SIMULATION OF GEOPENETRATOR IMPACT IN THE HIGH VELOCITY REGIME

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Hard and deeply buried targets are difficult to defeat with presently introduced weapon systems that operate in the velocity regime around 300 – 400 m/s. These new targets consist of a combination of different layers built up of sand, soil, rock and concrete and require a high penetration performance of the impacting projectile. The design of the necessary penetrator poses high requirements concerning the structural stability, penetration performance and impact conditions. Impact velocities for this application are in the range between 1000 and 1500 m/s. To improve and shorten the design process for these penetrators numerical simulations are helpful.

This work presents a simulation model capable of analysing typical problems occurring during the design process of high velocity geopenetrators. The model is based on a generic penetrator design and a representative monolithic concrete target. It can be used to analyse the influence of impact conditions on the structural loading of the projectile, the influence of impact velocity on penetration performance and the loads which the high explosive filling experiences during the penetration or perforation process.

INTRODUCTION

The process of penetration and perforation of high velocity geopenetrators gets more and more attention especially through the appearance of hardened targets. Experiments are often performed with scaled penetrators and targets to facilitate the handling and reduce the necessary target size. As concrete is one of the main constituents of real targets, tests are very often performed with plain concrete targets. In the open literature experimental data about such tests can be found for velocities ranging from 200 m/s up to 4300 m/s [1,2,3,4,5,6]. The behaviour of the penetrator depends strongly on the impact velocity. Most of the experimental data reported in the literature are in the velocity range up to 1000 m/s [1,2,3,5]. The penetration behaviour in this range is characterized by a rigid body motion within the target and none or only small erosion at the penetrator tip. A reasonable description can already be reached with analytical and empirical techniques [1]. Limited data is reported in the literature for very high velocities from 2000 m/s up to 4300 m/s [6]. Increasing velocities lead to a mushroom effect at the penetrator tip with strong erosion of the penetrator material (even complete penetrator erosion). The physical interpretation within this velocity range is easier because the high velocities lead to impact pressures that are significantly above the material strength and thus the purely hydrodynamic theory can be used for interpretation [7]. Presently most interest is focused on the velocity range between 1000 m/s and 2000 m/s which corresponds roughly to the transition region between rigid body motion of the penetrator and a purely hydrodynamic behaviour. Here already significant erosion of the penetrator tip is observed but material strength effects are still important [4]. Modified hydrodynamic theory can be used for first analysis but deeper understanding is only possible with numerical simulations. In this velocity range the involved materials (penetrator casing, HE filling, concrete target) experience very dynamical loads (high stress and strain states, high strain rates). Reliable simulations depend therefore on an exact material characterization in this loading regime [8,9,10]. An important point, too, is the selection of a numerical scheme that is available to treat the physical erosion at the penetrator tip. The presented work introduces a numerical simulation model applicable to the description of processes during high velocity geopenetrator impact.

PROBLEMS OF HIGH VELOCITY GEOPENERATOR DESIGN

The development of high speed geopenetrators requires the solution of the following three key problems: structural stability of penetrator casing, insensitive HE that survives the impact and a shock resistant fuze system. Numerical simulations can provide support for all three questions. This work concentrates on the analysis of stress and strain loading of the HE filling and on the stability of the penetrator design.

The HE filling experiences extreme stress and strain conditions during impacts in the velocity regime up to 1500 m/s. They can lead to modifications of the HE (debonding, crack formation) that might lead to formation of an increased number of hot spots and thus to an increased sensitivity of the HE. An important question to be answered is therefore what are typical load conditions of the HE filling and how do they change the HE and its sensitivity. This work shows how typical HE loads can be determined with numerical simulations.

Another important point concerns the stability of the penetrator casing. In the high velocity regime the impact pressures are already higher than the strength of the materials involved. In this case the penetrator tip starts to deform strongly and even erodes, which can lead to failure and disruption of the penetrator casing. Especially inclined impact conditions (aoi: angle of incidence, aoa: angle of attack) lead easily to catastrophic failure of the penetrator. Numerical simulations allow a detailed assessment of penetrator stability and deformation as a result of varying impact conditions and penetrator design modifications.

SIMULATION MODEL

The numerical models used for the simulations are shown in fig.1. For all grids a Lagrange representation was used. The Lagrange grid interaction is based on a numerical erosion algorithm for the strains in strongly deformed cells. It is assumed that the numerical erosion algorithm describes reasonably well the physical erosion of the penetrator tip and the concrete material in the interaction zone. The involved materials are: penetrator casing (high strength steel), HE filling and the concrete target. Following models were used:

- Concrete (RHT, Drucker-Prager)
- HE (elastic-plastic, viscoelastic)
- Steel (Johnson Cook).

