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EXPERIMENTAL AND NUMERICAL SIMULATION OF PROJECTILE PENETRATION IN CONCRETE

By

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Abstract

For protective structures, concrete is the commonly used material. These protective structures are usually exposed to a dynamic loading rather than static loading which arises from either explosions or penetration of projectiles. Military protective structures can also be exposed to both cases which can caused by military weapons. Traditionally, for prediction of the depth of penetration and crater size from projectiles, empirical relationships are used as discussed in TM5-1300 [6]. This paper presents numerical and experimental simulations of concrete penetration by 23mm steel projectiles with a velocity of 969 m/s and a comparison between the results and existing experimental investigations. The analysis is executed with AUTODYN [8]. To learn more about the structural behavior of concrete subjected to severe loading and to gain confidence in AUTODYN which is a powerful tool utilizing advanced non-linear FE analysis; this paper describes the methods used to validate ANSYS-AUTODYN capabilities and presents the results of the validation for a concrete model. The calculation is achieved using the empirical relationship from TM5-1300 and these data are compared to the obtained data from AUTODYN and the physical experiment.

Keywords: Sandwich Panels, Suppressive Core, Penetration, Projectiles.

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1. Objective

The objective of this paper is to validate and gain confidence in ANSYS-AUTODYN to describe the use the non-linear finite element (FE) method for concrete penetration analysis and to show examples where 3-dimensional (3D) numerical analysis software tools have been used in both the design process as well as in safety assessment studies.
Comparison of empirical, numerical and experimental data of penetration problems on concrete as well as the performance of the simulation for the penetration depth will be illustrated.

2. Introduction

A great range of penetration physical processes must be taken into account in order to be accurately characterized. It is the responsibility of the engineer/scientist/designer to consider these complexes and to interact with it using the appropriate techniques. This paper will represent three techniques that can be applied. First, ***hand calculation*** which can be applied only to the simplest, highly idealized problems that are practically solvable. Then, ***physical experiments***, that is being used and developed for study due to the difficulties in modeling the highly nonlinear problems, will be applied for the same problem. Finally, a numerical software tool that offers another approach to impact studies will be applied. Where numerical techniques are suitable for solving a wider range of problems [1], they enable great savings in the cost of investigative physical experiments and allow the analyst to look at a "perfectly instrumented numerical experiment". Thus, he can examine the parameters that are virtually impossible to be measured in physical experiments in whatever detail he can see appropriate.

3. Penetration and Perforation of projectiles:

The penetration of projectiles into targets involves complex mechanical interactions [2]. By convention [1] the following simplifying definition are adopted. When a projectile enters a target did not passes through it so this projectile it is said 'penetrated' [4]. On the other hand, when a projectile passes completely through a target, it is said 'perforated' [5]. The depth of penetration is given by the distance as show in Figure 2a and Figure 2b.

4. Analysis and Modeling of Concrete Penetration:

4.1. Hand calculation analysis:

From the technical manual TM5-1300 [6], a certain amount of experimental data, which is analogous to primary fragment penetration, has been accumulated in connection with projects to determine the effects of bombs and projectile impact on concrete structures [7]. This data has been analyzed in order to develop relationships for the amount of fragment penetration into concrete elements in terms of the physical properties of both the metal fragment and the concrete. A general expression for the maximum penetration into a massive concrete slab by an armor-piercing fragment has been obtained as follows:

$$X_f = 4.0 \times 10^{-6}\ KND\ d^{1.2}\, vs^{1.8} + d \qquad \text{for } X_f > 2d \qquad (1)$$

and

$$K = 12.91/\ (f'c)^{\ 1/2} \qquad (2)$$

Where:

X_f = penetration distance by armor-piercing steel fragments "inch"
K = penetrability constant
N = nose shape factor as defined in Figure 1
D = caliber density as defined in Figure 1" oz. /in^3"
d = fragment diameter "inch"
v_s = striking velocity " fps"
f'c= concrete strength " psi"

