19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

A PARAMETER THAT COMBINES THE EFFECTS OF BEND AND ANGLE OF ATTACK ON PENETRATION DEGRADATION OF LONG RODS

Joaquín M. Campos, William Reinecke, and Stephan Bless

Institute for Advanced Technology, The University of Texas at Austin, 3925 W. Braker Ln., Suite 400, Austin, Texas 78759-5316

Very slender rods have been shown to have desirable properties when attacking armor at hypervelocity. Experiments with rods having fineness ratios approaching 50 have been reported [1, 2]. But such rods also have weaknesses: they inherently have small critical angles of attack and tend to bend in flight more than conventional slender rods [3]. Both of these properties tend to decrease the penetration of very slender rods. This study was undertaken to elucidate and quantify the combined effects of bending and angle of attack in reducing the penetration of slender rods. A volumetric interference parameter "**q**" will be introduced as a geometric method to associate a yawed or bent and yawed penetrator with its penetration performance. This method is independent of velocity, or penetrator material type so long as it is a constant cross-section monolith. A validation will be conducted to show its effectiveness as a performance characterization tool.

METHOD DESCRIPTION

The entirety of this method is based on the principle that volumetric interference of the penetrator with the crater walls during penetration will degrade terminal performance. There are two assumptions that are made in this approach. The first assumption is that the projectile is assumed to have little or no angular rate at impact compared to the time scale of the penetration event, and secondly that there is no deformation during initial penetration. Better said, we assume that the angular and bending rates are small enough that the penetrator's angle of attack and bend does not change significantly during the penetration event.

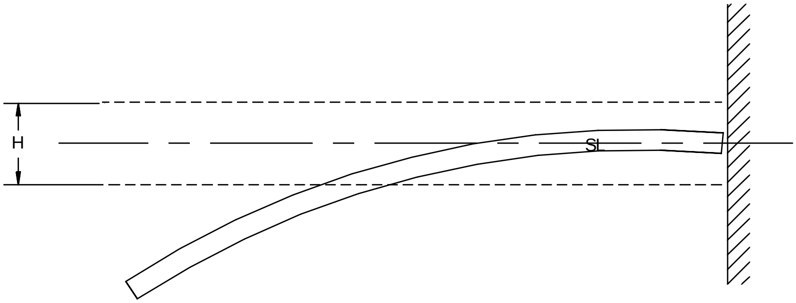

FIGURE 1. Defining geometric boundaries.

In order to relate the volumes of the penetrator and the crater it is necessary to describe the projectile in three-dimensional space an instant before impact. This approach required that the crater diameter (H) initiated by the nose of the penetrator be calculated as given by the empirical relation derived by Silsby *et al* [4]. The crater diameter (crater wall) is used as a geometric boundary from which interference between it and the penetrator is determined. The nose, or the crater-initiating element of the projectile, will be called the *principle point.*

To analyze the fit of the projectile through the impact crater, we considered the fit of the projectile within a tube whose forward end is centered on the principle point, and whose axis is parallel to the rod velocity vector. The tube diameter is the crater diameter, H. This tube or cylinder provides a geometric limit to judge projectile-crater interference, and any part of the projectile's body that protrudes out of the boundary cylinder will be judged as a degraded element. A figure of merit **q**, was derived by taking the projected length of the penetrator with respect to its velocity vector and dividing it by the length derived from the sum of the volumes of the interfering elements, those lying outside of the crater diameter H. **q** is given in equation form as:

$$q = \frac{I_L}{L_{proj.}} \tag{1}$$

where $\mathbf{I}_{\mathrm{L}}$ and $\mathbf{L}_{\mathrm{proj.}}$ are described as in Fig 2.

Home
Table of Contents

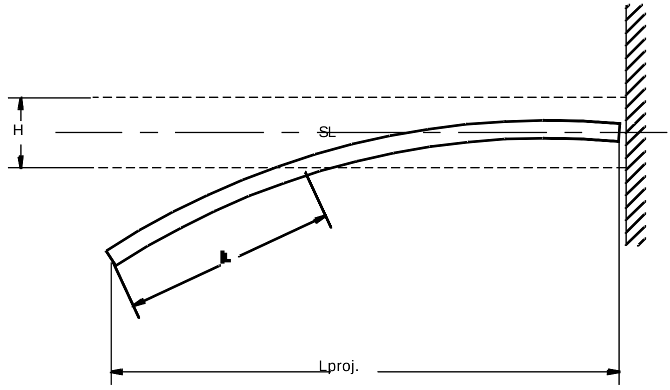

Figure 2. Defining **q**.