Depending on the impact conditions 2D or 3D models have to be used. For normal impact conditions 2D models are sufficient and allow already many types of analysis. For example pressure distributions in the HE, deceleration of the projectile or penetration depth can be determined. Inclined impact conditions (aoa and aoi) require the use of 3D geometrical models. More detailed studies on the structural stability of the casing, flight path in the target and penetrator deformation are possible. The penetrator design is not optimized with respect to casing stability but represents a generic design intended for studying the dynamical loads experienced by the HE filling.

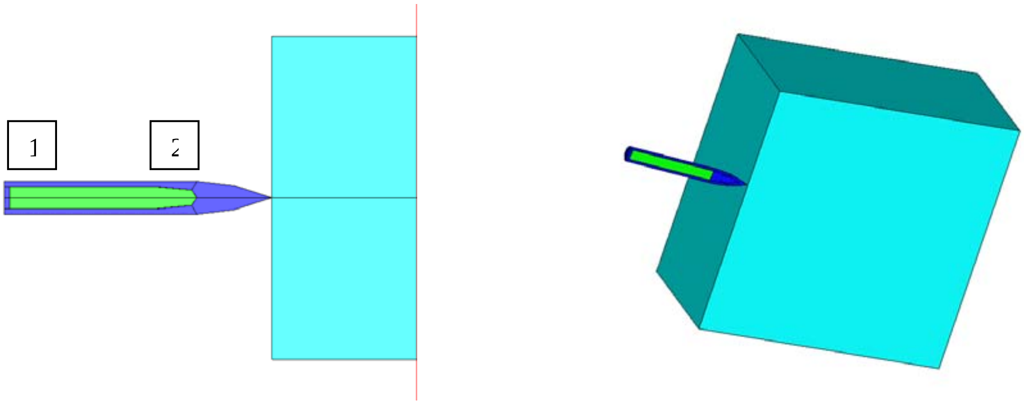

Figure 1.Simulation model for semi-infinite target (left: 2D) and layered target (right: 3D)

SIMULATION RESULTS

Representative results for the following numerical simulations are presented:

- 2D simulations, semi-infinite target, impact velocities 1000 and 1500 m/s
- 3D simulations, target thickness two times the penetrator length, aoi variation (0° and 10°), velocity 1000m/s.

The simulations are mainly intended to get information about the loads in the HE filling. This includes information about the stress state (pressures) and the strain state (compression and compression rate) and the dependence of these parameters on the impact conditions (normal or inclined impact). The positions of the gauge points for evaluation of the stress state in the HE are indicated in fig. 1 (position 1: rear, position 2: tip). Additional information is provided about the projectile trajectory within the target and the structural stability of the penetrator casing.

Penetration into Semi-infinite Concrete Target

Normal impact conditions on large targets (semi-infinite targets) are most conveniently simulated with 2D models. The results of these simulations allow already the assessment of penetration depth, deceleration of projectile and loading of the HE filling. The penetrator deformation 5 ms after the impact is shown in fig.2. For the impact velocity of 1000 m/s the penetrator tip shows only small deformations with nearly no erosion at the tip.

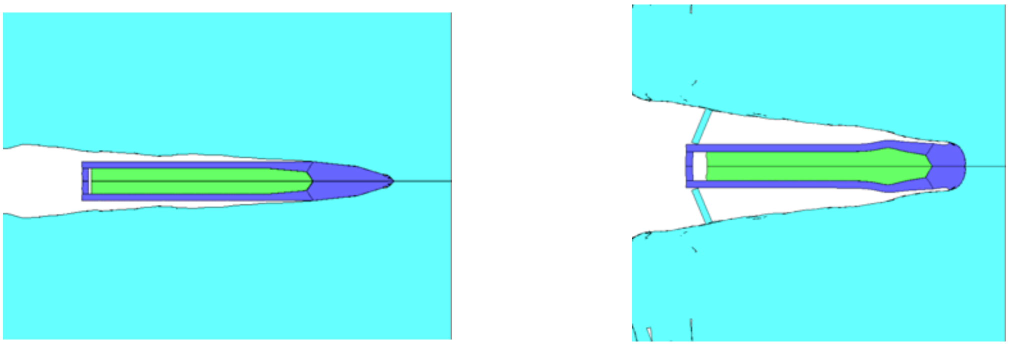

Figure 2. Penetrator deformation for 1000 m/s (left) and 1500 m/s (right) impact velocity

The situation is completely different for the impact velocity 1500 m/s. In this case severe distortion of the penetrator casing occurs and the penetrator tip shows already the typical mushroom effect expected in the high velocity regime. A comparison of the HE loads for the different velocities is shown in fig. 3. Maximum pressures for the 1000 m/s impact velocity are 1900 bar and increase significantly to around 6000 bar for 1500 m/s impact velocity. The time variation of the pressure shows the oscillating compression of the HE during the penetration process. The magnitude decreases due to the elastic-plastic model that was used for the HE.

