

**TM 5-855-1**

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**TECHNICAL MANUAL**

*Reference in RG 1.115 Rev. 2  
applicable pages only. (6-11 → 6-15)*

**FUNDAMENTALS OF PROTECTIVE  
DESIGN  
FOR CONVENTIONAL WEAPONS**

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**HEADQUARTERS, DEPARTMENT OF THE ARMY**

**3 NOVEMBER 1, 1986**

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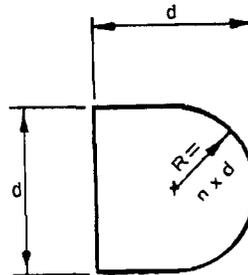
e. *Fragment shape, caliber density, and impact angle.* The assumed fragment shape for design purposes is shown in figure 6-6. This shape is not necessarily the most critical since it is statistically possible that some fragments will have a sharper shape than that shown. However, the number of these fragments is usually very small and the majority of fragments will have a more blunt shape than that shown. Therefore, the penetration predicted for the bullet-shaped fragment shown will be assumed as critical. Caliber density  $D_d$  is defined as

$$D_d = \frac{W_f}{d^3} \quad (\text{eq 6-7})$$

and the nose-shape factor  $N_g$  is defined by

$$N_g = 0.72 + 0.25 \sqrt{n - 0.25} \quad (\text{eq 6-8})$$

For the shape shown,  $D_d = 0.186 \text{ lb/in}^3$ ,  $n = 0.5$ , and  $N_g = 0.845$ . The impact angle is defined as the angle between the path of the fragment and the plane of the surface. In order to design for the most severe conditions, a normal (90-degree) impact angle is assumed.



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Figure 6-6. Primary fragment shape.

### 6-3. Penetration.

a. *General.* The impact of a fragment on a structure can have various effects ranging from possible shatter or ricochet of the fragment with essentially no damage to the structure to complete perforation of the elements. In addition to direct penetration effects, the impact may crater the structure on the front face and cause spalling on the rear face, especially in the case of concrete. The important parameters affecting damage to the structure are the characteristics of the fragment, the striking conditions, and the properties of the barrier material. The first two parameters were devined in paragraph 6-1. Design equations for perforation of various materials commonly used in construction and limits of spalling for concrete are presented below.

b. *Penetration of steel.* For the design fragment shape given in paragraph 6-1e and for normal impact conditions, penetration into common structural steel is given by

$$X = 0.21 W_f^{0.33} V_{sf}^{1.22} \quad (\text{eq 6-9})$$

where

- X = penetration depth, in.
- W<sub>f</sub> = fragment weight, oz.
- V<sub>sf</sub> = striking velocity, 10<sup>3</sup> fps

Thus, if the steel plate thickness t<sub>s</sub> is less than X, the steel will be completely perforated. The residual velocity of the fragment after perforation, in 10<sup>3</sup> fps, is given by

$$V_r = \left[ V_{sf}^2 - 12.92 \left( \frac{t_s}{W_f} \right)^{1.64} \right]^{1/2} / \left( 1 + 1.44 \frac{t_s}{W_f} \right) \quad (\text{eq 6-10})$$

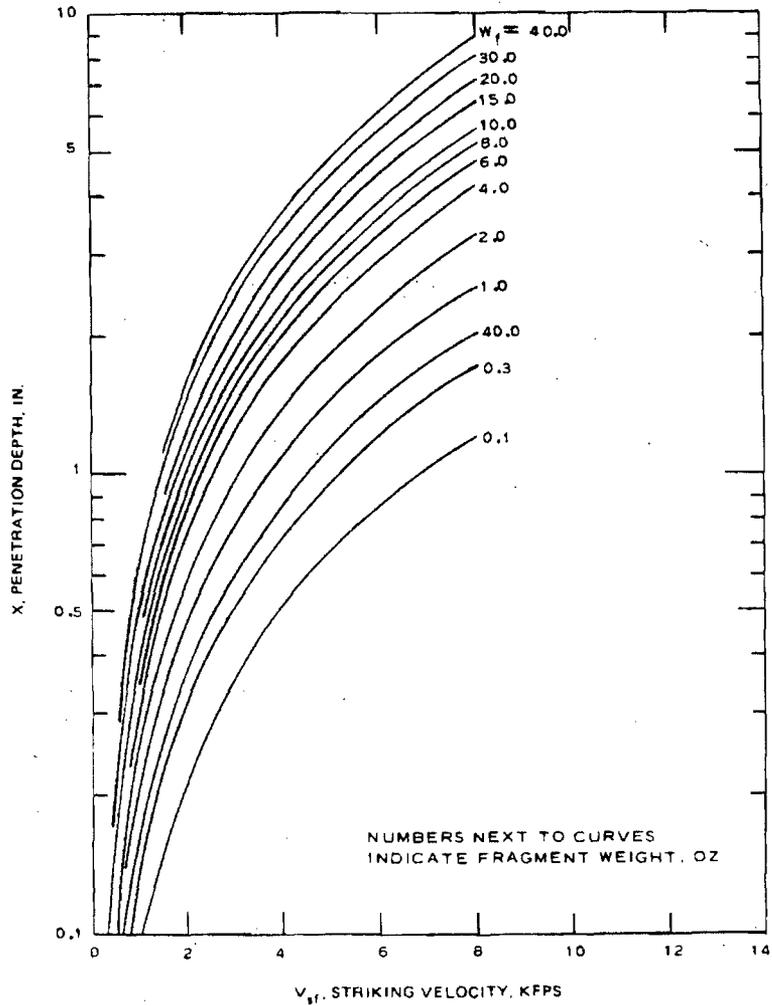
For other than common structural steel, perforation depth can be found from

