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Experimental and numerical analysis of the effect of the angle of impact of rigid projectiles on the depth of penetration and the amount of deflection in semi-infinite concrete targets

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Abstract

Penetration of projectiles in concrete targets may be oblique for various reasons, which, in addition to making its analysis more complicated, affects the penetration depth of projectiles. Therefore, it is necessary to study the penetration path and finally the penetration depth of the projectiles in the targets. In this article, numerical and experimental results have been investigated and compared for the oblique penetration path of a rigid projectile in concrete with compressive strength properties of 35MPa. LS Dyna software is used for numerical simulation and RHT model is used to express the behavior of concrete. The required coefficients for this behavioral model have been finally calibrated and extracted by performing Triaxial and Brasilia and Uniaxial tests. The projectile is made of hard steel to have the least deformation, so heat treatment was performed on them, as a result of which their hardness increased to 40 HRC and their yield strength increased to 1000 MPa. In addition, experimental ballistic tests have been performed at different speeds and angles, and after the test, the samples have been scanned to determine the penetration path of the projectile. The results show a good agreement between the numerical and experimental methods and the numerical method has been able to estimate the penetration behavior of the projectile in concrete.

Keywords: Oblique penetration; Path of penetration; Concrete scan; RHT model.

1. Introduction

Given the importance of designing resilient structures, the impact and penetration effects of rigid projectiles in concrete structures have been of interest since the 11th century. The need to obtain the results of scientific studies and research conducted in the world is one of the most important needs for the development of passive defense and its scientific culture at the level of society. The extent of this need is more related to specific categories of passive defense, including the category of safe structures. In modern battlefields, many valuable targets such as command and control centers, ammunition storage, etc., are protected by concrete structures.

Many studies have been conducted on normal penetration of concrete targets, the most important of which is the study by Forrestal et al. [1] in 1992 to predict the depth of penetration of a ogive projectile into soil. For this purpose, a gas gun was fired into the soil and the experimental, analytical and numerical test results were compared with each other. The problem of oblique impact of a projectile and its penetration into a target, which has many practical applications, has attracted the attention of many researchers. Chen et al. [2] investigated the analytical method of oblique and normal penetration of a projectile in thin and semi-infinite concrete targets. Liaghat et al [3]. analyzed the penetration of conical projectiles into thin metal targets under oblique angle impact and proposed an analytical model for it.

Kang et al. [4] presented a new formula for assessing local damage to thin reinforced concrete structures caused by oblique impacts based on experimental results and comparing the results with numerical simulation using LS Dyna software. Xiaojing et al. [5] numerically studied and investigated the trajectory deviation of the ogive projectile due to an

oblique impact at an angle of 70 degrees for two types of concrete and soil targets using LS Dyna software and examined the penetration depth and penetration velocity curves and energy changes.
When a projectile penetrates a target at an oblique angle, the asymmetric loading on the projectile surface leads to deflection of the projectile during penetration. Therefore, accurate prediction of the penetration path is an important issue during deep penetration. The deflection of the projectile during the penetration process can be affected by various factors, including the oblique angle of impact, the impact velocity, the shape and geometry of the projectile, and the strength of the target material. Most of the work done on oblique penetration has been for thin targets that the projectile pierces and completely passes through, and the investigation of the penetration path of the projectile during oblique impact in semi-infinite targets has not been done accurately.

2. Experimental Method

2-1 Preparation of projectile samples

The samples were made with an ogive nose with a diameter of 8 mm and a length of 27.31 mm and a ratio of the radius of curvature of the nose to the diameter (R/d) of 4, as shown in Figure (1).

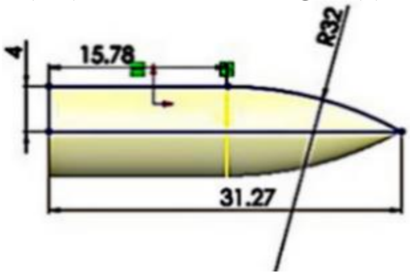

Figure 1. Dimensions of the projectile sample

2-2 Penetration Tests

To conduct ballistic tests, a combustion launcher was used as shown in Figure (2).

Figure 2. Combustion launcher

Then, for all tested samples, the concrete target was photographed to determine the penetration path, projectile stopping point, and penetration depth in all tests.

2-3 Determining the Properties of Concrete Targets

concrete compressive strength and axial, lateral, and volumetric strains is shown in Figure (3).

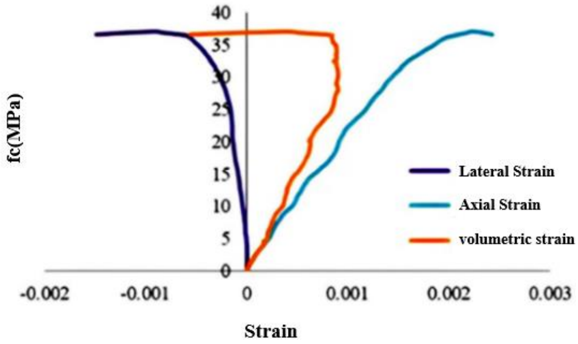

Figure 3. Stress-strain diagram from uniaxial compressive strength test of C35 concrete

3. Numerical Method

In this research, LS Dyna software has been used for simulation. Explicit and Lagrangian methods have been used for solving. RHT method has also been used for modeling the concrete damage model in this paper.

3-1 RHT Model

For accurate modeling of concrete behavior during impact and surface cracking, the RHT model is one of the best options. This model is able to simulate the behavior of cracks and surface failure of concrete under severe dynamic loads well.

