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NAVY DEPARTMENT

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Report on

Penetration of Face-Hardened Bullet
Proof Armor by Solid Cal .27 Bullet.

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ABSTRACT

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The following report contains the results of an initial experiment giving measurements of resisting force for normal impact of Cal .27 carboloy bullets on 1/4-inch carburized light armor. The carburized armor was softened to such a point that occasional carboloy bullets would penetrate unbroken at normal impact. It was possible, however, to maintain hardness at a level high enough to prevent complete petalling at the plate back, and the perforations were still typical of face-hardened armor.

Two clearly resolved maxima were found in the resisting force during penetration of 1/4-inch carburized armor. This is in contrast to the single force maximum always found during the penetration of an equal thickness of medium soft homogeneous STS armor by a bullet having the same shape and size. Comparison with a previously determined force vs. penetration curve for 266 BH STS shows that the force due to the carburized armor rises more rapidly and has a higher average value.

It is concluded that the ability of carburized armor to render projectiles ineffective by breaking them may be due not only to a high rate of increase in the resisting force and a high average value, but it may also be due to transient stresses set up by the second force maximum which follows immediately after the first.

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INTRODUCTIONA. Authorization and References

1. This problem was authorized by the Bureau of Ordnance letter S13-1(4/173)(Q8) of 13 December 1934. Other references mentioned in this report are listed below:

- (a) BuOrd ltr. S13-1(4/173)(Q8) of 13 December 1934.
- (b) NRL Report No. O-2276 of 13 April 1944.

B. Statement of Problem

2. The purpose of this report is to describe, in terms of measured forces, a typical normal penetration of 1/4-inch face-hardened bullet proof steel, referred to hereafter as F.H.B.P. steel, and to compare the results with those obtained from an analysis of the penetration of homogeneous armor of equal thickness, as reported in reference (b). In the case of homogeneous armor it is known that as the hardness increases the forces rise to higher values and yet maintain a rather continuous variation with respect to depth of penetration as long as petals are retained. This may not be true at a hardness where buttons or petals are thrown.

C. Method

3. A typical penetration of F.H.B.P. steel is considered to be one in which the projectile penetrates without failure and throws wiped petals. In order to obtain such a penetration of 1/4-inch plate it was necessary to use a stronger bullet than had been used hitherto, so a solid Cal .27 Carboloy dart of the same shape was substituted for the hardened steel bullet. Even with the stronger bullet, however, it was impossible to penetrate the armor selected for this study at limit velocity without shattering the bullet, and it was necessary to soften the armor somewhat by annealing. An annealing, consisting of heating in a furnace for one hour at 700°F, was found to soften the armor sufficiently without materially affecting the relative hardness from front to back. Hardness surveys, shown on Plate 1, were made on the armor as received and after annealing. It is seen that, while the hardness of the annealed specimen at any one point is lower than that at a corresponding depth in the original material, the treated plate still exhibits, as originally, a hard face, a uniformly softer middle portion and a much softer back surface.

4. The apparatus used was essentially that described in reference (b). It was found advisable to change the position of the slit to avoid damage from particles flying back from the surface of the plate. A new slit was placed so that it projected into the drum approximately .01 inch from the film.

5. The method used in the analysis of the data was that described in reference (b).

DISCUSSION OF RESULTS

6. Very little is known about the forces which resist projectile penetration in face-hardened armor, and the scope of the experimental work forming the basis for the present report is not sufficiently broad to justify other than explanatory remarks. It is to be expected, of course, that the force will depend on the depth of penetration in a more complex manner than in the case of homogeneous armor.

7. The force-penetration curve for 1/4-inch F.H.B.P. steel is shown on Plate 2. It can be seen that the force rises very quickly, falls sharply, and rises to a second well defined peak before falling rapidly to zero. The first peak occurs at a depth of penetration smaller than the thickness of the plate. The position of the second peak corresponds to the penetration at which the bullet becomes embedded up to its bourrelet in the plate.

8. The curves for 1/4-inch STS and mild steel taken from reference (b) are also shown on Plate 2. On comparing them with the curve for F.H.B.P. steel, it will be seen that the forces in the former rise more gradually to smaller maxima and fall off less abruptly and the peaks are not as sharp. More specific comparison may be made with the aid of the data in the following table.

Data from Force Curves of 1/4-inch Plate.