$$X' = X \exp [8.77 \times 10^{-6} (B'^2 - B^2) - 5.41 \times 10^{-3} (B' - B)] \quad (\text{eq 6-11})$$

where

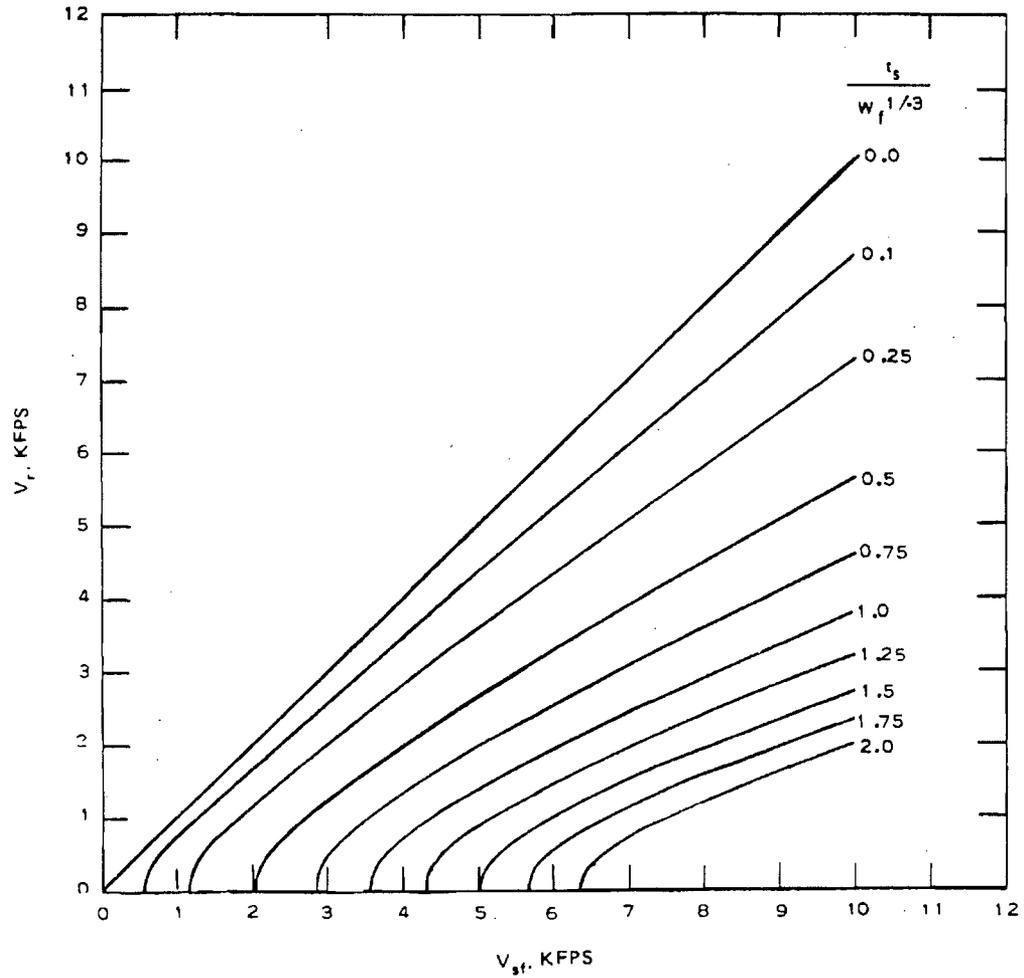
- X' = penetration into other than mild steel
- B' = Brinell hardness of other than mild steel
- B = Brinell hardness of common mild structural steel (taken as 150)

Figure 6-7 is a plot of X versus V<sub>sf</sub> for various values of W<sub>f</sub>. Figure 6-8 is a plot of V<sub>r</sub> versus V<sub>sf</sub> for various values of t<sub>s</sub>/W<sub>f</sub><sup>1/3</sup>. Finally, figure 6-9 is a plot of X'/X versus B'.



