. CHAMOND AP SHOT/SHELL
(From the Last Page in the Article)

INTRODUCTION

"SCALING" is the change in the NBL due to merely changing the size of the projectile and plate in step, keeping their designs and metallurgical properties the same. For example, replacing a 6" projectile and a 6" plate with identical (except for size) 12" projectile and 12" plate. This change is almost always downward as size goes up.

The scaling effect is caused by several factors:

(1) The fact that the crystals in the steel do not change their size, so the proportion of surface area sticking them together versus the forces within the crystals (usually much stronger) change. The smaller the plate, the bigger the crystals are in proportion and the less surface between them (down to the point of a microscopic plate made up of one crystal!). This crystal-caused effect is rather small for the large plates used in real vehicles and ships, but is evident in all armors, homogeneous and ductile (can bend and tear) or hard and brittle (break suddenly). For this reason, the armor has to be made progressively softer (and, thus weaker, since hardness and strength track rather closely as long as the plate is not breaking in a brittle manner) as the scale increases to keep it from getting too brittle under projectile impact (cracks through too easily), which gradually causes the heavier armor to lose some resistance.

(2) The fact that the brittle materials crack along surfaces (once a crack starts in such a material it tends to self-propagate unless somehow the tip of the crack is locked up). This lockup can be due to reducing stress points (curves instead of corners at edges, using nickel in the steel to replace iron at many points in the crystals, so that the sudden change in metal acts like a piece of cloth in a zipper and jams the crack tip, and so forth) or changing the metal properties so that the material that the crack tip enters is ductile and soft (relatively) and spreads the force on the crack tip, stopping it (an extreme example is that Jello does not crack!). Since a face-hardened plate has the face very hard and rigid, it does not resist cracking too well and the force from a sudden impact can cause the hard face to crack unless there is somewhere for the energy to go. The back layer, if properly made, will allow the shock-wave from the impact to move into it with no sudden changes that can start cracks, only failing if the energy is great enough to begin tearing out the back surface as it reflects back into the plate there (there is no place for most of the shock-wave to go at that point but back into the plate moving toward the face again). This takes a lot more shock energy than the hard face would require to split it open. This problem is compounded by the fact that the energy goes up in step with the weight of the projectile -- that is, with the cube of the increasing dimensions for exactly scaled tests -- but the surfaces that are cracking can only increase in size with the increase in surface area of the impact site -- that is, with the square of the increasing dimensions -- so the larger tests simply pour more energy into the cracks at the same rate (same speed of impact), causing the cracks to go farther before they can be slowed or stopped. The thicker the hard, brittle face layer in a face-hardened plate in proportion to it total thickness (the deeper the "chill"), the more this cracking can grow before the ductile back layer can disperse the remaining energy. This means that the thicker the face, the worse the plate resistance becomes for scaled tests with large projectiles hitting scaled-up plates. Conversely, with smaller scales, this works in reverse and can make thick-faced plates stronger against small projectiles which have much less weight and, thus, energy at a given striking velocity.

(3) The method of plate failure is crucially important. For hard materials struck in their face with enough energy to punch through, the entire face will be punched out a roughly cylindrical plug like a cork from a wine bottle, tearing out the back layer in a cone shape (usually) in a thick-faced face-hardened plate as the face acts like a billiard cue ball hit by the player, with the backing layer acting like the numbered billiard ball. However, in this case, the cue ball and the numbered ball fuse together and exit the plate back at a reduced velocity (due to the increased weight of this one large mass), though it may break apart as it exits the plate back, of course. The continued force of the projectile on the face ensures that nothing (except some surface flakes, perhaps) can move in that direction, focusing this cork effect into a narrow cone or cylinder directly in front of the projectile nose, at least a low obliquity (near right angles). While this cork effect puts a very large stress on the projectile nose tip, which must essentially stop cold as its energy is transferred to the face layer and, eventually, the entire plug of face plus back layer -- increasing the chance of the projectile nose shattering into pieces or suffering some other drastic damage, which usually reduces the ability of the projectile to continue trying to penetrate -- this cork is also a surface failure and follows the square-cube law mentioned above, so it actually takes LESS energy to make happen than if the projectile had to tear open the entire thickness of the plate made of a soft, ductile material before it could go through. Thus, the formation of a plug indicates that the plate is good at breaking up a projectile's nose (shatter into small pieces before the shell can penetrate more than a tiny distance being the most effective form of damage), but it also indicates that the plate is rather brittle and takes less energy than a similar softer plate that does no form such plugs (assuming the same strength for this solid all-the-way-through-softer armor ("homogeneous") to the back layer of the hard-faced plate). For small-scale tests, the energy that the projectile has due to its weight is going down faster than the needed energy to plug the plate, so if the scale is small enough, plugging does not hurt resistance and can even help it, again assuming similar soft-portion strength to all of the armors involved in the comparison. Note that if the face layer is very thin, as in Harvey armor in the thicker plates, the punching out of the face does not go very deep before the tough, ductile steel in the rest of the plate stops it, after which the projectile must push through more-or-less like a ductile, homogeneous plate, but if the nose tip of the shell is shattered, this becomes much more difficult, causing the projectile to crush itself between its base moving

forward at full speed (at least initially) and the broken nose trying to move forward at slow speed (relatively) through the steel armor. A shattered, weakened, flattened nose doesn't penetrate thick armor very well at right angles!