	FHBP Steel	Mild Steel	STS	% increase of force	
				F.H.B.P. Steel over MS	F.H.B.P. Steel over STS
Maximum Force-lbs	19,400	8600	14,460	125%	34%
Average over Penetration of 0.14 to 0.24 inches				111%	24%
Maximum Space Rate of Change of Force lb./in.	119,000	61,000	96,500		
Energy Absorbed ft.-lbs	467	263	450		

9. The higher force in the case of the F.H.B.P. steel is to be expected since it is known that the harder the material being penetrated the higher the resisting force.

10. After rising with a fairly constant slope for some distance the curves for the homogeneous material start bending over. As pointed out in reference (b) it is suspected that bulging of the back is responsible

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for this bending over. That the force of the F.H.B.P. steel rises straight to a peak instead of rounding off more gradually does not necessarily indicate the absence of bulging. The shape of the petals after they separate from the armor indicates that bulging certainly occurs, but it is not known whether it starts at the same relative time as in the case of homogeneous armor. Since at the depth of penetration under consideration the bourrelet of the bullet is still approaching the face of the plate, it may be, if there is any decrease in force due to bulging, it is compensated for by the higher force created as a result of increasing area of the bullet coming in contact with the hard surface layer of the plate.

11. If this is correct the force might be expected to continue to rise until the bourrelet enters the hard surface of the plate, unless some additional factor exists which can cause the force to fall suddenly. Just such a factor does exist. As will be seen from Plate 3, a ring of material around the perforation has broken away from the face of the plate during penetration. It is evident from traces on the film that the ring breaks up into small pieces and sprays backward from the face. From a study of these traces the approximate time at which the particles left the surface of the plate can be determined. This time closely corresponds to the penetration at which the first peak occurs. From the cross-section on Plate 4, it will be seen that when the ring on the face fails the nose of the bullet near the bourrelet suddenly has less support and it is believed that this is responsible for the dropping of the force away from the first peak. During this drop the nose of the bullet has reached the back of the plate and petals have started to open.

12. It is possible that the second peak marks the penetration at which the petals suddenly shear off. The rise in force to the second peak would then be due to an increased bearing of the material at the center of the plate upon the nose of the bullet near the bourrelet and to work hardening of the plastically deforming petals, and it would reach a maximum just before shear sets in. If the petal designated by p on Plate 5 is fitted around the bullet and into the specimen it becomes evident that penetration of the material forming the petal stopped at this point, indicating that the petals broke off and were pushed out ahead of the bullet. It is seen that the bourrelet has just become buried in the face of the plate. This is at the depth of penetration corresponding to the position of the second force peak.

13. After the petals break out, as can be seen by referring to Plate 4, the effective thickness of the plate is reduced. Very little of the material remains to be pushed aside by the bullet and the force drops rapidly, much more rapidly than in the case of the homogeneous armor.