Projectile weight = 6.7 onuses.
Projectile diameter = 23 mm = 0.91 inch.
Striking Velocity = 969 m/s = 3182.415 fps
Concrete strengths other than 4.000 psi is "f'c"
Penetrability constant "K" = 12.91/ (f'c)$^{1/2}$
K= 12.91/ (2500)$^{1/2}$
K= .258

Nose Shape factor "N" $N = 0.72 + 0.25\sqrt{\frac{r}{d} - 0.25}$ (3)

$$N = 0.72 + 0.25\sqrt{\frac{11.5}{23} - 0.25}$$

N = 0.845

Caliber Density "D" = W_f / d^3

$$D = W_f / d^3 = 6.7 / (0.91)^{1/3} = 8.89 \text{ oz. /in}^3$$

$$X_f = 4.0 \times 10^{-6}\ KND\ d^{1.2}\, vs^{1.8} + d$$

$$X_f = 4.0 \times 10^{-6}\ (0.258 * 0.845 * 8.89) * (0.91)^{1.2} * (3182.415)^{1.8} + 0.91$$

= 14.88 inch
= 37. 799cm ≈ 38 cm

4.2. Experimental Analysis:

4.2.1. Test set up

The gas gun test were carried out to investigate the penetration depth of the concrete model exposed to ballistic impact (very high velocity of projectile) as shown in Figure 3. This test was carried out according to laboratories of USA army corps of engineering (ACE) in laboratories of military factory no.45 using an Aircraft 23 mm cannon as shown in Figures 3 and 4. The used projectile was blunt-nose steel penetrator 23 mm diameters and 64 mm length as shown in Figure 5 and 6 which illustrate the dimension and details of the penetrator, the material prosperities of the penetrator are listed in Table (1). The impact velocity was measured and reported for every shot with electro-optical velocity measurement device which is connected with computer as shown in Figures 8 and 9 (it was 969 m/sec).

The illustrated test model in Figure 10 is formed of four concrete blocks with the dimension of (0.6m×0.6m×1.0m). The model boundary condition was simply supported on the ground and the models back side is fixed. The target model is formed of plain concrete.

4.2.2. Experimental Test Result

The 23 mm projectile impacted the concrete model which consists of two concrete blocks and has perforated from the first block then, it penetrated into the second block for a distance of 0.072m. The total penetration depth of the projectile into the model is 0.372m.

4.3. Numerical analysis:

4.3.1. Description of finite element model

The finite element program AUTODYN was used to create finite element model for the previous experimental model. This was to simulate the penetration process of projectiles into the concrete model. The material or component is discredited into forming cells or meshes. Each mesh interacts with another one by defined strength model for each material that has an equation of state. The line of interaction between materials is defined; time step is determined in order to satisfy the stability condition for the problem. Finally, a matrix of unknowns is solved for non-linear system indicating each effect of stresses on the whole materials.

4.3.2. Material Description

4.3.2.1. Projectile Material

The material model used to simulate the projectile in the model is (STEEL 4340) which was chosen from the AUTODYN library. The equation of state is linear equation of state, and the strength model is Johnson Cook strength model, whereas the failure model was (None) and the erosion model was selected to be Instantaneous geometrical strain. The data defines of the penetrator material in the hydrocode were chosen from the library and modified, according to used material listed in Table (2).

4.3.2.2. Concrete Material

The material model used to simulate the plain concrete in the used model is (CONCRETE 35 MPa). This material model was chosen from the AUTODYN library. The equation of state was P-Alpha equation of state, and the strength model was RHT CONCRETE strength model. The failure model was RHT CONCRETE and the erosion model was selected to be instantaneous geometrical strain. The data defines of the concrete material in the hydrocode were chosen from the library and modified, according used material listed in Table (3).

