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Numerical analysis of shaped charge jet penetration into discrete concrete targets using LS-DYNA and ANSYS-AUTODYN

H. Mehmannavaz[1], A. Ramezani[2], G. Liaghat[3], H. Fazeli[*4], M. Rouhbakhsh[5], M. A. Nabakhteh[5]

[1] Mechanical Engineering Department, Mechanical, Electrical and Computer Engineering Faculty, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2] Mechanical Engineering Department, Mechanical Engineering Faculty, Sharif University of Technology, Tehran, Iran
[3] Mechanical Engineering Department, Mechanical Engineering Faculty, Tarbiat Modares University, Tehran, Iran
[4] Mechanical Engineering Department, Mechanical Engineering Faculty, Malek Ashtar University, Tehran, Iran
[5] Mechanical Engineering Department, Mechanical Engineering Faculty, Tehran University, Tehran, Iran

ABSTRACT: Discrete concrete targets show more resistance to penetration against shaped charges. The purpose of this study is to simulate the penetration of shaped charge in discrete concrete targets using LS-DYNA and ANSYS-AUTODYN and compare the results. For this purpose, the simulation process for one of the experimental results is performed and the results obtained from both software are validated. Finally, the results of two software in the fields of jet velocity, penetration depth, entry diameters, middle and exit crater, and run time are compared. Application of the ALE method for jet elements and the RHT concrete model to simulate the concrete behavior at high strain rates yielded good results. Differences in numerical solution method and command differences in the interaction of the Lagrangian and Eulerian elements in two software caused the depth of penetration in ANSYS-AUTODYN to be less than the LS-DYNA and the diameters of entry, middle and exit crater in ANSYS-AUTODYN become larger than the LS-DYNA and closer to the experimental results. The results of the two software are in good agreement with the experimental results. Continuous concrete was also simulated and it was found that the penetration depth of discrete concrete was lower than continuous concrete.

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1- Introduction

A cone-shaped container filled with explosives at one end and a detonator at the other end is called shaped charge. The shaped charges show a remarkable penetration in targets and a remarkable penetration-to-destruction ratio, as well. In peaceful applications, shaped charges are used for excavation, while in military applications, they are used against safe structures and various types of armors.

Concrete is widely used for the construction of safe structures. One of the methods to secure these structures is to use discrete concrete structures. Therefore, the need to analyze and secure these structures against impact and penetration has been considered.

Previous studies have shown that discrete targets are more durable against high-velocity projectiles and result in a lower penetrated depth compared to the uniform targets [1,2]. However, the velocity of the projectile in these studies is much lower than the shaped charge, and a few studies have been performed in this field.

The purpose of this study is to compare the results of the analysis of the formation and penetration of the shaped charge in discrete concrete targets using LS-Dyna and Ansys-Autodyn software. So far, various models such as RHT and Johnson-Holmquist models have been proposed to simulate the behavior of concrete at high strain rates. Each of these models has shown acceptable results in various studies.

In order to validate the simulation results, the experimental results of Wang et al. [3] were used and then, considering the existing relations for cut-off velocity, important parameters in the study of the shaped charge penetration process (including penetration depth, crater diameter of the hole, and jet tip velocity) have been examined and compared.

2- Numerical Simulation

Regarding the axial symmetry in the geometry of the shaped charge and target, the problem is modeled as s 2D case with axial symmetry to reduce significantly the calculation and runtime duration. ALE elements have also been used to simulate explosives, liners, and the air. The advantage of using the ALE elements rather than the Eulerian ones is the deformation of the elements, which reduces the displacement of the material and the solving duration [4]. Concrete target elements are also defined as Lagrangian ones. Table 1 shows the strength model and the considered equation of state of different components of the shaped charge in the two software.

