# Simulation of Bullet Penetration using Finite Element Method

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***Abstract*—Present research work simulates the dynamics of a bullet and its penetration over a steel plate. The role of various parameters such as angle of impact, velocity of impact, angular velocity of bullet and mass of the bullet have been investigated numerically using finite element method. To start with, a configuration from literature has been taken and numerically investigated to establish the robust simulation technique based on explicit dynamics. The demonstrated estimated simulation result agrees to the reported experimental result adequately. Subsequently, various configurations of bullets such as ak47 7.62×39 bullet, 7.62×25 bullet and hollow point bullet have been taken for investigation. The influence of angle of impact has been examined by changing the angle of impact ($0^0$-$60^0$) with constant linear and angular speed. Subsequently, the linear and angular velocities, and density of the bullets have been varied with respect to angle on incidence and the corresponding results have been demonstrated to understand the most optimal performance of the bullet and bullet parameters. Moreover, the estimated penetration depths and analytical validation of kinetic energy for all configurations have been presented in the paper in detail.**

***Index Terms*—Bullet Penetration, ak47 7.62×39 Bullet, 7.62×25 Bullet, Hollow Point Bullet, FEA**

## I. Introduction

Public security and premises security became cumbersome because of increasing terrorism, road accident and public violence. In this present era, due to cut throat competition among peoples and countries security is very essential factor. Security can be done by either hiring security guards, building weapons or either building objects or materials that protects life [2], [5]. Building bullet proof jacket, cars or environment may help to achieve so. Such intension provokes us to simulate the various scenarios of bullets penetrating on plates and analyze the corresponding variations so that an effective conclusion can be made which can enhance the designing of bullet or bullet proof materials. However, in order to do that the dynamics of bullet need to be understood. The design of bullet is equally important to achieve desired performance of a gun system. The present research focuses in simulating the impact of the bullet and try to estimate its penetration on soft as well as hard material. In other way around, the same approach may be used to enhance the design of the bullet which is definitely enhance the weapon strength of the defence system [3], [6].

## II. Finite Element Modelling

The underneath mathematical model used to estimate the stiffness and force, used in present finite element formulation, can be stated as [1], [7].

$$[K]\{u\} = \{F^a\} + \{F^r\}$$

where, $[K] = \sum_{m=1}^{N} [k_e]$ is stiffness matrix and $\{u\}$ is nodal displacement vector. The $N$ is number of elements. The $[K_e]$ is the stiffness matrix and the $\{F^r\}$ is known as reaction load vector. Using such formulation, the applied load, $\{F^a\}$, in vector form can be stated as:

$$\{F^a\} = \{F^{nd}\} + \{F^{ac}\} + \sum_{m=1}^{N} (\{F_e^{th}\} + \{F_e^{pr}\})$$

where, the $\{F^{nd}\}$ is nodal load vector, and $\{F^{ac}\}$= -$[M]\{a_c\}$ is corresponding acceleration vector. The total mass matrix has been defined as $[M]$ = $\sum_{m=1}^{N} [M_e]$. Where, the $[M_e]$ is element mass matrix, $\{a_c\}$ is acceleration vector and $\{F_e^{th}\}$, and $\{F_e^{pr}\}$ is element thermal and load vector, respectively. The above formulation has been solved using nonlinear structural solver in explicit dynamics module in ANSYS platform.

## III. Benchmarking and Validation

To start with first a bullet (7.62×39 steel and cupper core ak47 bullet) has been taken from investigation from literature [4]. The detailed geometry and corresponding 3D model has been shown in Fig.1. In this particular simulation, a steel plate of 200mm×200mm×4mm has been taken as target to be penetrated. The density, youngs modulus, poisons ratio, yield stress and elongation for the target material have been defined as 7.8e-9 mg/mm$^3$, 2.1e5 MPa, 0.3, 1.7e3 MPa and 7%, respectively. In a similar fashion, the bullet material properties such as density, youngs modulus, and poisons ratio have been taken as 11.3e-9 mg/mm$^3$, 1.6e4 MPa, and 0.4, correspondingly. The target has been fixed and the velocity of the bullet has been assigned to have 710 m/s and rotational