The length $\mathbf{I}_{\mathrm{L}}$ is defined as the total interference volume divided by the cross-sectional area of the penetrator and is written as:

$$\mathbf{I}_{\mathbf{L}} = \frac{V_i}{A_{cs}} \tag{2}$$

where V_i is the total interference volume between the penetrator and the crater. $\mathbf{L}_{\mathbf{proj.}}$ is defined as the projected length of the penetrator with respect to its velocity vector, and is measured from the center of the furthest up-range penetrator edge to the center of the furthest down-range edge parallel to shot line.

APPLICATION

The application of this method requires that pre-impact conditions are known well enough to plot a chosen set of points along the penetrator's centerline in 3-D space. A 3-D (solid) modeling program should then be used to plot the points. The penetrator body is then drawn, approximated with a series of segments of the correct penetrator cross-section extruded between the plotted points. The H cylinder is then constructed around the penetrator with solid corresponding to target material (i.e. a thick walled tube with the penetrator inside). The interference can then be determined between the penetrator and the cylinder by using an interference calculating routine that is available with most solid modelers. The value of **q** is then calculated as shown earlier. The penetration for **q** = 0 is denoted as $\mathbf{p}_{\mathbf{n}}$. This is the 'normal' penetration of a rod with perfect impact conditions. Presumably the degraded penetration $\mathbf{p}/\mathbf{p}_{\mathbf{n}}$ is a function of **q**. Once the functional form of $\mathbf{p}/\mathbf{p}_{\mathbf{n}}$ is known for a reference penetrator and target, the relative sensitivity of other targets and penetrators can be evaluated.

The technique could also be used as a predictive value of the performance of a bent and yawed projectile into a target with unknown performance, as long as the rod had previously been characterized with **q** into a known target. This then can be used to evaluate and compare a known target with an unknown target.

Thus this technique gives a method of correlating a non-dimensional parameter to degradation in penetration performance and can be used to get a comparison of sensitivity to **q**. Penetrator and target performance can now be evaluated even when a test goes "bad" and the angle of attack or bend is excessive.

VALIDATION

A case study was performed to show that a feasible correlation between **q** and penetration performance could be attained. The study's results show a trend of **q** with respect to penetration performance of a high L/D (42) right circular cylinder penetrator. The penetrators used for these tests were right circular cylinders made of A.O.T. tungsten, and the targets were normal RHA. All the penetrators were the same diameter but differing L/D's (see Table 1 below). The penetrators were shot at velocities between 2.1 and 2.2 km/s. All shots had some pitch and yaw, and in addition, some were bent. The Lanz-Odermatt penetration function [5] is used to predict normal penetration. Preliminary validation of **q** was done by graphing $\mathbf{p/p_n}$ vs. **q.** With the data set acquired, these graphs should show that there is a reasonable correlation for **q** with penetration performance. A graph of normalized angle of attack $\mathbf{p/p_n}$ vs. γ/γ_c, where γ_c is critical total angle of attack and $\mathbf{p_n}$ is the undegraded normal penetration, will be used as a comparison to $\mathbf{p/p_n}$ vs. **q** in order to see which correlation is more descriptive.

RESULTS

Data for the validation study is in Table 1 below. Values of **q** were attained using the method described above with the assistance of AutoCAD Mechanical Desktop for the solid modeling and interference volume calculations. The data for **q** and $\mathbf{p/p_n}$ [= $(P/L)/(P/L)_0$] are plotted in Fig. 3.