CONCLUSIONS

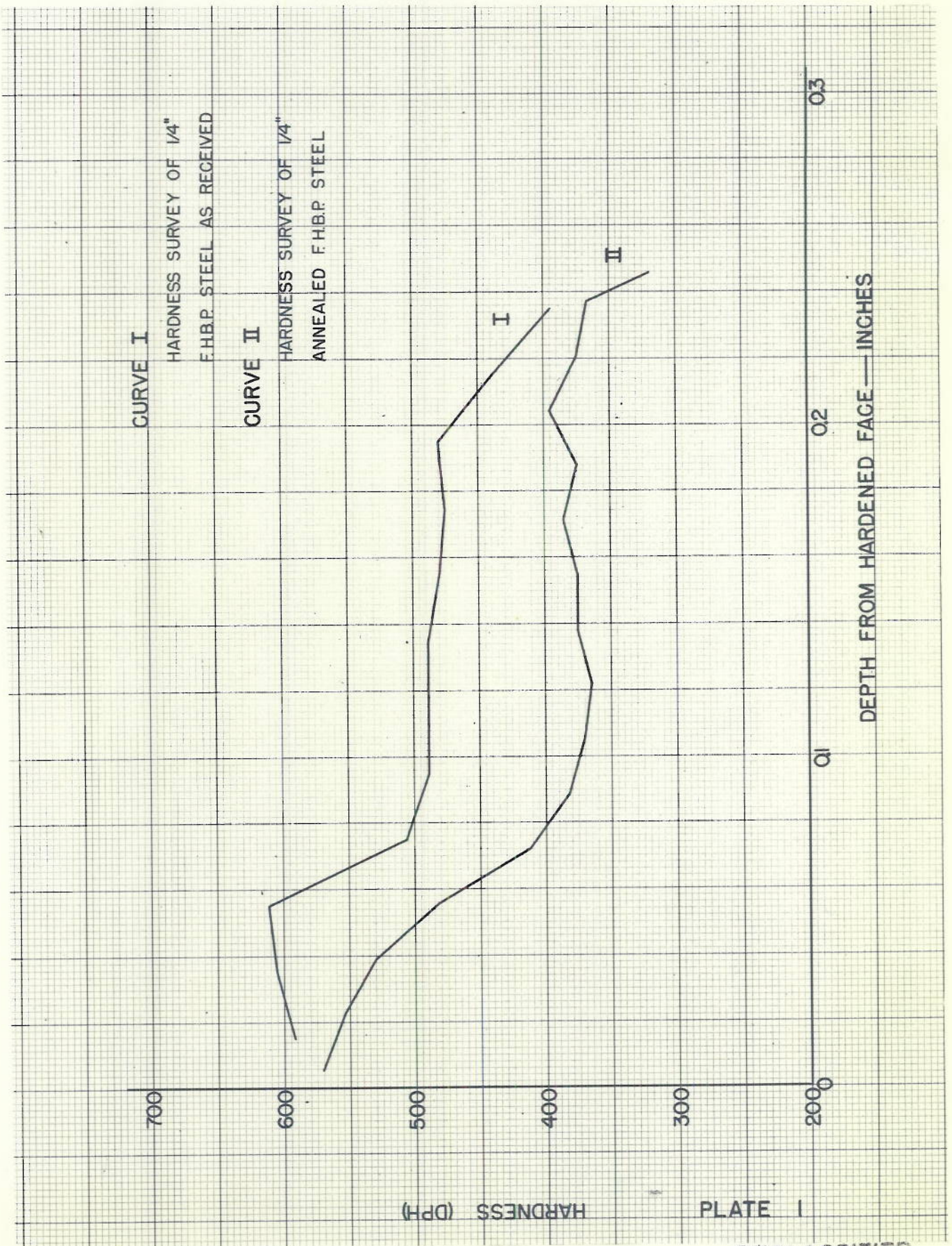
14. Any conclusion drawn must be tentative since it cannot be said that the force curve for the one penetration studied is necessarily typical of all face-hardened armor. From the present investigation, it is concluded that the superiority of the F.H.B.P. steel in defeating projectile penetration by breaking the projectile may be due to the higher

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maximum force and the higher rate of increase of force. It must be remembered in comparing the properties of the F.H.B.P. steel with those of the homogeneous armor that the plate tested was softened by annealing and that the normal 1/4-inch F.H.B.P. steel plate would give still higher values for maximum force and rate of increase of force and would therefore be more efficient than the figures in this report might indicate.

15. It may be that the occurrence of a second force peak within a short time interval as observed would give rise to transient stresses in the projectile of such magnitude that the projectile would be rendered less effective or completely ineffective by fracture. This would be of particular interest in the case of large caliber projectiles.