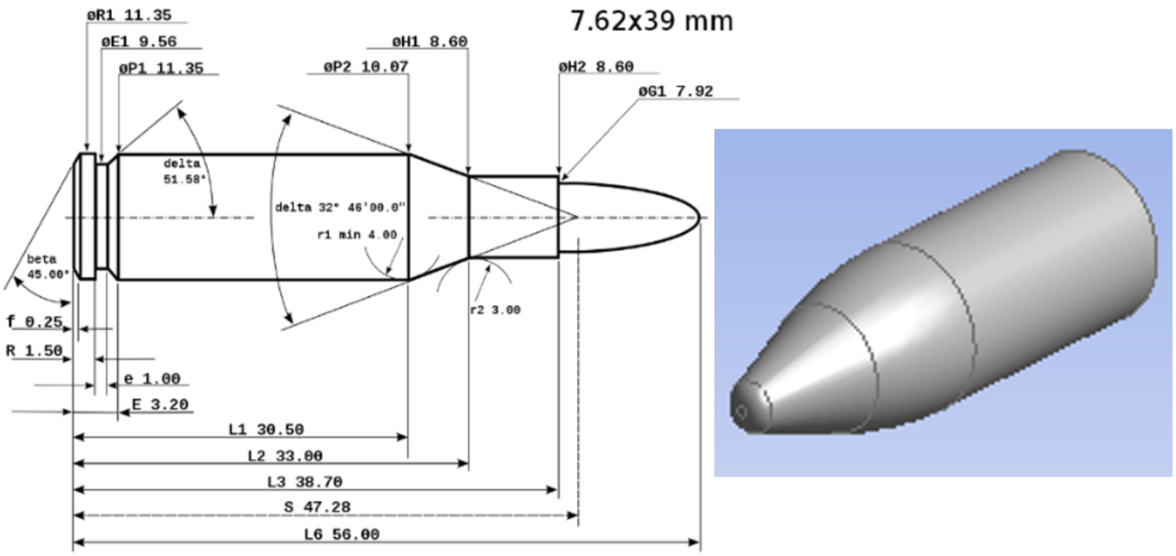


Fig. 1. Dimension and corresponding CAD model of ak47 bullet core.

velocity=36000 rpm. Bullet has been kept 500mm from the target.

Using very fundamental physics, the kinetic energy (KE) of the aforesaid bullet has been calculated (KE=$mv^2/2$=2.36$\times$10$^6$ mJ). Next, as discussed earlier, the simulation has been carried out in ANSYS explicit dynamics module. The modelling and desired meshing has been carried out including a grid testing to conclude the final desired meshing. The boundary conditions of the bullet and the target have been assigned as mentioned above. The transient analysis has been carried out with a time step 1e-7 second. The observed residual error in convergence has been observed to be below 1e-3. On executing the simulation, it has been observed that the bullet couldnt penetrate the target. The kinetic energy of the bullet decimates over time and have been shown in Fig.2. The numerical and experimental [4] kinetic energy agree to each other up to very large extent. From demonstrated simulations, it can be inferred that the proposed simulation technique is reliable enough to understand the dynamics of the bullet.

Generally, bullets do not impact normally because of its own inertia and it moves down while firing in real cases. In general, such variation has been observed from $0^o$ to $60^o$. The linear velocity of the bullet has maximum impact on depth of penetration and variation from 300m/s to 800m/s have been observed. However, the bullet has also the angular velocity and which in general varied from 36000rpm to 216000 rpm. The mass of the bullet linearly proportional to the inertia of the bullet and having a proportional effect on depth of penetration which varies from 4850kg/m$^3$ to 9850kg/ m$^3$ [2], [3], [5], [6].

## IV. Simulation

Next, three different types of bullets have been taken for investigation such as ak47 7.62$\times$39 bullet, 7.62$\times$25 bullet and hollow point bullet. The influence of angle of impact has been examined by changing the angle of impact with angle variation ($0^0$-$60^0$) with constant speed. Afterward, the velocity, density of the bullets has been varied with respect to angle on incidence. First, by keeping rotational speed constant, 36000 RPM, the linear velocity of the bullet has been varied from 300m/s-800m/s. Next, the angular velocity of the bullets has been varied from 36000 RPM to 216000 RPM by keeping linear velocity constant such as 500 miles per second. At last, the bullet mass has been varied by changing the density from 4850 kg/mm$^3$ to 9850 kg/mm$^3$. The simulations for all aforementioned conditions have been carried out as discussed in earlier section. In all analyses the target remains same as steel plate mentioned in earlier section.

## V. Results and Discussion

First, the bullet parameter such as impact angle has been varied from $0^o$-$60^o$ to demonstrate its role in penetration. In this simulation three different types bullets such as ak47 7.62$\times$39, rifle 7.62$\times$25 and hollow point bullet and target as steel plate. The linear velocity and angular velocity have been kept as 710m/s and 500 RPS, respectively. The numerically estimated results have been shown in Fig. 3(a). From figure, it can be noticed that the maximum penetration when the bullet impacts normal to surface, however, very poor penetration has been observed below $45^o$. Next, the linear velocity of the aforementioned bullets has been varied form 300m/s to 800m/s. The penetration depth for corresponding velocities have been shown in Fig.3(b). From figure, it can be inferred that the penetration depth is proportional to impact velocity as the KE (mv$^2$/2) of bullet is directly proposal to $v^2$.