4.3.3. Geometry and Mesh Description

Lagrange processor has been used in AUTODYN for the analyses. In this paper, the considered target panel was plain concrete. Projectile and the concrete target are modeled as Lagrangian meshes in the model. All parts were symmetric on X=0 and Y=0 planes to reduce the size of the computational domain. The geometry of the projectile part is defined in the model using a structural Lagrangian mesh. Due to the symmetric conditions, the projectile geometry, which is 23 mm diameter and 64 mm length is modeled as a 1/4 cylinder, it was divided to nodes in the I, j , k-directions. This IJK-index is known as a Cartesian co-ordinate system. The projectile part filled material is (STEEL 4340) Figure 7, shows the geometry and mesh description for the projectile part.

For plain concrete model, concrete material (Conc.35MPa) is defined using a structural Lagrangian mesh. Due to the symmetric conditions, the geometry of the model is modeled as 1/4 box and filled with it Figure 12 shows the geometry of model.

4.3.4. Numerical Test Result

From the result we found that the penetration of the projectile is almost 34.41 cm as the projectile velocity approaches to zero.

5. Result Analysis:

The penetration depth of the projectile into the model is shown in Figure 13 and 14 which present the projectile penetration depth time history for the model. Analysis with AUTODYNE for the concrete target was made by using the RHT model.

The 23 mm projectile stroking velocity with the concrete model is 969 m/s. For this experiment, the Lagrangian method was used for the numerical analyses. The model and the projectile were meshed into nodes and elements to produce accurate results.

The results gained from AUTODYNE program represented that the 23mm projectile penetrated the concrete model for a distance of 0.38 m as illustrated in

Figure 13 before the Z-velocity as well as the Z-force decline to reaches zero (Figure 14 and 15).

The maximum depth of penetration was 34.41 cm, then the projectile stop and reflected with negative velocity as shown in Figure 13.

6. Conclusion

From the previous study, the following conclusions can be drawn out:

1. The AUTODYNE code satisfactory simulates the penetration experimental tests.
2. The response of concrete panel under the penetration load can be simulated using ANSYS software, it has the advantage, and thus it has higher analysis precision, compared to the common analysis.
3. The penetration distance of a projectile is being affected by many parameters such as nose shape factor because the penetration of projectile into targets involves complex mechanical interactions were AUTODYN has proven its efficiency in dealing with it.
4. Due to the time consuming and the expensive cost of experimental work, AUTODYN software can be used successfully as an alternative means to study different parameters that can affect the behavior of different sandwich panels with suppressive cores.

7. References

[1] "ANSYS Theory Reference", ANSYS, Inc., 1997.

[2] Joosef, L.: "Dynamic Behavior of Concrete Structures subjected to Blast and Fragment Impacts", Chalmers University of Technology, Sweden, 2002.

[3] Hetherington, J.G.: "The Terminal Ballistic performance of Small to Medium Caliber Kinetic Energy Ammunition", School of Mechanical, Materials and Civil Engineering, Royal Military College of Science (Cranfield) Report No 0303-003, 1984.

[4] Johanson G. R.; Beissel S. R.; Homquist T. J. and Frew D. J.: "Computed radial stresses in a concrete target penetrated by a steel projectile" Fifth International Conference on Structure under Shock and Impact V, pp. 794-806,1998.

[5] Recht, R.F.: "Ballistic Perforation Dynamic of Armor-Piercing Projectiles", NWC TP4532, Naval Weapons Center, China Lake, California, 1967.

[6] TM5-1300: "Structures to Resist the Effects of Accidental Explosion", Department of Defense, USA, 2008.

[7] Li, Q.M.; Reid, S.R; Wen, H.M. and Telford, A.R.: "Local impact effects of hard missiles on concrete targets", International Journal of Impact Engineering, Vol. 32, pp. 224-284, 2005.

[8] "AUTODYN Interactive Non-Linear Dynamic Analysis software", Theory Manual, Century Dynamics Company, Inc., 2005.