SOFT AP CAPS work because they give the projectile nose its own "shock-absorber" that works just like the tough back of the face-hardened plate. The energy that passes through the plate face into its back layer does not break the face as long as there is no spot in the face that causes a crack to start prematurely. Similarly, the shock of impact into the projectile nose can be resisted as long as there is somewhere to hand off the energy fast enough to keep it from bouncing around in the nose and starting cracks. The shockwave moving directly down the projectile's length has to go all the way to the base (most of it, except for some that reflects off of the upper end of the explosive cavity) before it can reflect and go back into the nose; by that time, the armor impact is already decided one way or the other as to penetration. The energy going SIDEWAYS in the nose has no such long delay; in fact, it has no real delay at all before it hits the sides of the nose and reflects, cracking the nose if the impact is of high-enough energy (which it almost always is against a good face-hardened armor). If you add a tightly-fitting thick ring of steel to the sides of the nose (the deeper the hard face of the plate, the larger the needed absorption ring), the shockwave can be handed off to that ring and it exits the nose. If the ring is too small to stay in one piece under the impact blow, it literally explodes outward as the shockwave reaches its outer boundary, absorbing the energy and making the projectile nose much less liable to be damaged. Thus, a soft AP cap merely has to flatten out evenly and in a ductile manner as it is squeezed between the plate and projectile nose tip, forming a tight-fitting cup surrounding the nose. This requirement restricts the obliquity angle that this kind of cap will work, however, since as the obliquity goes over about 15 degrees, the sides of the cap fold and leave air gaps, which are places where the impact shock is not absorbed and shatter can start. By 20 degrees obliquity, soft AP caps are virtually useless and very rarely work. On top of this, later extra-tough face-hardened armors could remain uncracked at any impact angle even after the soft cap had been destroyed, forcing the hard nose tip and hard face layer into a "Sumo"-style pushing contest which the projectile nose tip almost always loses, since the plate is so much bigger and can resist more in such a relatively slow-motion brute-force contest. (Hard caps, introduced later, gouge a pit into the plate face as they are crushed, so they work much like a center-punch with a drill (the nose), destroying much of the hard face layer and seating the projectile nose into the pit to concentrate its impact force. Hard caps are MUCH better and work at almost every angle of impact.)

In the KC tests given below, I give two or more computations where I adjust the thickness of face for the armor -- change the percent of unhardened back, UB in the program, which is UB = 100 - (face layer thickness percentage) -- and I also throw in a test of a similar Harvey Nickel-Steel plate (as computed using the Harvey test data given above to calibrate FACEHARD). The usual KC a/A armor of the period, as actually applied by Krupp to warships starting in the mid-1890's, had a roughly 35% face, though this varied quite a bit from manufacturer to manufacturer and time to time as the they tried to find the "sweet spot" of maximum resistance against various projectiles at different scales. I think that Krupp did a lot of experimenting with this face depth before coming up with the 35% as the best all-round compromise. The results below seem to indicate this. The projectiles are all the rather brittle uncapped steel AP shot of the late 1890s, which fail much more easily than the later improved steel projectile introduced during the 20th Century -- those Midvale AP projectiles demonstrate how much of an improvement was made, once the ability to stiffen up the tough projectiles to reduce the rather extreme upset (compression lengthwise) effects they suffered from. The results are interesting.

ANALYSIS

Virtually all of the KC plates here, except for the 30cm (11.8") plate, failed by plugging whether or not the projectile made it through the plate afterwards. These uncapped brittle AP projectiles were almost all destroyed by their impacts, again with the partial exception of the 30cm plate, where the second impact had the projectile body remain intact, though its nose was crushed into the plate a remained imbedded there. This also indicates that the shock effect on this plate was reduced.

The two 8cm (3.15") plates are wildly different as to their resistance, indicating a large quality control problem. This is different from the two 14.5cm (5.71") plates, which seem to be practically identical as to resistance. Indeed, after WWI, virtually nobody made KC-type plates that thin for warships any more, with thinnest I know of being 90mm (3.54") fro the French cruiser ALGERIE and many nations not making it under 5" or even thicker (the minimum thickness in the Japanese WWII YAMATO Class battleships for their last Vickers Hardened face-hardened armor was 25cm (9.84")). This was partially due to the high cost of quality control for the face of such thin plates (even a small error in hardening or cementing thickness would compromise the standard quality of the plate; not much leeway) and due to the fact that there were few small projectiles against which the hard face would really help. Most cruisers and battleships had guns at least 11.4cm (4.5") or larger for use against surface ships, even for their secondary batteries, so you get a lowered resistance with large projectiles against thin face-hardened plates that you will not get with ductile homogeneous armor. Finally, with the advent of the single-gun-size battery with reasonable rates of fire even for the larger guns (starting with HMS DREADNAUGHT in 1905), the need of thinner face-hardened plate against the enemy's smaller "quick-firing" guns evaporated, mostly you had to worry about the large main guns, which needed much heavier armor to stop. These two plates indicate that this was a problem right from the start and only a few manufacturers bothered with such thin KC plates.