*Corresponding author's email: hamidfazeli1985@gmail.com

Fig. 1. Setup of the test [3]

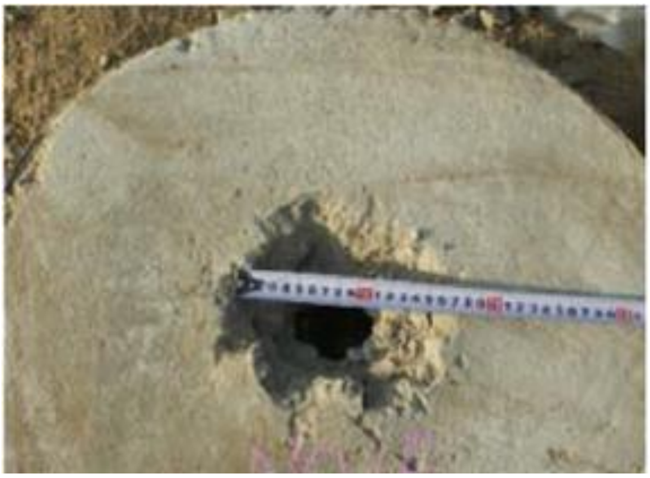

Fig. 2: Hole crater of the first target [3]

3- Results and Discussion

In order to validate the simulations, the experimental results Wang et al.'s study [3] were used. Fig. 1 shows the setup of Wang et al.'s experimental study, and Fig. 2 shows the penetration in the first target. The jet tip velocity at the moment of touching the target, hole diameter, and penetration depth are compared in Table 1. To calculate the penetration depth, the simulation is stopped right at the moment that the jet reaches the cut-off velocity. Using the results of Murphy's study [5], the cut-off velocity of copper penetration in the concrete is 1430 m/s.

In addition to the penetration depth, some other parameters are also important. Among these parameters are the diameter of the entry, the middle, and the output diameters. As can be seen in Table 1, Ansys-Autodyn calculated the middle diameter as 15 mm larger than the experimental value, while LS-Dyna calculated it as 15 mm smaller.

This could be due to differences in the interaction between Lagrangian and Eulerian elements in the two software. In the jet penetration process, it seems that the Ansys Autodyn couples more Lagrangian elements of the target with Eulerian jet elements. The same holds for the output diameter, and the output diameter in the Ansys-Autodyn simulation is 20 mm larger than that of LS Dyna, which, of course, is more consistent with the experimental results.

4- Conclusions

The use of the ALE method to simulate the process of penetration of the shaped charge jet in the concrete was efficient in both LS-Dyna and Ansys-Autodyn software and makes use of the advantages of both Lagrangian and Eulerian methods.

The results obtained from the RHT concrete model show the efficiency of this model for simulation of the behavior of concrete in loads with a high strain rate.

The jet tip velocities in both software are very close to each other and show relatively good agreements with the generalized PER theory. The concrete damage parameter in LS-Dyna gives reasonable results for concrete destruction and the entry, middle, and output crater diameter. In Ansys-Autodyn, the radial cracks created in the concrete provide a good pattern of the amount of damage and destruction.

The differences between the numerical solution methods used in the two software and the differences in the interaction method of Lagrangian and Eulerian elements in the two software resulted in a smaller penetration depth in Ansys-Autodyn than that of LS-Dyna, and higher entry, output and middle crater diameters in Ansys-Autodyn than those of LS-Dyna, as well. The penetration depth in LS-Dyna, and the entry, middle and output crater diameters resulted from Ansys-Autodyn were closer to the experimental results.

Regarding the reasonable results of both software, it is acceptable to use either of these two software so as to simulate the shaped charge penetration process and there are not much differences between the results. The LS-Dyna software is faster in solving the problems, and has more controlling capabilities for material models and command codes (especially the Lagrangian and Eulerian elements interaction), while the advantage of Ansys-Autodyn software is its easier simulating process and achieving acceptable accuracies for longer solving runtimes.

Totally, the comparison between the results of the simulations of discrete and uniform concrete targets indicates the reduction of the penetration depth in concrete, which is because of the discrete design of concrete target.

Table 1. Comparison of simulation and experimental results

parameter	Jet tip velocity (m/s)	Entry diameter of the hole crater (mm)	Penetration depth (mm)
Experiment [3]	7494	180	538
Ansys-Autodyn	5910	164	420
Error of Ansys-Autodyn	21%	9%	22%
LS-Dyna	6108	162	470
Error of LS-Dyna	18%	10%	13%

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