

PENETRATION PERFORMANCE OF SEGMENTED RODS – COMPARISON WITH CONTINUOUS RODS AT HIGH VELOCITY

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Abstract. A study was conducted to compare the high velocity penetration performance of segmented-rod projectiles of various spacer and segment lengths with that of continuous rod projectiles of the same mass and diameter. A high-pressure pre-burned propellant gun was built for this study. Analytical models by Tate and Charters were used to predict the penetration performance predicted. Computer simulations using the AUTODYN 2D package were run to study the penetration process. It was predicted that at velocities around 1800 ms⁻¹ and above, the performance of the steel-segmented rods was much superior to continuous rods. In trials, a 5-segment rod, with spacing of $l/d=2.25$, fired at 1800 ms⁻¹, achieved a penetration performance 44% higher than continuous rods of similar mass and diameter fired at similar velocities. Simulation of segmented projectiles with 10 segments, compared to continuous rod of similar mass and diameter, impacting at 3000 ms⁻¹, produces an increase of 59% penetration.

INTRODUCTION

Although segmented rods appear to give little advantage over continuous rods at low velocities, above 1.5kms⁻¹ the predicted penetration begins to be impressive. At 5kms⁻¹, penetration of a device with 15 segments is expected to be twice as effective as the same length of continuous rod, and with increasing velocity the advantage of the segmented device continues to grow [1]. Tests of segmented rods penetrating spaced armour showed that the armour is defeated by the front segment (or segments) punching a hole in the front plate allowing the remaining segmented rod through, intact, to attack the main armour [2]. The potential benefits of segmented rods over equivalent continuous rods are based on the advantage of multiple impacts by well aligned and well separated rod segments [3].

PENETRATION BY SEGMENTED RODS AT HIGH VELOCITY

Continuous Rod Penetration Prediction Using Tate's Model.

Tate [4] considered two cases of penetration. For the case of a hard penetrator against a soft target, the penetration process passes through two stages: at sufficiently high impact velocity, both the penetrator and target first flow hydrodynamically; later, after the penetrator has decelerated, it ceases to flow and penetrates as a rigid body. In the second case of a soft penetrator impacting a hard target, both penetrator and target initially behave hydrodynamically; then after the penetrator has decelerated to below a critical velocity, the initial stage of pure hydrodynamic behaviour is absent.

Tate takes into account the dynamic strength of the rod material, Y_p , and the target material strength at high strain rate, R_t , to predict penetration performance. Dynamic strength of the rod and target are obtained from the following formula:

$$Y_p = 1.7\sigma_{yp}$$

$$R_t = \sigma_{yt} \left(\frac{2}{3} + \ln \frac{1.14E_t}{2\sigma_{yt}} \right) \quad (1)$$

where σ_{yp} is the yield strength of the rod, σ_{yt} is the yield strength of the target, and E_t is the Young Modulus of the target. The study conducted assumes that $R_t > Y_p$ and the densities, ρ , of both the target and the rod are the same. In this simplified case, the penetration of the rod, p in relation to length of penetrator, l , is:

$$\text{For } \frac{R_t}{Y_p} = 1, \quad \frac{p}{l} = 1 - \exp\left[\left(\xi^2 - 1\right)\gamma^2\right]$$

$$\text{For } \frac{R_t}{Y_p} = 3, \quad \frac{p}{l} = \left(1 - \frac{2}{\gamma^2}\right) - \left(\xi^2 - \frac{2}{\gamma^2}\right) \exp\left[\left(\xi^2 - 1\right)\gamma^2\right]$$

$$\text{For } \frac{R_t}{Y_p} = 5,$$

$$\frac{p}{l} = \left(1 - \frac{1}{\gamma^2} + \frac{4}{\gamma^2}\right) - \left(\xi^4 - \frac{4\xi^2}{\gamma^2} + \frac{4}{\gamma^4}\right) \exp\left[\left(\xi^2 - 1\right)\gamma^2\right] \quad (2)$$

$$\text{where } \xi = \frac{v}{v_p} \text{ and } \gamma^2 = \frac{\rho v_p^2}{4Y_p}$$

(v_p is the impact velocity and v the instantaneous velocity)

Segmented Rod Penetration Prediction Using Charters' Model.

In describing the penetration process of a continuous rod in the hydrodynamic regime, Charters [5] assumes that the rod penetrates the target in two successive phases: a fluid dynamic phase, followed by a residual phase.

The fluid dynamic stage consumes the length of the rod, except for a residual length equal to the diameter of the rod. The rod penetrates the target as though it were a fluid jet impinging on a large body of fluid [6]. Since the rod is used up at the same rate that the interface penetrates the target (in case of target and penetrator of the same density), the depth of penetration of the fluid dynamic phase always equals the length of the rod involved, ($l-d$), regardless of the velocity.

$$\text{In general, } p_f = \sqrt{\frac{\rho_p}{\rho_t}}(l-d)$$