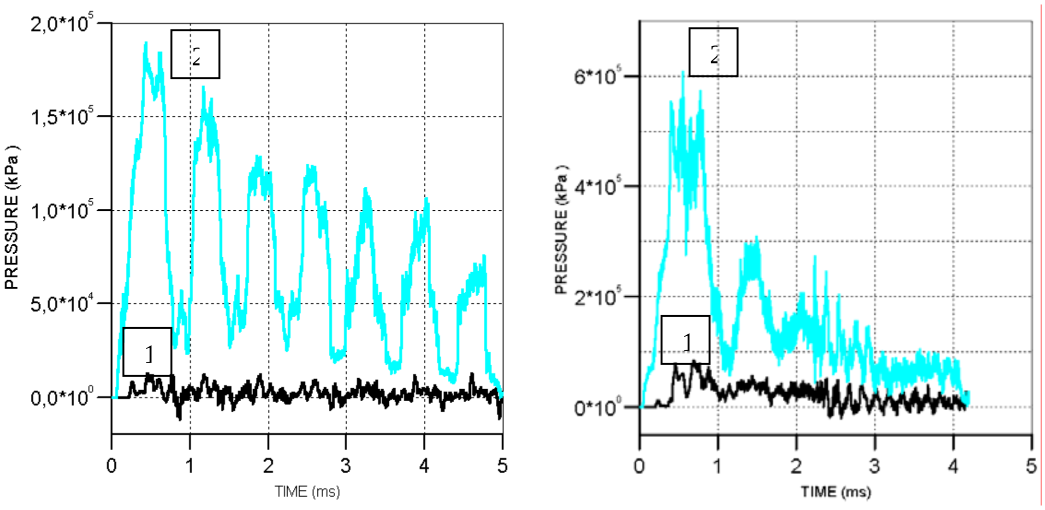

Figure 3. Pressure in HE for 1000 m/s (left) and 1500 m/s (right) impact velocity

Perforation of Layered Concrete Target

Taking inclined impact conditions into account requires 3D models. Two cases were analysed: normal impact (aoi=0° and aoa=0°) and inclined impact (aoi=10° and aoa=0°) with an impact velocity of 1000 m/s. A comparison of the resulting penetrator deformation is shown in fig. 4. Normal impact conditions lead to only minor penetrator deformations, whereas aoi=10° lead to high bending moments and shear forces in the penetrator casing followed by failure of the penetrator structure. The penetrator casing shows strong bending effects and the trajectory within the target deviates strongly from the original impact direction (curved trajectory).

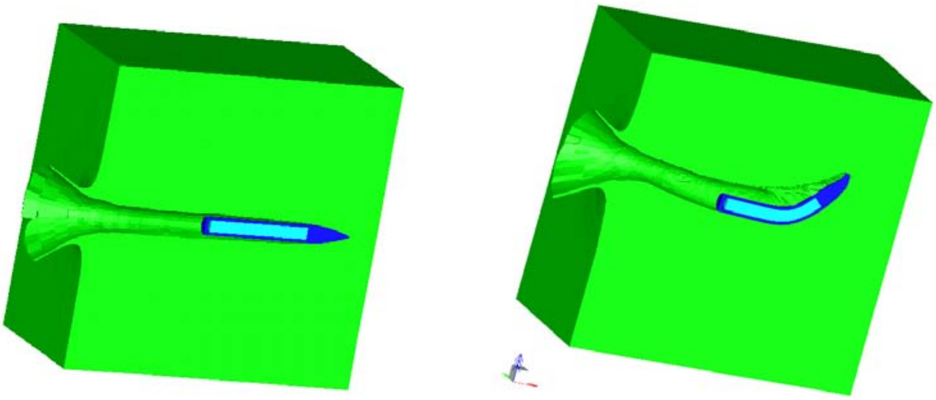

Figure 4. Penetrator deformation as a function of aoi (left: 0° and right: 10°)

The analysis of the respective pressures in the HE filling can be found in fig.5. The maximum value for the normal impact is 1500 bar (which compares well with the 2D simulation of 1900 bar for the semi infinite target) and the maximum pressure for inclined impact is slightly higher with 1800 bar.

