IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 4 Issue 8, August 2017
ISSN (Online) 2348 – 7968 | Impact Factor (2016) – 5.264
www.ijiset.com

Numerical Simulations of RC Panels Subjected to High Speed Projectile - Erosion Selection in AUTODYN-3D code

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Abstract
Erosion is defined in AUTODYN as a numerical mechanism for the automatic removal (deletion) of elements during a simulation. The primary reason for using erosion is to remove high distorted elements from a simulation before the elements become degenerate. The objective of this paper is to study the erosion effect on the numerical simulation of reinforced concrete (RC) panels subjected to the impact of high speed projectile (.50 cal. Bullet). The bullet and reinforced concrete panel were modelled by Lagrange grids using AUTODYNE code v. 17. In the simulations, the variations of erosion strain values and mesh size of the concrete panel on the response of the bullet residual velocity and damage depths at front and rear faces of the concrete panel were investigated. The bullet residual velocity and damage depth of concrete panel were obtained and compared with experimental results. The results showed that the erosion strain value and mesh size had a significant effect on changing the residual velocity of the bullet and the damage depth of concrete panel.

Keywords: *Erosion, Concrete, Residual Velocity, Bullet, Penetration and AUTODYN.*

1. Introduction

In AUTODYNE, the discarding of the target's and projectile's cells that suffer large distortion in the grids is defined as Erosion [1]. The element erosion function, provides a useful means of simulating the spalling and scabbing of concrete and provides a more realistic graphical representation of actual impact problems. Erosion is characterized by the physical separation of the eroded solid element from the rest of the mesh [2]. Without numerical erosion, severely crushed elements in Lagrangian calculations would lead to a very small time step, resulting in the use of many computational cycles with a negligible advance in the simulation time. Moreover, Lagrangian elements which have become very distorted have a tendency to lock up, thereby inducing unrealistic distortions in the computational mesh [3]. Therefore, one of the solutions is to remove distorted cells and ignore their mass after their effective strain exceeds the adopted erosion strain value. On the other side, erosion criterion and erosion limit used in Lagrange simulations have been found that the stability of the numerical solution strongly depends on them.

Although experimental research should be carried out to understand the behavior of concrete structures against high speed impacts, numerical simulation is usually used for predicting the response of structures to impact loads since experimental studies are usually expensive and time consuming. Hence, many efforts have been devoted to model the dynamic response of concrete elements subjected to high speed impacts [4-6]. Nevertheless, further investigation must be carried out through numerical simulations, to understand the effects of mesh sizes and erosion limits on the impact performances in terms of the total penetration depth, damage patterns and bullet residual velocity.

The objective of this paper is the study of the erosion and mesh sizes effects on the numerical solution of concrete panels against high speed impacts using AUTODYN code. The code provides three kinds of effective strain: plastic strain, incremental geometric strain and instantaneous geometric strain. Instantaneous geometric strain is selected as an erosion criterion from AUTODYN library with different erosion values to obtain a numerical simulation that reproduce experimental results. The Lagrange processor was used to represent both bullet and concrete panel. This processor attaches the mesh to the material and they deform together. The convergence of the numerical results is also test using different mesh sizes. It is proved that if erosion limit based on strain values and mesh size of the concrete panel are ignored, a significant difference between experimental result and simulation is achieved.

2. Numerical Simulation

In this study, a concrete panel with dimensions of 600 × 600 x 100 mm and a compressive strength of 35 MPa was used as a target. The panel is reinforced with 10 mm diameter hot rolled deformed steel bars in two perpendicular directions with spacing of 200 mm between the bars [7]. Details of the reinforced concrete panel are shown in Figure 1. A 60 mm ogive-nosed bullet (.50

caliber barrel) was used to hit the concrete panel at the center with an initial velocity of 640 m/sec. The bullet model consists of two sections; outer copper jacket and inner lead core. Details of the shape and dimension of the bullet are shown in Figure 2. All the numerical investigations presented in this paper were performed by AUTODYN 3D v.17 using Lagrange processor and taking into account the symmetry of the problem. The boundary conditions for the concrete panels were assumed to be fixed, i.e. zero velocities in x, y and z directions. The numerical model used to simulate this problem is represented in Figure 3.