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Figure 6-7. Steel penetration design chart — mild steel fragments penetrating mild steel plates.



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Figure 6-8. Residual velocity after perforation of steel.

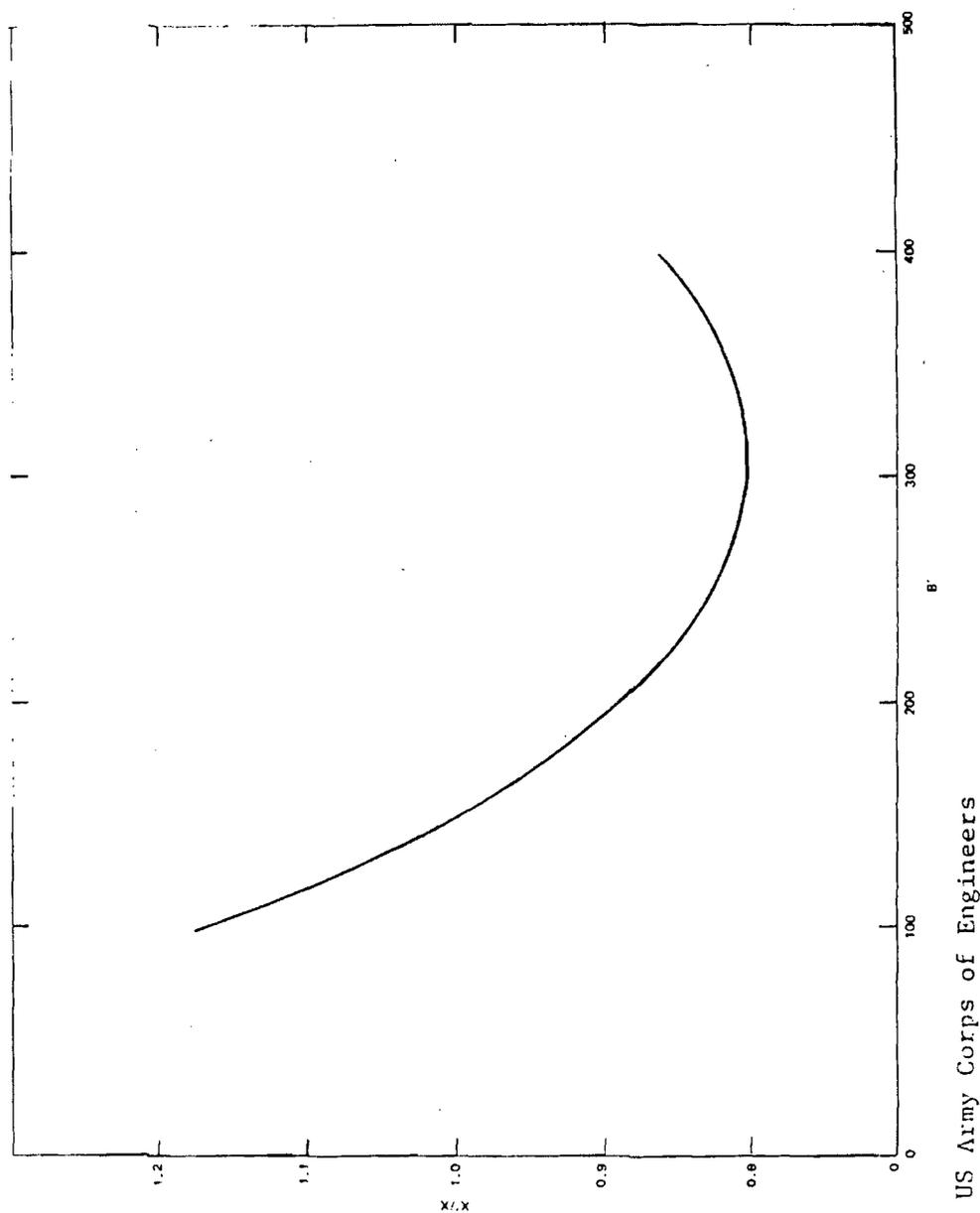


Figure 6-9. Variation of steel penetration with Brinell hardness.

*c. Penetration of concrete.*

(1) Penetration depth. The procedure for calculating the penetration effects in concrete is more involved than that for other materials due to significant spalling which may occur on the rear face. First, it is necessary to calculate the penetration depth into massive concrete by using the following two equations.