Table 1

Shot	L/D	V (m/s)		γ_C	γ/γ_C	Bend	q	$(P/L)_0$	P/L	$(P/L)/(P/L)_0$
387	45	2180	0.28	0.96	0.29	Y	0.007	1.30	0.95	0.73
392	42	2210	2.96	1.05	2.81	N	0.558	1.31	0.80	0.61
393	42	2210	1.60	1.05	1.52	Y	0.157	1.31	0.83	0.63
398	42	2210	4.31	1.05	4.09	N	0.686	1.31	0.51	0.39
409	42	2180	3.75	1.03	3.64	Y	0.640	1.30	0.62	0.48
417	42	2200	2.64	1.04	2.55	N	0.563	1.31	0.72	0.55
420	40	2200	1.50	1.08	1.39	Y	0.142	1.31	0.97	0.74
429	40	2210	0.48	1.08	0.44	Y	0.000	1.31	1.26	0.96
433	40	2240	0.89	1.10	0.81	Y	0.001	1.33	1.25	0.94
447	30	2160	1.82	1.42	1.28	N	0.020	1.29	1.17	0.90
451	30	2170	2.66	1.43	1.86	Y	0.126	1.31	1.00	0.77

The plateau in Fig. 3 of normalized penetration versus the interference parameter **q** between the values of .2 and .5 is suggestive. An explanation could be that there is a region where the penetrator interacts with the crater wall and ‘bounces’ back into the channel but not with enough velocity to interact with the other side of the crater wall before the penetration event is complete. In his CTH calculations of pitched rods impacting RHA, Littlefield [6] has observed a qualitative difference in the crater as the pitch angle increases from just above the critical angle to much above it. At the lower pitch angle, the crater resembles a mirror image of the impacting rod. That is, if the tail of the rod impacts to the right of the nose, then the bottom of the crater is to the right of the crater mouth. At larger pitch angles, the opposite occurs: a tail-right impact results in a crater the bottom of which is to the left. This suggests that there may be a range of intermediate, transitional pitch angles that result in a straight crater and that may correspond to the plateau in Fig. 3.

The next plot (Fig. 4) shows how normalized penetration varies with increasing γ/γ_C for the same data set as plotted for Fig. 3. Comparing this trend to the previous trend in Fig. 3 implies that some information is not being captured about the condition of the rod prior to impact when using the γ/γ_C correlation. The **q** method (Fig. 3) demonstrates a tighter grouping with an R^2 value that is about 10% better for a third order polynomial fit as compared to the γ/γ_C method (Fig. 4) for measuring penetration performance. Thus the volumetric interference method will be a more descriptive method of performance characterization.

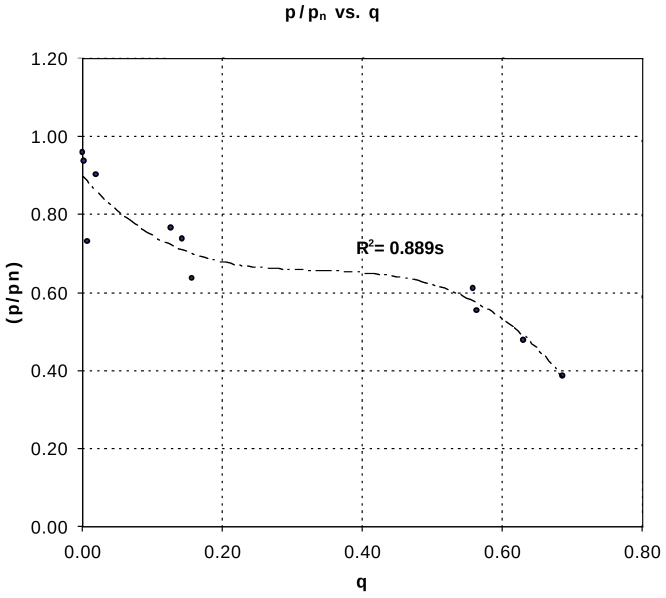

Figure 3.

Fig. 5 on the following page shows how **q** varies with increasing angle of attack. Again, these are all right circular tungsten cylinders into normal RHA at a nominal 2.2 km/s. This graph shows that the relation between **q** and angle of attack is behaving as one would expect: the higher the angle of attack, the higher the value of **q** thus not acting in a manner that would cause suspicion of the method's reliability. Using **q** also has the logical advantage of collapsing all values of γ/γ_C less than one, a regime where no penetration degradation should occur, onto a single value of **q** = 0.