Note also for these thin plates that the Harvey armor is SUPERIOR to the Krupp Cemented armor!! This is due to the fact that the face layer is somewhat thinner and, being due to high carbon content and not a very-hard-to-control short time for the KC armor's decremental hardening process (variable hardness, high near the face surface and low at the joint where it flow into the ductile back layer of the plate), the face is well-defined and easily

hardened without causing the back to get too hard and make the plate brittle (and inferior in resistance). Thus, the Harvey plate can be maximized for resistance even in such a thin plate without having to compromise to make the majority of the plate tough enough. Even though the nickel steel used in the Harvey plates is not as strong as the chromium-nickel steel used in the KC armor, in these thin plates, the scaling effect on the face against the small projectiles used here (10.5cm (4.1") and 15cm (5.9")) compensates by causing about as much damage to the projectiles as the KC plate does. This is particularly true for these weak, brittle projectiles (by later standards), which suffer far more shatter-type damage than later projectiles did on any hard-faced plate, Harvey or KC. The advantage that the deep face gives a KC plate in more thoroughly pulverizing the attacking projectile when shatter sets in (giving a greater step increase in resistance when shatter occurs compared to when it does not) is wasted here, as the shell is being pulverized quite adequately by either kind of plate, especially in the thin armor against small projectiles were scaling is working in favor of the armor. Finally, the plugging failure mode of KC armor weakens it with nothing to compensate for it (usually by greater projectile damage), so the KC plate is inferior to the more ductile Harvey armor, even with the Harvey armor's somewhat weaker steel. All-in-all, trying to make KC armor this thin or, indeed, any face-hardened armor this thin, is kind of a non-cost-effective proposition.

The 10cm (3.94") plate is similar to the 8cm plate in that Harvey armor is again superior, for the same reasons, but here it looks like Krupp may have thickened the face to around the 50% level (circa 2" cemented-plus-decrementally-hardened deeper face compared to a 1-1.5" cemented-only Harvey face), since that gives an almost exact match to the assumed NBL for the 10.5cm projectiles. The estimated resistance against the 15cm projectiles using this face thickness is a little high, but possible, since there is no real upper bound given in the tests. I am estimating the NBL using the fact that the projectile pieces are in the wood backing layer behind the plate, so the shell could not be going very fast after penetrating the plate. Note that this is a single plate and, as with the 8cm plate, the quality control may be suspect and the plate not really average for its thickness (I really need about half-dozen test plates to get a good feel for the average resistance). It again indicates that Harvey armor was better due to its higher body ductility and equal ability to destroy these old brittle projectiles in this size of tests with its pure cemented-only very high hardness face compared to the KC armor's three-part face -- high-hardness cemented plus moderately-hard decrementally hardened face plus smooth hardness-drop transition region to the ductile low-hardness back layer. Against these weak projectiles only the cemented surface was of any real advantage, the deeper face of the KC plate made it weaker with no compensation.

For the 14.5cm (5.71") KC plate, if you assume a circa 50% face you get quite close to the indicated NBL with the 15cm projectile. The 21cm (8.3") projectile is of consistent quality, as are the two 14.5cm KC plates, but this projectile seems to be somewhat inferior to the 15cm projectiles, requiring a higher striking velocity to penetrate. The 15cm projectile and the 30.5cm (12") projectiles used in these tests seem to be of roughly the same quality. For this plate, Harvey and KC are about equal in resistance against these weak, brittle projectiles. Harvey's advantage is dropping, though, as the thin face and all-round inferior steel used in the Harvey armor are beginning to overcome the better face-to-back ratio in that armor compared to KC.

We now have a huge jump in thickness and projectile size to 30cm (11.8") plates hit by 30.5cm *12") AP projectiles (both Krupp and French St. Chamond). This plate is not damaging the projectiles as much and does not throw plugs, indicating a more ductile plate and probably a thinner face layer. Using a somewhat thinner face gives a close approximation to the low end of the possible range of NBL values -- there is not enough information to nail down the NBL closer than 2050-2150 ft/sec. This plate is at least as good as the regular KC a/A armor used in WWI-era German battleships and much better than Harvey armor against these weaker shells. Against stronger shells, it probably would be even better, since shatter would play less of a role in resistance and better toughness, indicated by no plugs, compensate for any loss due to less projectile damage. After WWI, British and US naval proving ground tests of Krupp KC a/A armor showed that it lacked toughness, since it was optimized to smash uncapped projectiles. This 30cm plate shows that this was really a mistake, since this plate probably would have given superior results against the later, stronger, tougher AP projectiles, capped or not, used in these tests.

As to the last two plates, 35cm (13.8") and 36.8cm (14.5"), they give exact results if you assume a 45% face (55% ductile back) -- FACEHARD steps around this value using a staircase change in the scale factor and only gives a difference in results if the face layer is under 38% or is 48% and up (38-47.99% gives the same result). In reality, there is a more gradual change in the scale factor, I assume, but variations in plate quality, projectile quality, plate face thickness from plate to plate (though some manufacturers are quite consistent in this regard), exact test conditions, etc., make this not worth the effort and is a confusion factor for any given plate type. Both of these plates seem to be of virtually identical quality. The 30.5cm AP projectiles seem consistent, too, even though they are made not only by different manufacturers, but in different countries. They also agree EXACTLY with the projectile quality I worked out when doing the Harvey analysis (the difference was less than 0.085% between all of the projectiles!). Harvey armor is grossly inferior here, with the thin face being unable to damage these large projectiles enough to compensate for the inferior steel used. Even though the KC armor is failing by plugging and is thus acting in a more brittle manner than the nickel steel used in the Harvey armor, it is strong enough to compensate for this by causing more damage and by being somewhat tougher to start with.

All-in-all, this set of tests seems to show that Krupp was experimenting with some of the properties of his KC armor and for the most part had an armor that was acceptable even when the face thickness and plate toughness varies rather a lot. Against the stronger, later AP projectiles, the deep face was an absolute requirement to get enough damage to compensate for the brittle face layer's plugging failure mode. In that case, Harvey armor failed miserably against any size projectiles, in a comparison.