Subsequently, the angular velocity of the bullet has been varied form 36000rpm-216000 rpm for afore mentioned bullets. The corresponding estimated penetration of the bullets have been shown in Fig.3(c). From figure, it can be inferred that the penetration depth does not depend upon the angular velocity

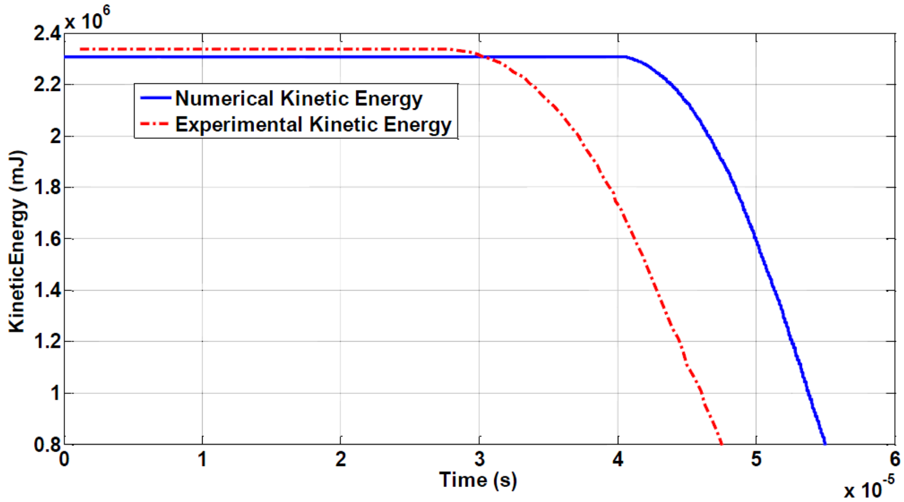


Fig. 2. Time domain simulation and decimation of kinetic energy of the bullet over time.

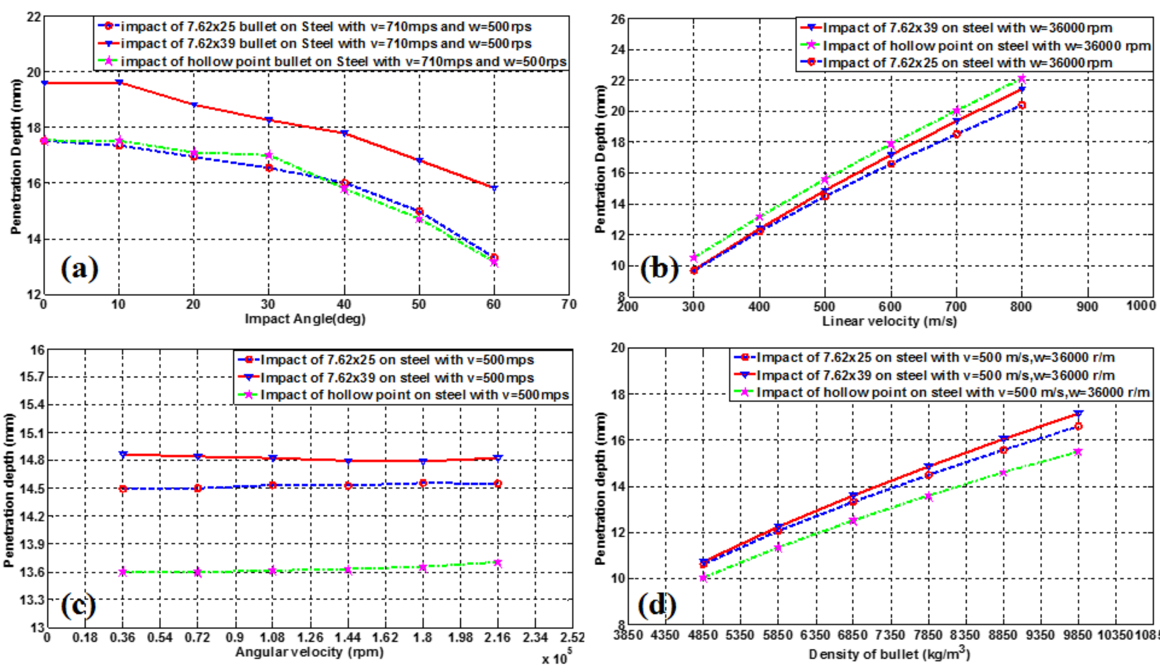


Fig. 3. Estimated simulation results; (a) angle of impact verses penetration depth, (b) linear velocity verses penetration depth.

unlike linear velocity of the bullet as the angular velocity of the bullet is responsible for flying far. At last the mass of the bullet has been varied by altering the density of the material form 4850kg/m$^3$ to 9850 kg/ m$^3$. The simulations have been carried out by keeping linear velocity and angular velocity to 500m/s and 36000rpm, respectively. The corresponding estimated penetration depths have been shown in Fig.3(d). As the KE of the bullet is directly proportional to mass of the bullet, it can be seen in figure that the penetration depth linearly changes over mass of the bullet.

## VI. Conclusion

The numerical simulation of dynamics of the bullet and its penetration on a steel plate has been benchmarked and the estimated numerical results agree to analytical and experimental observation adequately. The potential of the proposed simulation has been shown by investigating three different types bullet such as ak47 7.62×39, rifle 7.62×25 and hollow point bullet. Various parameters of bullet such as angle of impact, linear velocity, angular velocity and weight of bullet has been varied and corresponding effect on penetration have been demonstrated. The discussed method of simulation may have been reckoned as real-time design of bullet or bullet proof material. However, optimization of such parameters are interesting and may be considered as future scope of work.

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