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CURVE I
HARDNESS SURVEY OF 1/4"
F.H.B.P. STEEL AS RECEIVED

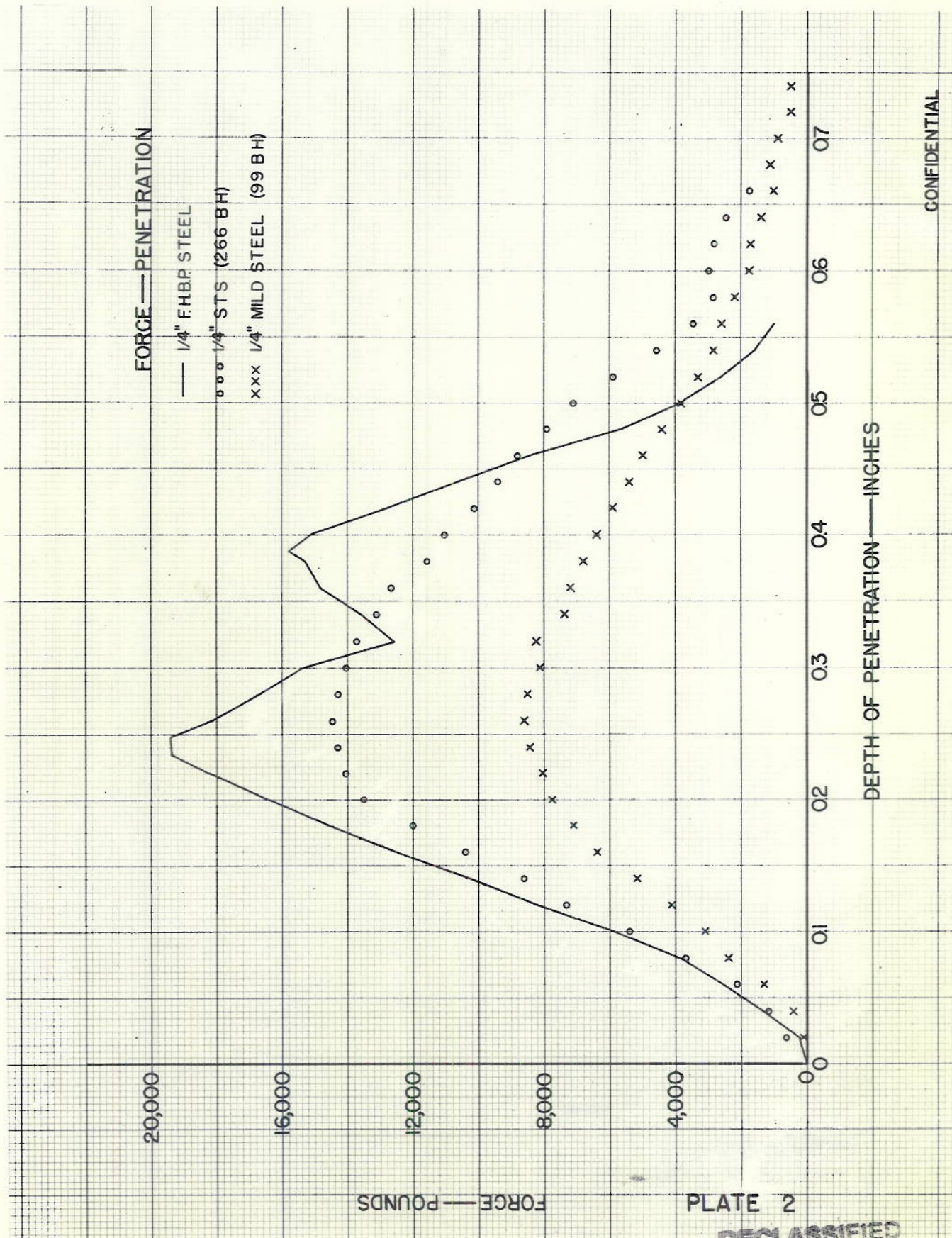
CURVE II
HARDNESS SURVEY OF 1/4"
ANNEALED F.H.B.P. STEEL

DEPTH FROM HARDENED FACE — INCHES

HARDNESS (DPH)