For example, if we assume a Midvale Unbreakable 1916 projectile without an AP cap, being about the strongest WWI-era projectile there was at right angles impact, we get these NBL values using FACEHARD 6.8:

12" (uncapped, 800 lb):

5.71" Harvey armor:	HBL = 734	NBL = 792	5.71" KC a/A armor (35% face):	HBL = 897	NBL = 1025
14.5" Harvey armor:	HBL = 1335	NBL = 1363	14.5" KC a/A armor (35% face):	HBL = 1939	NBL = 2217

12" (capped, 870 lb):

5.71" Harvey armor:	HBL = 763	NBL = 823	5.71" KC a/A armor (35% face):	HBL = 656	NBL = 751
14.5" Harvey armor:	HBL = 1388	NBL = 1417	14.5" KC a/A armor (35% face):	HBL = 1419	NBL = 1623

6" (uncapped, 100 lb):

5.71" Harvey armor:	HBL = 1307	NBL = 1410	5.71" KC a/A armor (35% face):	HBL = 1632	NBL = 1866
14.5" Harvey armor:	HBL = 2368	NBL = 2417	14.5" KC a/A armor (35% face):	HBL = 3525	NBL = >4000

6" (capped, 109 lb):

5.71" Harvey armor:	HBL = 1361	NBL = 1468	5.71" KC a/A armor (35% face):	HBL = 1196	NBL = 1368
14.5" Harvey armor:	HBL = 2466	NBL = 2517	14.5" KC a/A armor (35% face):	HBL = 2583	NBL = 2955

Note how the ability of the KC armor to shatter the otherwise invulnerable Midvale Unbreakable projectiles when they have no caps makes the KC armor much better than the Harvey armor virtually at all times, something not evident with the weaker, brittle AP projectiles used in the late 1890's (only the old Midvale projectiles could act somewhat like this, in that they would not shatter on the Harvey armor either, but they deformed so much that they did not get much of an advantage over simply adding a small soft cap to the other, inferior projectiles).

Note also that adding a cap to these projectiles HELPS considerably against both thicknesses of KC armor by either size projectile, but actually HURTS against the Harvey armor, since the small added weight of the cap does not compensate for the energy lost in deforming it (this is for soft caps only on the stronger projectiles, where it puts a lid on maximum penetration quality of the shell) and the projectiles were not shattering in the first place, so the cap is a dead weight with no purpose against Harvey armor. However, the addition of a cap against 5.71" armor of either kind by either projectile has the interesting effect that it helps so much against the KC armor that the Harvey armor, which has the penalty for using a soft cap, is now superior against either projectile size. Thus, KC armor, due to its heavy face, has more to lose when capped projectiles are employed than Harvey armor does, since it starts off weaker, but thus it also has less to lose when caps are added to these strong projectiles.

This subject of face-hardened armor is not quite as simple as those old documents said. It depended A LOT on how good the ammunition you had when firing at the plates. It can be summed up in part as "the bigger you are, the harder you fall" when AP caps and stronger projectiles came into use.

Proj. Diam. |Weight|Vel.|Pen |Dpth|Proj Damage| Damage Details

8cm (3.15")

PLATE TESTED WITH KRUPP 4.1" & 5.9" AP SHOT:

105mm 4.1" 35.3 1775 PP Thru BB NB Proj. upper half pieces in back, rest in front. Plug thrown into backing. PLATE #1

" " 35.3 1376 PP Thru BB NB Proj. nose tip through plate, rest in front. Plug thrown into backing. PLATE #2

=== NBL (#1) > 1775 (= ~1800 may be close) & NBL (#2) > 1376 (= ~1450 may be close) --> Average = ~1625

+++

150mm 5.9" 88.2 1334 CP Thru BB NB Proj. thru everything. Broken plug thrown into backing. PLATE #2

=== NBL (#2) << 1334

COMPARE RESULTS TO FORMULAE:

4.1" Uncapped AP Shot (Weight 35.3 lb):

FACEHARD 6.8: Uncapped 4.1" Shell VS Harvey Ni: HBL = 1755 NBL = 2021 EBL = NEVER (Shatter assumed)<NOTE!!

FACEHARD 6.8: Uncapped 4.1" Shell VS 20% face: HBL = 1567 NBL = 1599 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 4.1" Shell VS 25% face: HBL = 1599 NBL = 1632 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 4.1" Shell VS 35% face: HBL = 1599 NBL = 1632 EBL = NEVER (Shatter assumed)<AVERAGE

FACEHARD 6.8: Uncapped 4.1" Shell VS 50% face: HBL = 1689 NBL = 1724 EBL = NEVER (Shatter assumed)

5.9" Uncapped AP Shot (Weight 88.2 lb):

FACEHARD 6.8: Uncapped 5.9" Shell VS Harvey Ni: HBL = 1327 NBL = 1529 EBL = NEVER (Shatter assumed)<NOTE!!

FACEHARD 6.8: Uncapped 5.9" Shell VS 20% face: HBL = 1193 NBL = 1218 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 5.9" Shell VS 25% face: HBL = 1217 NBL = 1242 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 5.9" Shell VS 35% face: HBL = 1215 NBL = 1240 EBL = NEVER (Shatter assumed)<WORKS

FACEHARD 6.8: Uncapped 5.9" Shell VS 50% face: HBL = 1240 NBL = 1266 EBL = NEVER (Shatter assumed)

10cm (3.94")

PLATE TESTED WITH KRUPP 4.1" & 5.9" AP SHOT:

105mm 4.1" 35.3 2067 Hole ***??*** BB NB Proj. pulverized; all in front. Plug thrown into backing. Proj. probably did not penetrate very far into plate (~1" max).