3-2 Numerical Modeling Method

For numerical simulation, LS Dyna software was used. Also, RHT material model was used to estimate the behavior of concrete. The modeling was done in a completely three-dimensional manner. Figure (4) shows the modeling of the target and projectile as well as the angle of the projectile.

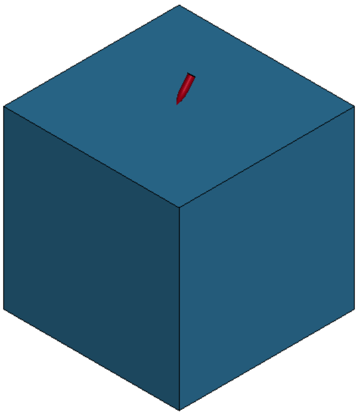

Figure 4. Target and projectile modeling in LS Dyna software

4. Results and Discussion

To scan the concrete target samples, a CT scanner with different capacities was used according to the dimensions of the concrete target samples.

Figure (5) shows two concrete target samples after testing along with the scan results.

Figure 5. Sample photo after testing and scan results for a projectile with impact angle of 5 degrees and an impact velocity of 552 m/s

To measure the path and depth of penetration in the numerical method, the geometric location of the tip of the projectile sample is calculated at any moment and finally the penetration path is extracted. In Figure (6), the geometric location of the tip of the projectile sample is shown for an angle of 5 degrees.

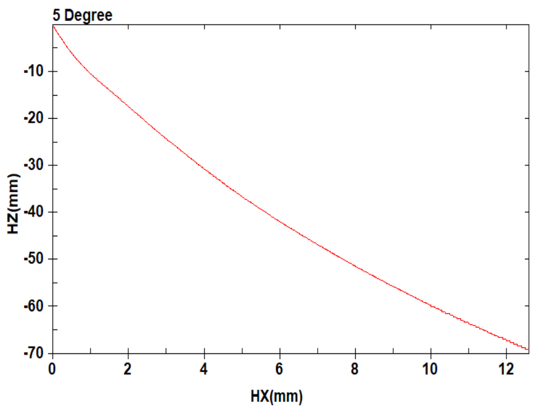

Figure 6. Geometric location of the tip of the projectile with an impact angle of 5 degrees and impact velocity of 552 m/s in numerical method

Also, the results of numerical simulation and comparison of the damage model for an impact angle of 5 degrees with the experimental method are given in Figure (7).

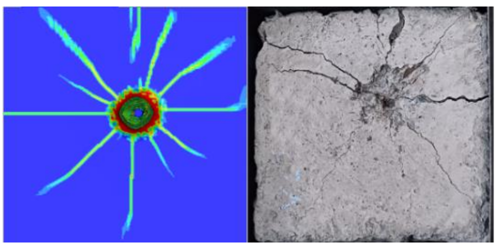

Figure 7. Comparison of damage results of numerical and experimental methods for an angle of 5 degrees and a velocity of 552 m/s

The geometric location of the projectile tip trajectory in each simulation mode has been extracted and compared with the penetration trajectory in the experimental method, which is shown in Figure (8) for an angle of 5 degrees, and the results indicate that the numerical and experimental results are close.

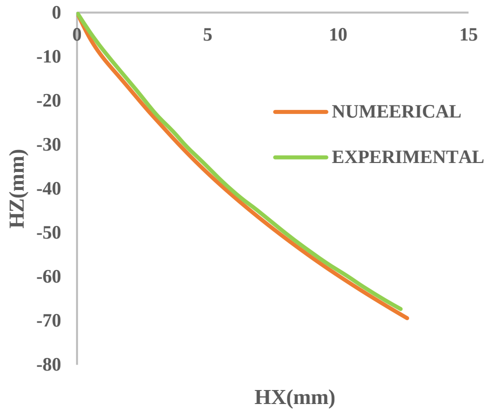

Figure 6: Comparison of the projectile penetration path by numerical and experimental methods for angle of 5 degrees and an impact velocity of 552 m/s.

Table (1) shows the results of the geometric location of the projectile stopping point for numerical solution and experimental test for different angles and velocities. The results show good prediction of the numerical method with the experimental method, and the penetration depth decreases with increasing impact angle.in table Length dimensions are in mm and angle in degrees.

Table1. Comparison of numerical solution results and experimental method for the geometric location of the projectile tip stopping point

Velocity(m/s)	Oblique Angel	Numerical(Z)	Numerical(X)	Experimental(Z)	Experimental(X)	Error(Z)%	Error(X)%
546	0	70/6	0	69/2	0	2/2	0
552	5	69/4	12/6	67/3	12/4	3/2	1/6
549	10	64/3	20/9	60/3	20.2	6/7	3/5
550	15	60/3	29/1	55/2	27/8	9/3	4/7
606	20	63/4	45/5	57	42	10/8	8/3

5. Conclusions

In this paper, numerical and experimental results for the inclined penetration path of a rigid ogive projectile in concrete targets with compressive strength properties of 35MPa have been investigated and compared. The RHT behavioral model has been used for numerical simulation, and the required coefficients of concrete material behavior have been extracted by performing various tests and calibrating the coefficients, and a qualitative comparison of the results of numerical simulation with experimental observations and using the results of reputable articles has been obtained. The projectile is made of hard steel to have the least deformation. Experimental tests have been performed for different velocities and angles, and after performing ballistic tests, the results have been scanned. The results of the projectile penetration path show a good agreement between the numerical and experimental methods, and the numerical method has been able to estimate the behavior of concrete well. The amount of projectile penetration during the penetration process is affected by various factors, including the oblique impact angle and impact velocity.

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