Table (1) Mechanical properties of the 23 AP projectile materials

Brinell hardness Number [HB]	Yield strength	Ultimate strength,	Strain to fracture [%]
475	1726	1900	**7**

Table (2) The data defines the projectile materials

Reference Density (gm/cm^3)	7.83	Hardening constant (Kpa)	1.7851E7
Bulk Modulus (Kpa)	1.67E8	Hardening exponent	0.26
Reference temperature (K)	300	Strain rate constant	0.014
Specific heat (C.V.) (j/kgK)	477	Thermal softening exponent	1.03
Shear modulus (Kpa)	7.98E7	Melting temperature (k)	1793
Yield stress (Kpa)	1.726E6	Ref. Strain Rate (/s)	1

Table (3) Data defines the concrete materials

Porous density (gm/cm^3)	2.75	Failure Surface parameter A	2
Porous density(gm/cm^3)	2.314	Failure Surface exponent N	0.7
Porous sound speed (m/s)	2.92E3	Tens./Comp. Meridian Ration	0.6805
Initial compaction pressure (Kpa)	2.33E4	Brittle to Ductile Transit	0.0105
Solid compaction pressure (Kpa)	6E6	G (elas.)/G (elas.-plas.)	2
Compaction exponent n	3	Compaction curve	Standard
Solid EOS	Polynomial	Elastic Strength /ft	0.7
Bulk Modulus A1 (kPa)	3.527E7	Elastic Strength /fc	0.53
Parameter A2 (kPa)	3.958E7	Use cap on Elastic Surface	1
Parameter A3 (kPa)	9.04E6	Residual Strength Const. B	1.5
Parameter B0	1.22	Residual Strength exponent M	0.61
Parameter B1	1.22	Comp. Strain Rate Exponent a	0.032
Parameter T1 (kPa)	3.527E7	Tens. Strain Rate Exponent D	0.025
Parameter T2 (kPa)	0	Max. Fracture strength Ratio	1E20

Reference temperature (K)	3E2	Damage Constant D1	0.04
Specific heat (C.V.) (j/kgK)	6.54E2	Damage Exponent D2	1
Shear modulus (kPa)	1.67E7	Min. strain to failure	0.01
Compressive strength fc (kPa)	3.50E4	Residual Shear Modulus Frac.	0.13
Tensile strength ft/fc	0.088	Tensile Failure Model	Hydro Tens.
Shear strength fs/fc	0.18	Erosion strain	0.7

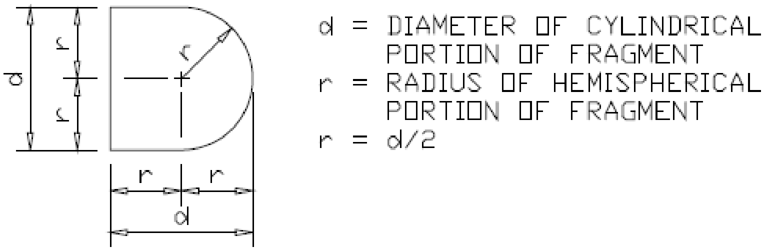


Figure 1: Shape of standard primary fragments

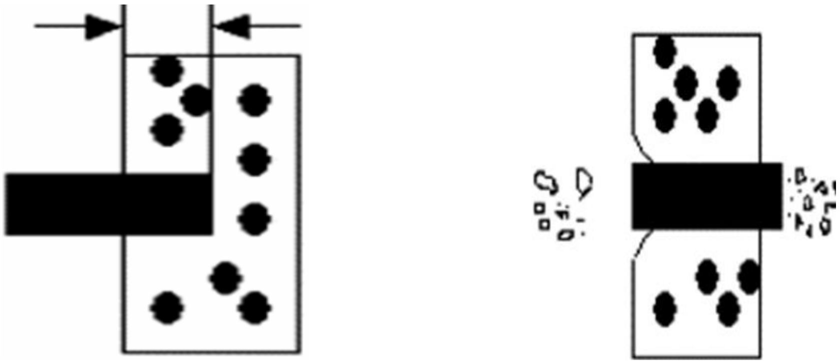

(a) (b)