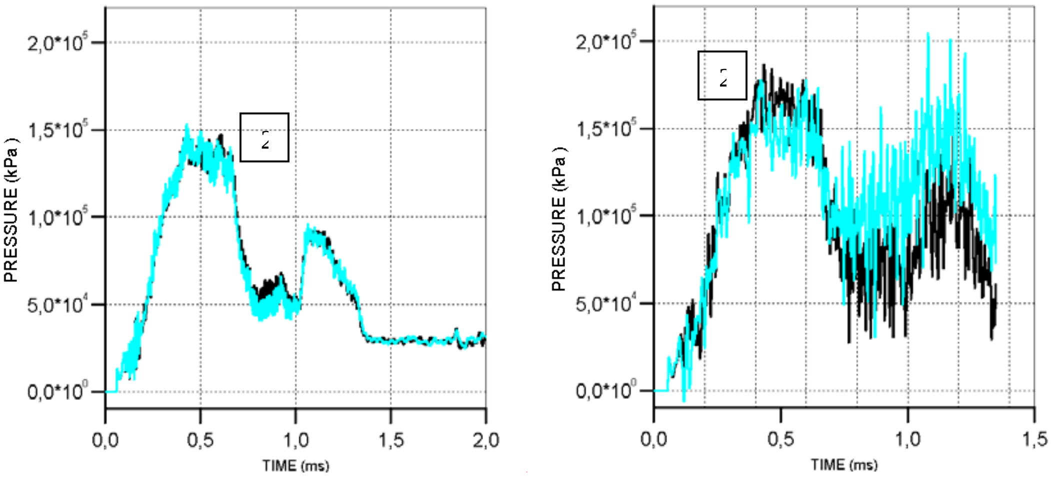

Figure 5. Pressure in HE for normal (left: aoi=0°) and inclined impact (right: aoi=10°)

SUMMARY

Numerical simulations of the impact of geopenetrators on concrete targets have been presented. The impact velocities were in the range 1000 m/s up to 1500 m/s. The results show that even for normal impact conditions erosion of the penetrator tip occurs at the impact velocity of 1500 m/s. Up to 1000 m/s, normal impact conditions do not lead to severe deformations or plastic strains in the projectile. Variations of the aoi on the other hand increase the loads on the penetrator casing significantly. The pressures induced in the HE filling depend mainly on the magnitude of the impact velocity (less on aoi) and are in the range of 1900 bar at the velocity of 1000 m/s and 6000 bar at the velocity 1500 m/s. The simulations can be used to evaluate additional parameters as for example penetration depth, plastic strains in the penetrator casing or further loading parameters in the HE filling.

REFERENCES

[1] N. Heider, U. Günther, Modern Geopenetrators and Relevant Revision of Concrete Penetration Models, *Proceedings of SUSI Symposium*, Thessaloniki, June 1998

[2] D.J. Frew, S.J. Hanchak, M.L. Green, M.J. Forrestal, Penetration of Concrete Targets with Ogive-Nose Steel Rods, *Int. J. Impact Engng. Vol. 21 No. 6 pp. 489-497* (1998)

[3] M.J. Forrestal, D.J. Frew, J.P.Hickerson, T.A. Rohwer, Penetration of Concrete Targets with Deceleration-Time Measurement, *Int. J. Impact Engng. Vol. 28 pp. 479-497* (2003)

[4] V.M. Gold, G.C. Vradis, J.C. Pearson, Concrete Penetration by Eroding Projectiles: Experiments and Analysis, *J. Engng. Mech Vol. 122 No. 2 pp. 145-152* (1996)

[5] R.N. Davis, A.M. Needy, S.E. Jones, Mass Loss and Blunting During High-Speed Penetration, *Int. J. Impact Proc. Instn. Engrs. Vol. 218 pp. 1053-1062* (2004)

[6] D.L. Orphal, C.W. Miller, W.L. McKay, W.F. Borden, S.A. Larson, C.M. Kennedy, Hypervelocity Impact and Penetration of Concrete by High L/D Projectiles, *Proc. 6th International Symosium. on Ballistics* (1982)

[7] V.P. Alekseevskii, Penetration of a Rod Into a Target at High Velocity, *Combustion, Explosion and Shock Waves, Vol. 2 pp. 63-66*, (1966)

[8] H. Schuler, N. Heider, S. Hiermaier, W. Riedel, K. Thoma, Simulation of Dual Stage Warheads Impact on Concrete, *10th International Symposium on Interactions of the Effects of Munitions with Structures*, San Diego, 7.-11. Mai 2001

[9] N. Heider, S. Hiermaier, Numerical Simulation of the Performance of Tandem Warheads , *19th International Symposium on Ballistics*, Interlaken, 7.-11. Mai 2001

[10] N. Heider, Numerical Simulation of the Penetration Process of Geopenetrators into Pre Damaged Concrete Targets, *20th International Symposium on Ballistics*, Orlando, 23.-27. Sept. 2002