A Comparison of Three Empirical Methods for Concrete Penetration Depth by a High Speed Ogive Shaped Projectile

BM Wade

Department of Aerospace Engineering Georgia Institute of Technology Atlanta, GA, USA

Corresponding author's Email: brian.wade@gatech.edu

Author Note: Brian Wade holds a PhD in Aerospace Engineering from the Georgia Institute of Technology. His research interests include combat modeling, metamodels of computer simulations using machine learning, air vehicle design, and military wargaming. This work was completed as part of his dissertation research.

Abstract: This paper compares experimental data to three empirical models for determining the depth of penetration into concrete for a hard ogive shaped projectile fired at high speed normal to the surface of the concrete. The three empirical models are the Modified National Defense Research Council Formulas, the Haldar-Hamieh Formulas, and the Sandia Formulas. These empirical methods are compared to six experimental test cases published in three separate articles for concrete with an unconstrained compressive strength ranging from 34.6 MPa to 62.8 MPa shot with different sized and shaped light-weight projectiles. The results show that the Sandia Formulas predicted the concrete penetration depth closest to the observed depth, but only for impact velocities less than 800 meters per second.

Keywords: Concrete Penetration, Projectile, Impact Engineering

1. Introduction

There is a significant amount of ongoing research into concrete penetration theories. An excellent summary of the current work is from Li, Reid, Wen, and Telford (2005). Most research in the last ten to twenty years has been in the field of numerical simulation using software such as ABAQUAS, AUTODYN, and LS-DYNA (Yu, Spiesz, & Brouwers, 2013). This is because concrete has a complicated, non-linear response to impact loading (Haldar & Hamieh, 1984; Yu et al., 2013). As a result, there is not a closed form solution for the penetration depth of a projectile into a concrete structure. Most empirical formulas make use of test data curve fits or very idealized models. Although numerical simulation is more accurate than these empirical formulas, the empirical formulas have the advantage of computational speed and can capture a wide range of impact and target conditions that would be difficult for a single numerical model (Ben-Dor, Dubinsky, & Elperin, 2005). For first-order analysis, these empirical formulas are even recommended by various Army and Air Force Manuals (Li & Chen, 2003). The computational speed of the empirical formulations make them excellent candidates for parameter sweep analysis during the conceptual design phase, or for stochastic optimization during the preliminary design phase. Both of these types of analyses require many function calls, making the computationally expensive numerical simulations impractical.

2. Empirical Formulas

The focus of this paper is to compare the performance of three of the most commonly used empirical formulas for concrete penetration depth against experimental data. The three empirical formulas are the Modified National Defense Research Council (NDRC) formulas, the Haldar-Hamieh formulas, and the Sandia formulas. An underlying assumption for all three models is that the impacts occur at high-speed with non-deformable missiles. In reality, all missiles that impact at high speeds will deform to varying degrees. The deformation has the effect of reducing the actual depth of penetration; however, the missile must deform at least 40% of their non-deformed shape before the deformation effects become significant (Kennedy, 1976). The experimental penetrators used for this analysis did not deform a significant amount making the hard impact assumption valid. Each of the three empirical formulas will be addressed in the following sections. This is then followed by an overview of the experimental data used for the comparison. The final section is a review of the experimental penetration depth against the predicted penetration depth based on the three empirical formulas.