Figure 2: Penetration and perforation phenomena

Figure 3: Aircraft 23 mm cannon

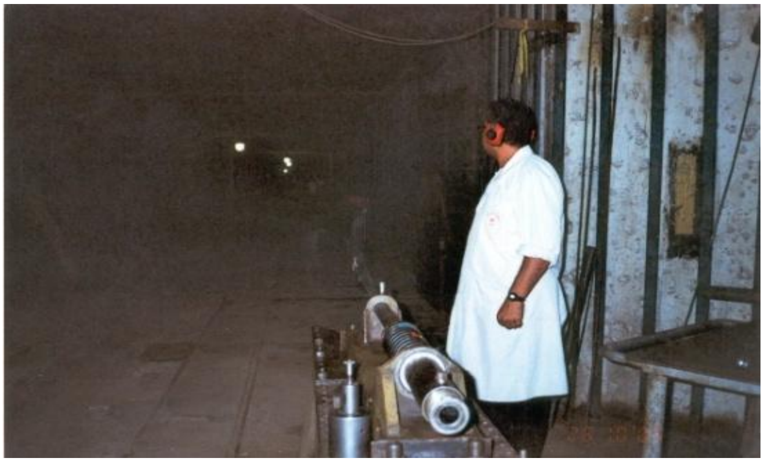


Figure 4: Aircraft 23 mm cannon

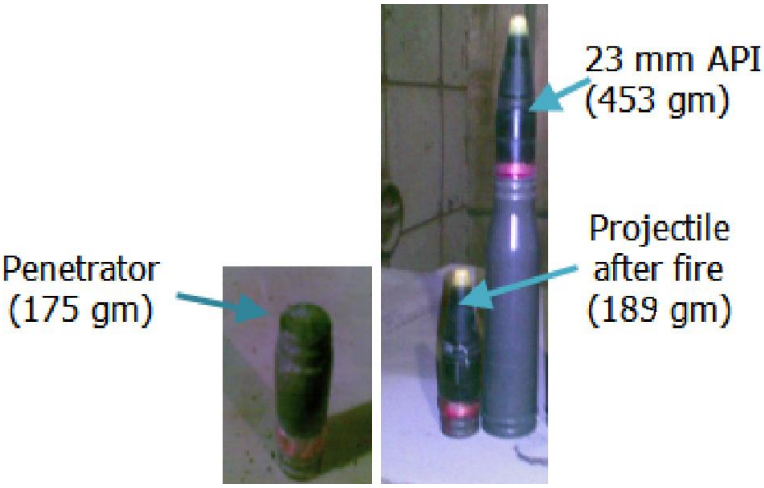


Figure 5**:** Different firing stages of 23 mm API projectile

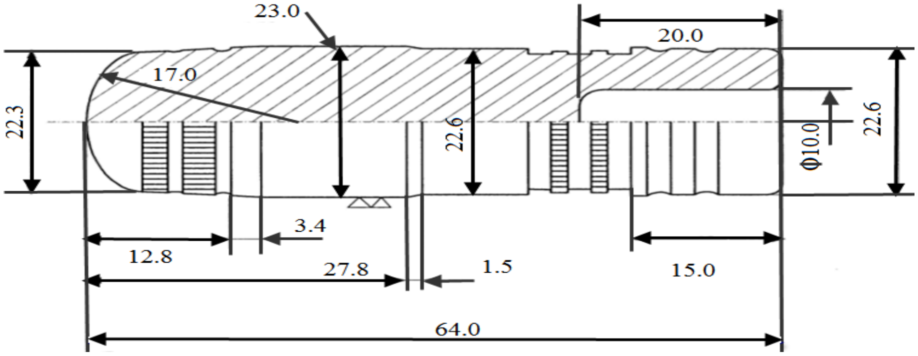


Figure 6: Dimension of 23 mm API projectile

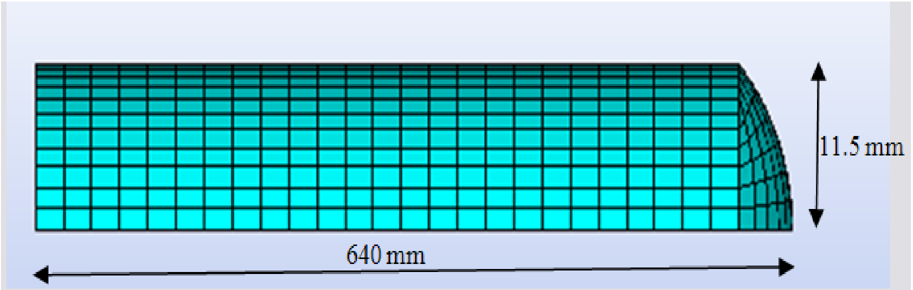
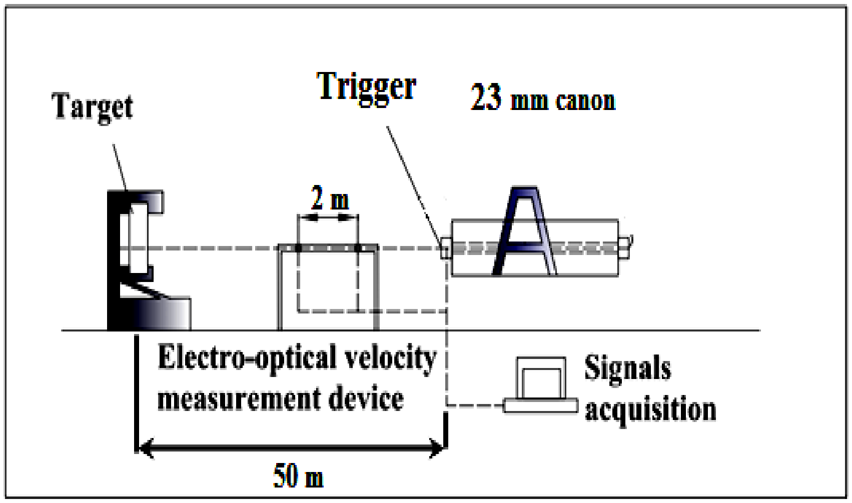


Figure 7: 23 mm API projectile mesh

Figure 8**: Velocity measurement device.**