PLATE I

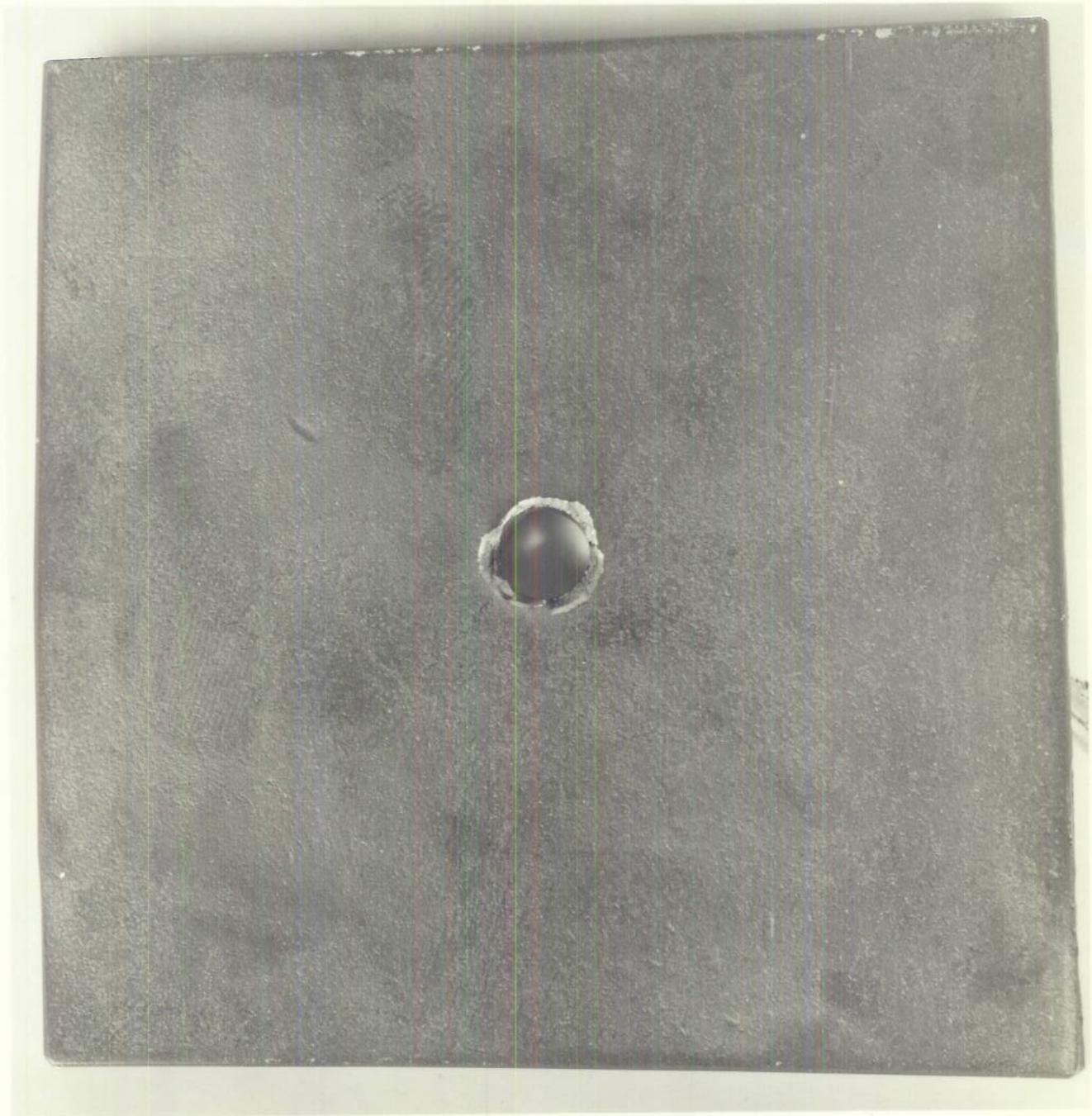
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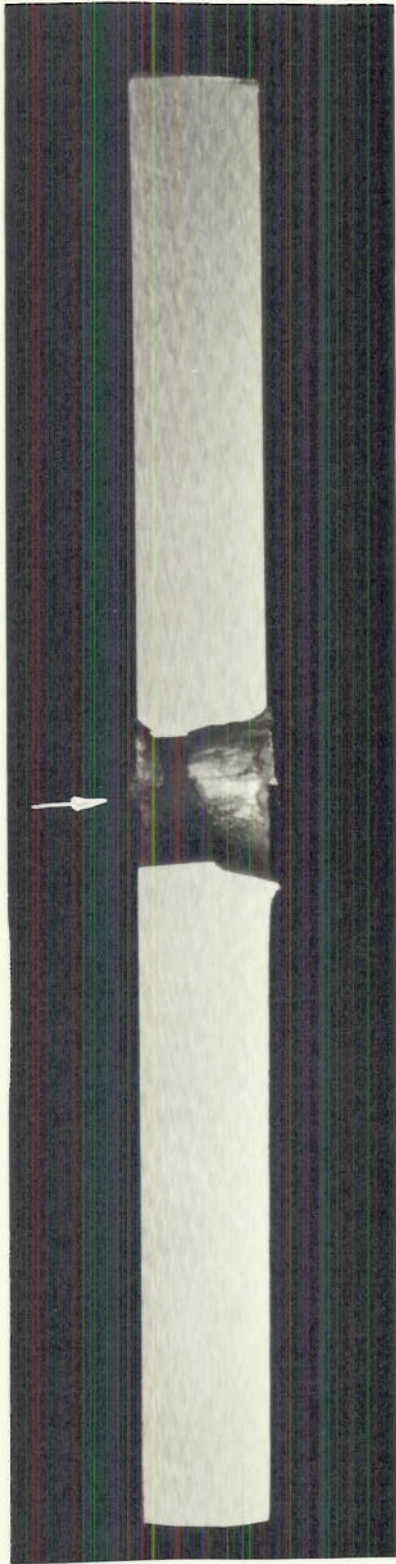