=== NBL > 2067 (= 2100-2125 may be close)

+++

150mm 5.9" 112.4 1342 PP Thru BB NB SIP Proj. nose pieces in back, base pieces in front. Plug thrown into backing.

=== NBL > 1342 (= ~1375 may be close)

COMPARE RESULTS TO FORMULAE:

4.1" Uncapped AP Shot (Weight 35.3 lb):

FACEHARD 6.8: Uncapped 4.1" Shell VS Harvey Ni: HBL = 2051 NBL = 2314 EBL = NEVER (Shatter assumed)<NOTE!!

FACEHARD 6.8: Uncapped 4.1" Shell VS 35% face: HBL = 1923 NBL = 1963 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 4.1" Shell VS 50% face: HBL = 2032 NBL = 2074 EBL = NEVER (Shatter assumed)<CLOSE

5.9" Uncapped AP Shot (Weight 112.4 lb):

FACEHARD 6.8: Uncapped 5.9" Shell VS Harvey Ni: HBL = 1501 NBL = 1693 EBL = NEVER (Shatter assumed)<NOTE!!

FACEHARD 6.8: Uncapped 5.9" Shell VS 20% face: HBL = 1398 NBL = 1427 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 5.9" Shell VS 25% face: HBL = 1407 NBL = 1436 EBL = NEVER (Shatter assumed)

FACEHARD 6.8: Uncapped 5.9" Shell VS 35% face: HBL = 1404 NBL = 1433 EBL = NEVER (Shatter assumed)<WORKS

FACEHARD 6.8: Uncapped 5.9" Shell VS 50% face: HBL = 1433 NBL = 1463 EBL = NEVER (Shatter assumed)

14.5cm (5.71")

PLATE TESTED WITH KRUPP 5.9" & 8.3" AP SHOT:

150mm 5.9" 112.4 2021 CP Thru BB NB Proj. pulverized; all in backing. Conical plug thrown. PLATE #1

=== NBL <= 2021 (Close)

+++

210mm 8.3" 210 1562 IP <3 BB NB Proj. pulverized. PLATE #1

210mm 8.3" 210 1627 PP Thru BB NB Proj. pulverized; about half in backing. PLATE #1

210mm 8.3" 210 1643 CP Thru BB NB Proj. pulverized; all but one piece in backing. Three FC. PLATE #2

=== NBL <= 1643 (Close for both plates)

COMPARE RESULTS TO FORMULAE:

5.9" Uncapped AP Shot (Weight 112.4 lb):

FACEHARD 6.8: Uncapped 5.9" Shell VS HARVEY Ni: HBL = 1899 NBL = 2048 EBL = NEVER (Shatter assumed)<NOTE!!

FACEHARD 6.8: Uncapped 5.9" Shell VS 50% face: HBL = 1948 NBL = 1988 EBL = NEVER (Shatter assumed)<CLOSE

FACEHARD 6.8: Uncapped 5.9" Shell VS 70% face: HBL = 2326 NBL = 2374 EBL = NEVER (Shatter assumed)

8.3" Uncapped AP Shot (Average weight 210 lb):

FACEHARD 6.8: Uncapped 8.3" Shell VS HARVEY Ni: HBL = 1529 NBL = 1649 EBL = NEVER (Shatter assumed)<NOTE!!
FACEHARD 6.8: Uncapped 8.3" Shell VS 20% face: HBL = 1530 NBL = 1562 EBL = NEVER (Shatter assumed)<LOW
FACEHARD 6.8: Uncapped 8.3" Shell VS 25% face: HBL = 1536 NBL = 1568 EBL = NEVER (Shatter assumed)<LOW
FACEHARD 6.8: Uncapped 8.3" Shell VS 35% face: HBL = 1527 NBL = 1559 EBL = NEVER (Shatter assumed)<LOW

Proj. Diam. |Weight|Vel.|Pen |Dpth|Proj Damage| Damage Details

30cm (11.8")

PLATE TESTED WITH KRUPP 12" AP SHOT:

305mm 12"	715.4	1889	IP	7	BB NB NSIP	NC. Plate rather soft; it allowed deep penetration w/o plugging.
305mm 12"	712.6	1993	IP	??	NB	Proj. body intact. Three FC. One BC on 3" back bulge.

=== NBL > 1993 (= 2050-2150 may be close, depending on how deep the second round went into plate)

COMPARE RESULTS TO FORMULAE:

12" Uncapped Krupp AP Shot (Average weight 714 lb):

FACEHARD 6.8: Uncapped 12" Shell VS HARVEY Ni: HBL = 1693 NBL = 1728 EBL = NEVER (Shatter assumed)<NOTE!!
FACEHARD 6.8: Uncapped 12" Shell VS 20% face: HBL = 2009 NBL = 2050 EBL = NEVER (Shatter assumed)
FACEHARD 6.8: Uncapped 12" Shell VS 25% face: HBL = 2008 NBL = 2049 EBL = NEVER (Shatter assumed)<CLOSE??
FACEHARD 6.8: Uncapped 12" Shell VS 35% face: HBL = 1976 NBL = 2017 EBL = NEVER (Shatter assumed)
FACEHARD 6.8: Uncapped 12" Shell VS 50% face: HBL = 1813 NBL = 1850 EBL = NEVER (Shatter assumed)

35cm (13.8")

PLATE TESTED WITH ST. CHAMOND 12" AP SHOT OR SHELL:

305mm 12"	717.3	2116	CP	Thru	BB NB	One proj. piece in front; rest in back. Plug thrown into backing. Several FC.
305mm 12"	718.6	2120	IP	??	BB NB SIP	Proj. split lengthwise in two. Back bulge cracked split & open to 3.15" width. Probably imbedded ~8" into plate. No plug here.
305mm 12"	715.6	2104	PP	Thru	BB NB	Proj. body pieces all in front; nose flattened and welded to plug. Plug thrown into backing. Several more FC.