Figure, 9: Penetration depth setup for concrete

Figure 10: Concrete model.

Figure 11-A: Details of Concrete model penetration.

Figure 11-B: Details of the concrete model penetration.

Figure 11-C: Details of the Concrete Model Penetration.

Figure 11-D: Details of the Concrete Model Penetration.

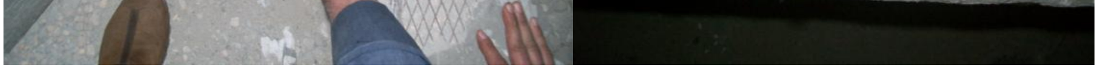


Figure 11-E: Details of the Concrete Model Penetration.

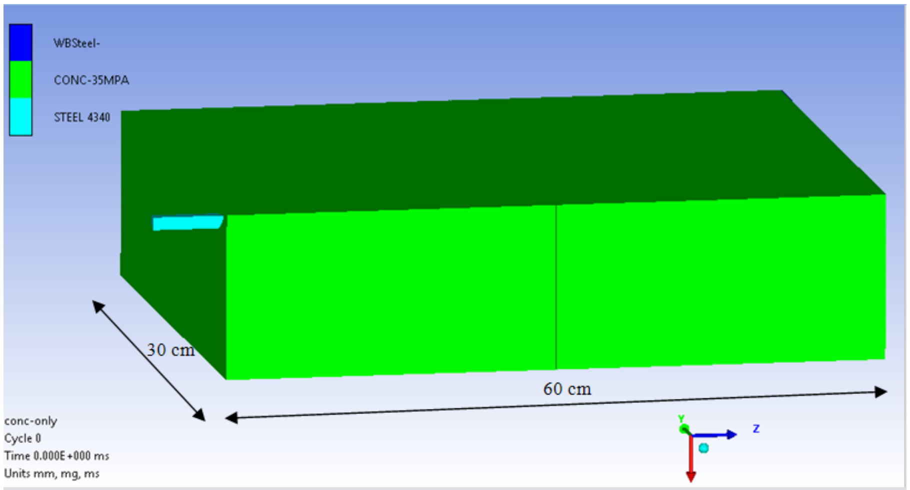


Figure 12: Details of the projectile and Concrete Model.