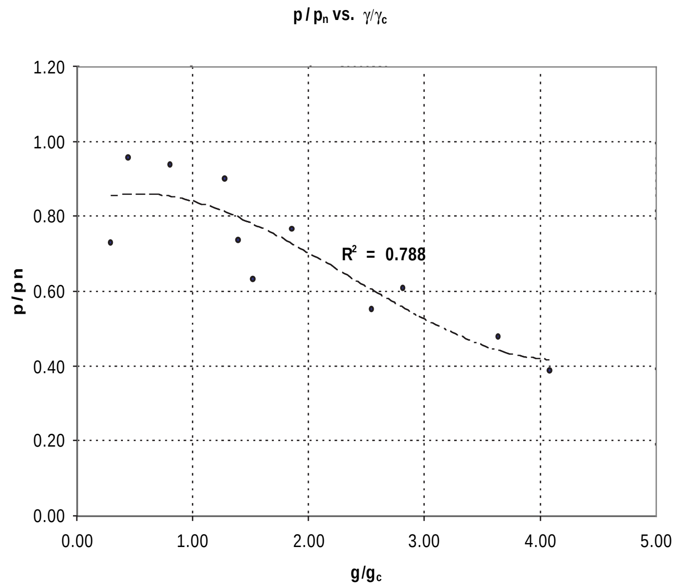

Figure 4.

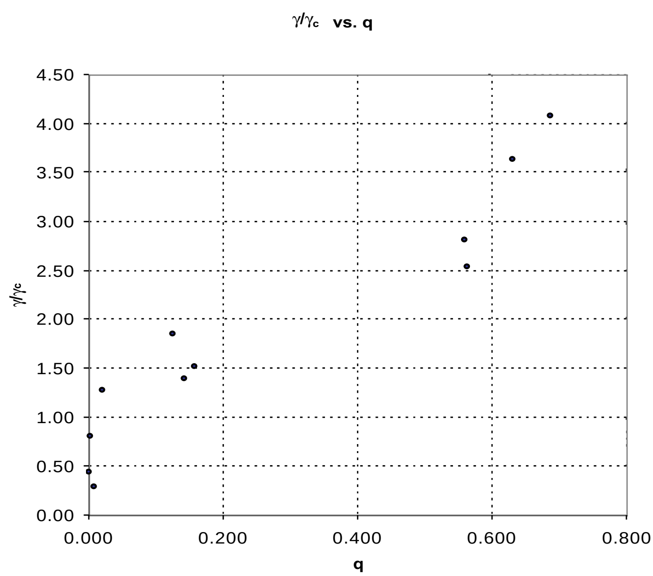

Figure 5.

CONCLUSIONS

Based on the results of this case study, the proposed method of penetration performance characterization seems viable. As in the applications section, the proposed parameter is a tool that could have many uses for both penetrator and target characterization. More studies should, and will be, conducted to verify the results by using other data sets for different penetrator L/Ds and velocities to see whether or not the same types of trends occur.

REFERENCES

1. W. Reinecke, H. Legner, and E. Lo, "Hypervelocity Projectile Design Implications at High Fineness Ratio," Paper 95-0064, AIAA 33rd Aerospace Sciences Meeting, Jan 1995, Reno, Nevada.
2. W. Reinecke, S. Bless, D. Barnette, and J. Campos, "Tongue-In-Groove Extending Rod [TIGER], A Novel Kinetic Energy Penetrator", Proceedings of the NDIA Second Joint Ballistics Symposium, Monterey, California, May 1999. (IAT.P0357, May 1999.)
3. W. Reinecke, "A Comparison Of RHA Penetration and Critical Angle of Attack Among Monolithic, Segmenting, and Extending Tungsten Rods At 2.5 Km/s", Proceedings of the 17th Int. Symposium on Ballistics, Midrand, South Africa, Mar 1998. (IAT.R 109, Apr 1996.)
4. G. Silsby, R. Roszak, and L. Giglio-Tos, "BRL's 50mm High Pressure Powder Gun for Terminal Ballistics Testing – The 1st Years Experience", BRL-MR-03236, U.S. Army Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, Jan 1983.
5. W. Lanz and W. Odermatt, "Penetration Limits of Conventional Large Caliber Anti-Tank Guns / Kinetic Energy Projectiles", 13th Int. Symposium on Ballistics, FOA, Sundyberg, Sweden, 1992.
6. D. J. Gee and D. L. Littlefield, "The Effect of Yaw on the Penetration of Long-rod Projectiles", 9th Annual Army Ground Vehicle Survivability Symposium, Monterrey, CA, Mar 31–Apr 2, 1998.

ACKNOWLEDGMENT

This work was supported by the U.S. Army Research Laboratory (ARL) under contract DAAA21-93-C-0101.