=== NBL >= 2125 (Close)

COMPARE RESULTS TO FORMULAE:

12" *ST. CHAMOND* Uncapped AP Shot or Shell (Average weight 717 lb):

FACEHARD 6.8: Uncapped 12" Shell VS HARVEY Ni: HBL = 1846 NBL = 1884 EBL = NEVER (Shatter assumed)<NOTE!!
FACEHARD 6.8: Uncapped 12" Shell VS 40% face: HBL = 2203 NBL = 2248 EBL = NEVER (Shatter assumed)<BRACKET▼
FACEHARD 6.8: Uncapped 12" Shell VS 50% face: HBL = 2063 NBL = 2106 EBL = NEVER (Shatter assumed)<BRACKET▲

36.8cm (14.5")

PLATE TESTED WITH BOTH KRUPP 12" AP SHOT AND ST. CHAMOND 12" AP SHOT OR SHELL:

305mm 12"	715.6	2159	PP	Thru	BB NB	ST. CHAMOND --Proj. body pieces in front; nose flattened and welded to plug. Plug thrown into backing. Several FC.
305mm 12"	715.7	2157	PP	Thru	BB NB	SAME AS ABOVE.
305mm 12"	718.1	2152	Hole	??	BB NB NSIP	KRUPP -- Proj. pulverized; all in front. Plug thrown into backing. Several FC. Proj. probably didn't penetrate deeply.

=== NBL > 2160 (= 2200-2250 may be close)

COMPARE RESULTS TO FORMULAE:

12" Uncapped AP Shot/Shell (Average weight 716 lb) (both shells are within 0.085% of each other so Krupp used):

FACEHARD 6.8: Uncapped 12" Shell VS HARVEY Ni: HBL = 1893 NBL = 1932 EBL = NEVER (Shatter assumed)<NOTE!!
FACEHARD 6.8: Uncapped 12" Shell VS 40% face: HBL = 2295 NBL = 2342 EBL = NEVER (Shatter assumed)<BRACKET▼
FACEHARD 6.8: Uncapped 12" Shell VS 50% face: HBL = 2150 NBL = 2194 EBL = NEVER (Shatter assumed)<BRACKET▲

END OF KRUPP CEMENTED Cr-Ni-STEEL ARMOR DATA

KEY AND NOTES

FACEHARD "6.8" is my current modified FACEHARD version with more debugging and with Harveyized Nickel-Steel and Harveyized Mild Steel (estimated) added into the plate quality database. It was modified to handle the data from this and other sources concerning old AP shot and shell versus Harveyized Ni-Steel Armor Plate, which FACEHARD 5.8, the version used in the initial analysis, did not handle very accurately. The success of this upgrade is given in this revised analysis of the extensive data in the Cleland Davis PROCEEDINGS article described below. FACEHARD when doing damage effects, uses NONE, SHATTER ONLY ("perfect" uncapped projectile), MAX DAMAGE w/o SHATTER (typical damage effects on the projectile due to this impact if the shell does not shatter), and MAX DAMAGE w/SHATTER (all remaining applicable damage effects when shatter occurs first -- shatter replaces many other kinds of damage, precluding them from ever happening). Damage effects, including those of shatter, vary from impact to impact, forming a "blur" of results through which I drew a line in the middle of to get my estimates in the FINAL RESULTS output (I tried to round the curve toward the worst damage results when doing this to give a better "feel" of the spread of effects in the output, unless they were very rare). Thus, for example, if the MAX DAMAGE w/SHATTER and SHATTER ONLY detailed results bracket the actual results, this indicates that the projectile is within the expected blurry-results range for shatter and, if shatter is indicated in the FINAL RESULTS for that impact, the program is working properly.