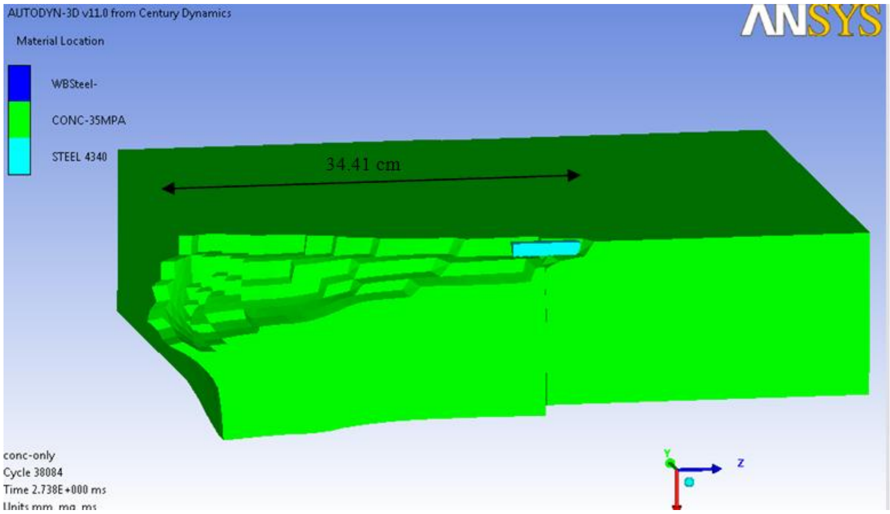


Figure 13: Penetration Depth for the Concrete Model.

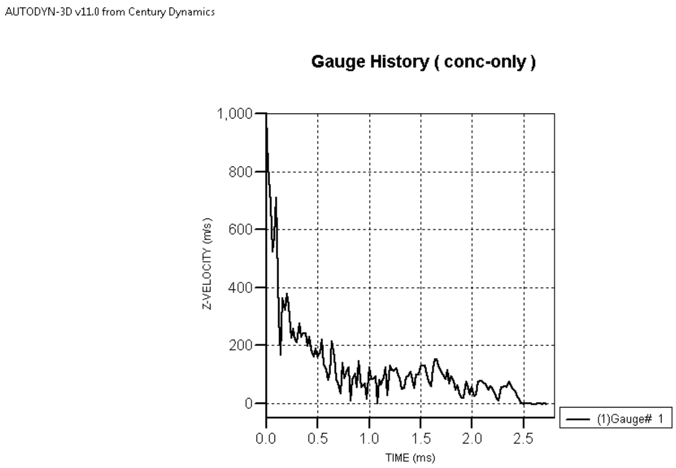


Figure 14: Projectile Velocity Profile.

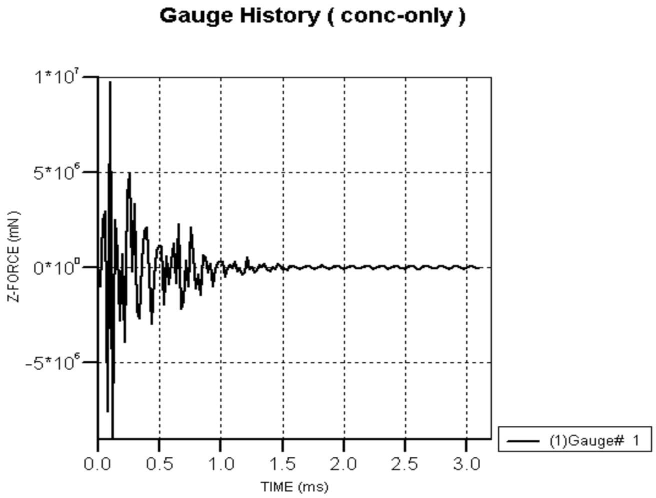


Figure 15: Z-Force Profile.