FACE VIEW OF PERFORATED F.H.B.P. STEEL

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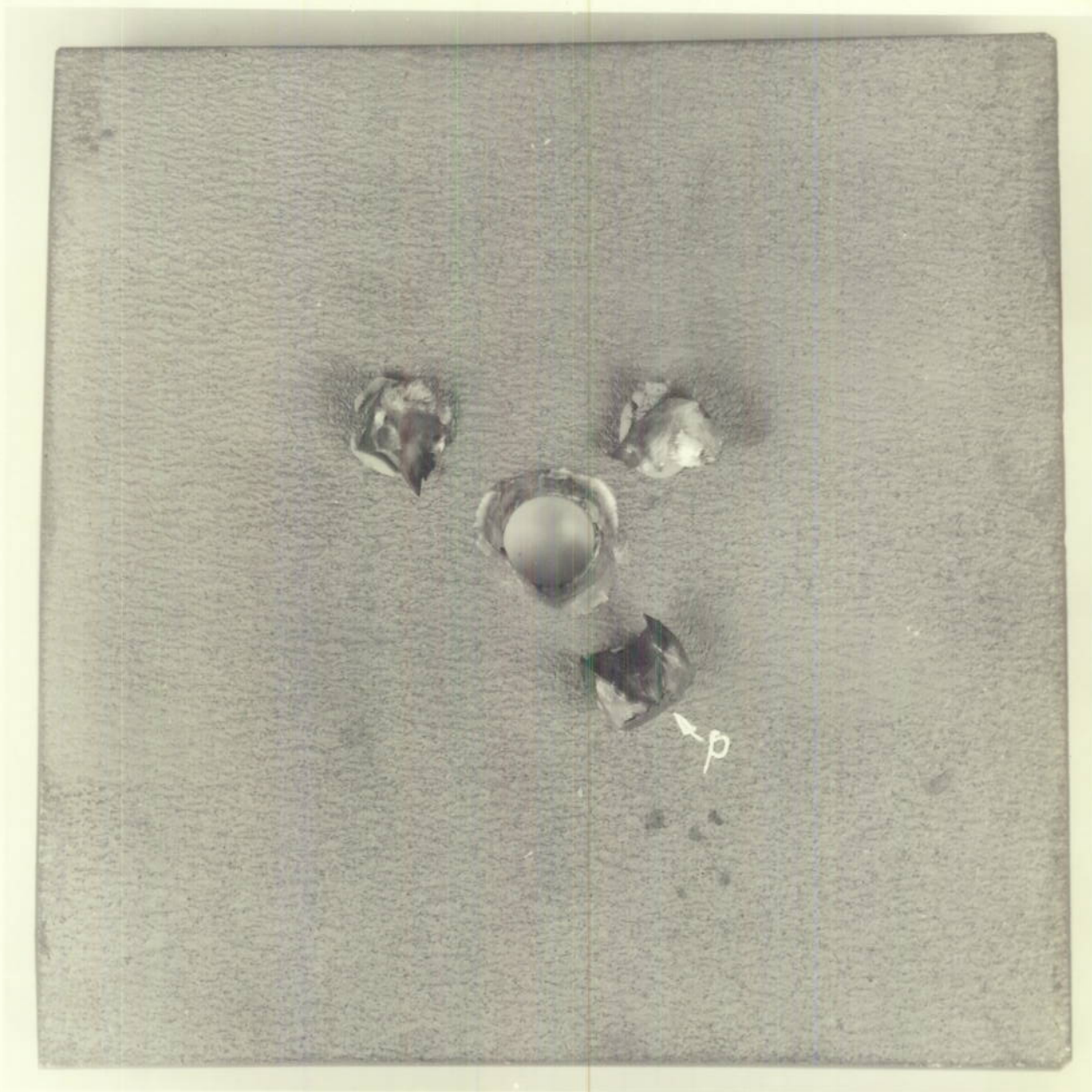
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CROSS-SECTIONAL VIEW OF
PERFORATED F.H.B.P. STEEL

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BACK VIEW OF PERFORATED F.H.B.P. STEEL

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