These results in my revised FACEHARD 6.8 are derived from: (1) When all estimated damage, but not shatter, is used, these old AP/APC shells have an average Q(Projectile--DAMAGE) = PDAM = 0.7 (compared to the best US Navy WWII AP projectiles with Q(Projectile) = 1.00). The projectile is penetrating in this damaged condition, bent, compressed, and/or broken in some manner, which requires a significantly higher velocity to accomplish. This is used for determining the kind of damage and the EBL, not the HBL or NBL (see definitions below). When shatter occurs, this is ignored and damage is determined by the various versions of shatter (nose-only or complete). (2) When no penetration-modifying damage occurs when going through the plate or when shatter occurs with weak-bodied shells, the value used for the HBL and NBL for these shells is Q(projectile--BALLISTIC LIMIT) = PLIM = 0.795 (based on tests against Krupp KC armor of the period ("KC a/A" or KC Old Type, as Krupp later called it)). When no damage occurs, this non-1.00 projectile quality is due to the fact that when hitting at a velocity less than that using this value in the formulae, the projectile deforms or breaks up instead of penetrating -- if shatter also occurs, you get the sum of both this damage and shatter damage degrading penetration. That is, there is an "extra" velocity that must be added to allow the impact shock to the plate to be great enough that it breaks before the projectile does from this kind of damage and, at oblique impact, that the projectile is deflected less from its original path, reducing the twisting forces that can damage the middle and lower body. The better the projectile, the less such added velocity is needed and closer to 1.00 the value of Q(Projectile) is. (It is possible to have a value greater than 1.00, but this is for hard-capped AP shells where the AP cap is superior in design and causing more plate damage, allowing a small reduction in the penetration velocities over a projectile which is otherwise "perfect" at Q(Projectile) = 1.00. This does not ever apply to shatter, though.) It merely raises the shatter NBL and HBL velocities by the same amount that it raises the non-shatter NBL and HBL velocities (there are come complex rules for this, but most do not apply here). However, when shatter only occurs (a "perfect" uncapped projectile, which in this case merely means that the projectile does not break up when if fails to penetrate at right angles, whenever shatter is not a factor -- US Navy mid-WWI Midvale "Unbreakable" AP projectiles, for example, but none being discussed her), then all other kinds of projectile damage are ignored, since the projectile is now in pieces by the time any other of these could be applied and no non-shatter damage occurred from any other cause. The only adjustment is due to the effect of the AP cap, if used, which is minimal for soft AP caps, anyway. Thus, "pure" shatter always implies a 1.00-quality shell, cap adjusted. This forms the bottom edge of the striking velocity range required to penetrate when shatter happens (and the top for these stronger projectiles). The shatter velocity when the 0.795 value is applied due to these weaker projectiles being discussed here forms the top edge of this range. Anything in-between can occur, though most impacts will be near the top end with these weaker projectiles.

M79APCLC is a program developed to incorporate a medium-long-nose (tangent ogive with radius of 1.667 calibers) pointed projectile of any size manufactured with high quality (resistance to damage from impacts) into WWII homogeneous armor steel penetration logic. It is based on extensive data developed during and after WWII at the US Naval Proving Ground, Dahlgren, Virginia, under Dr. Allen V. Hershey. Added to it was data concerning low-ductility plates from German Krupp Corporation WWII Wh-armor tests and penetration curves (the Percent Elongation logic). It is a complete, far superior replacement to the 1890 French DeMarre Nickel-Steel Armor Penetration Program good for undamaged uncapped AP projectiles to up to 80 degrees obliquity, plates up to 2 caliber thick, and striking velocities up to 3000 ft/sec, whichever of those three reaches its maximum first. The standard plate type is US Navy WWII Special Treatment Steel (STS) or Class "B" armor of 225 Brinell Hardness, 115,000 psi ultimate tensile strength, 95,000 psi yield strength, and 25% Elongation -- this is rather low for US Army tank Rolled Homogeneous Armor (RHA), which is designed for small-size-projectile, very-high-velocity impacts, unlike ironclad naval armor. The DeMarre Formula has a plate/projectile combined quality modifier call the "DeMarre Coefficient" -- given as "C" -- to divide the actual striking velocity to give the expected complete penetration striking velocity (= US Navy NBL) for the plate and projectile used in a given test. This formula was only good at normal (right angles) impact; any other angle gives very poor results unless a complex adjustment for C is employed (rarely used). For example, C = 1.21 gives a value for the NBL very close to my M79APCLC program when the Ni-steel plate thickness is one-caliber -- T = D -- at normal obliquity, which is equivalent to Q(Armor) = 0.76 in M79APCLC when an uncapped projectile suffers no damage due to the impact with an 1890 Ni-steel plate. M79APCLC as-is and the DeMarre Formula using C = 1.21 give rather close results to one-another for the entire most-probable naval plate thickness range of 0.2-1.1 caliber at normal obliquity, which is to be expected, since DeMarre did a rather good job in his analysis work!

To do an actual analysis, one should adjust the striking velocity up and down from the actual one by 2.5% and also the impact obliquity up and down by 2.5% (0 degrees minimum, of course, and above the maximum allowed obliquity value for that impact -- 70-80 degrees -- would mean no penetration possible for that adjustment). This gives the blurry results "box" about the actual impact. Only if ALL adjusted value combinations give the same results (COMPLETE PENETRATION or NO PENETRATION with the same projectile damage in all cases, for example), is that result probably solid for all such impacts in that blurry region. Otherwise, you can "roll a die" to get which result will happen in any given impact.

On top of that, when shatter occurs, an additional factor is that the range is somewhat wider when there is a range of results between the no-non-shatter damage applied and the full non-shatter damage applied cases, here with another die roll, but being more like with two dice, going from rolling a 7 for full non-shatter damage applied down to a 2 for the no non-shatter damaged applied (ignoring rolls above 7), linearly stepping the HBL and NBL down by (DIE ROLL/6) times the difference between the two velocities as one gets the intermediate die rolls, if you want a simple way to do this. FACEHARD gives the various HBL and NBL values for all cases on its last optional screen, indicating the ones it used in its output screen, but also showing those it calculated, but skipped over, too.

Ensign Cleland Davis, USN, Formula for Harveyized Ni-Steel versus Uncapped AP Projectiles at Normal:

$$T/D = (0.000034661)(D^{0.3333})[(W/D^3)V^2]^{0.66667}$$

Ensign Cleland Davis, USN, Formula for Harveyized Ni-Steel versus Capped AP Projectiles at Normal:

$$T/D = (0.000085822)(D^{0.25})[(W/D^3)V^2]^{0.625}$$

where: T = Plate thickness in inches
D = Projectile diameter (nominal gun bore diameter) in inches
W = Projectile weight in pounds
V = Striking velocity (minimum) in feet/second to give a Complete Penetration (all or almost all, if broken, of the projectile on the far side of the armor plate -- in or through backing, if any -- after the impact) = US NBL

Ensign Davis used the above tests to match "best-fit" curves for (soft) capped (APC) & uncapped (AP) Armor-Piercing projectiles, resulting in the above two formulae. His results were presented in the US Naval Institute PROCEEDINGS, Volume XXIII, Number 2, of 1897, Pages 284-299 + 8 pages of the raw test result data referenced in the text, in an article entitled *"On the Perforation of Face-Hardened Armor"*.

Interestingly, the capped formula above is the same as the formula used by Krupp in WWII for armor-piercing capped (APC) projectiles versus nickel-chromium-steel face-hardened Krupp Cemented "New Type" (KC n/A) and homogeneous "Wotan Härte" (Wh, "Odin Hard") naval armors, though the Krupp formula changed to metric units, the constant 0.000085822 was replaced with another value, and the striking velocity was divided by a variable "C" -- exactly equivalent to the "DeMarre Coefficient" used in that 1890 French homogeneous Ni-steel armor penetration formula of that name to adjust the test results for each set of test conditions (plate type, plate thickness, projectile type, projectile diameter, obliquity, and the striking velocity that gave the desired limit condition estimated by averaging several results under similar conditions) to match the formula as well as possible, smoothed into a curve of average C values versus obliquity for each projectile/armor combination. The Krupp version of this formula thus create tables of C values to adjust the results to match test results for normal and oblique impact up to 70 degrees from normal. This was for complete penetration for KC and Wh armors and, for KC armor only, for holing (caliber-size, I think) entirely through the plate, each projectile having its own set of C-value tables.

Projectile Manufacturers:

Carp. = Carpenter	(US)	
Holt. = Holtzer	(France)	
John. = Johnson	(US)	
Krupp = Krupp	(Germany)	
Midv. = Midvale	(US)<---(NOTE: MIDVALE projectiles bent but ***never*** broke in any test given here!)	
St.C. = Saint Chamond	(France)	
Whlr. = Wheeler	(US)	
W-S. = Wheeler-Sterling	(US subsidiary of the British Sterling Steel Corporation, who bought Wheeler)	

Armor Manufacturers:

Beth = Bethlehem Steel Corporation	(US)	(Harvey Ni-Steel)
Carn = Carnegie Steel Corporation	(US)	(Harvey Ni-steel)
Krup = Krupp Iron & Steel Corporation	(Germany)	(KC)

PENETRATION TYPES

NBL = US Navy "Navy Ballistic Limit" striking velocity where all of a projectile (body minus windscreen and AP cap, if any) or, if it breaks up on impact, circa 80% of its body weight (rough guess) would be expected to barely make it through the plate under the given impact conditions 50% of the time (sometimes there is a wide spread of results from test to test and sometimes this number is quite accurate and specific) -- if shatter occurs that destroys the projectile and pieces start passing through the hole at the HBL (see below), the NBL is very hard to define, as it merely is a point where a few more pieces make it through the plate and thus has little meaning
NOTE: The NBL has nothing to do with the effects of the explosive filler on penetration, since with sensitive fillers, such as tri-nitro-phenol (British "Lyddite" or picric acid), the projectile may only be halfway through the plate when it detonates, so hits at and above the NBL are not much different from a hit at the HBL as to results inside the target. Also, instantaneous-type impact-nose-fuzed High-Explosive-filled shells (those with detonating fillers, not black powder) may detonate so rapidly as to preclude ever having an HBL or NBL against the given plate, no matter what the impact conditions or what the shell could do if it was inert.

HBL = "Holing Ballistic Limit" is that minimum striking velocity where, 50% of the time, at least a caliber-width hole (possibly longer in the direction the projectile was moving at an oblique impact and usually wider if shatter occurs or the plate is very brittle) is expected to occur, regardless of how much of the projectile itself makes it through (it may be the same as the NBL, though this is rare for face-hardened or other hard, brittle armor types)

EBL = "Effective Ballistic Limit" is the striking velocity, if it exists at all for that kind of projectile/plate combination (rarely for SHATTER, for example), where the projectile is expected 50% of the time to be able to explode properly after the impact (fuze still functioning within its manufacturing tolerances for expected random failures; explosive filler still inert and undamaged; shell's explosive cavity intact, including the base plug still seated properly) -- it may be at or below the HBL or at or below the NBL or at some higher velocity, especially at oblique impact

DAMAGE ABBREVIATIONS:

PROJECTILE

BB = Body broken into pieces (few or many)
BO = Body offset (bent/twisted), but not broken
BU = Body upset (shortened and widened)
BsB = Base broken off (entirely or partially)
NB = Nose broken into pieces (few or many)
NU = Nose upset (shortened and widened)
NSIP = Nose broken off and stuck in plate pit/hole
SIP = Projectile partly intact and stuck in plate

PLATE

BC = Back crack
FC = Face crack
TC = Through cracks (through plate from face to back)
NC = No cracks formed by this impact (may be old ones)
Hole = Large hole through plate (no pieces of shell in back)

DEPTH

Nmbr = Farthest behind face surface nose tip reached in inches (IP, NSIP, SIP)
Thru = Projectile (or at least one piece of it) behind plate (PP, CP)