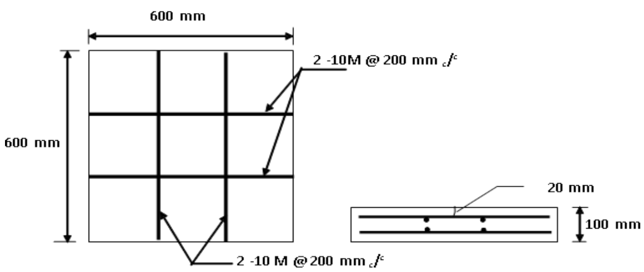

Fig. 1: Details of the Reinforced Concrete Panel

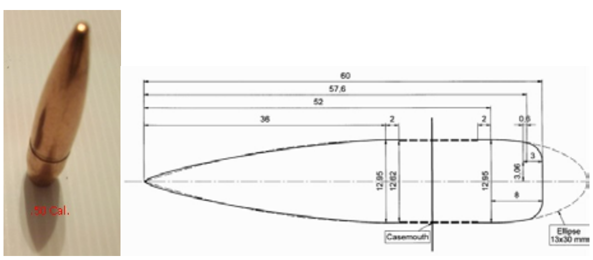

Fig. 2: Shape and dimension of the bullet (0.50 Cal.)

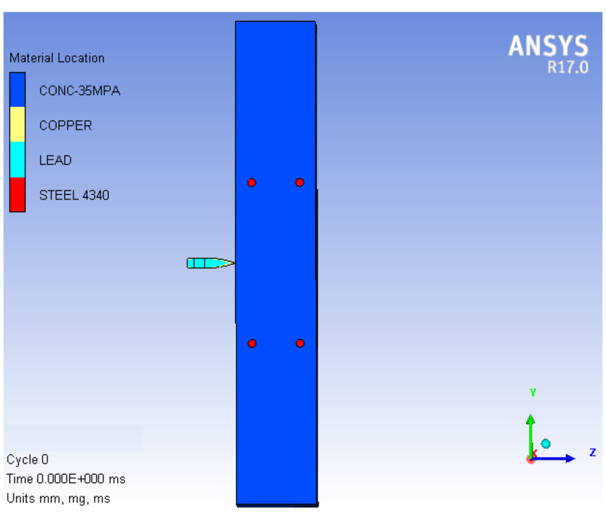

Fig. 3. Numerical model for the RC panel and bullet

In AUTODYN, any material model has typically four basic types of information to be specified for each material; equation of state (EOS), strength, failure and erosion models [1]. All materials specifications and requirement input parameters are defined in the AUTODYN library. Some of the parameters for EOS and strength models for all materials used in the simulation are given in Table 1. The numerical simulation was conducted for different erosion strain values and different concrete meshes. Instantaneous geometric strain was used as erosion criterion in this simulation. The initial value of the erosion strain for the concrete is selected as 0.5 with an increasing interval of 0.25 and with maximum values of 2, while the erosion strain for the steel reinforcement remains constant as 2.0 for all analyses. The parameters of the failure and erosion models for the RC panel and bullet components are given in Tables 2 and 3.

Table 1: Parameters of EOS and strength models for all materials

Material	*Model* and Parameter	Value	*Model* and Parameter	Value
Concrete (35MPa)	*EOS*	P-alpha	*Strength*	RHT Concrete
	Reference density	2.75 (g/cm^3)	Shear Modulus	1.67x10^7 kPa
			Compressive strength	35 MPa
	Bulk Modulus (A1)	3.527x10^7 (kPa)	Tensile strength (ft/fc)	0.10
			Shear strength (fs/fc)	0.18
Steel 4340	*EOS*	Linear	*Strength*	Johnson Cook
	Reference density	7.83 (g/cm^3)	Shear Modulus	7.7 x10^7 (kPa)
	Bulk Modulus	1.59 x10^8 (kPa)	Yield stress	3.5 x10^5 (kPa)
Copper	*EOS*	*Shock*	*Strength*	*Piecewise JC*
	Reference density	8.9 (g/cm^3)	Shear Modulus	4.64 x10^7 (kPa)
	Guneisen coefficient	2.0	Yield stress	1.2 x10^5 (kPa)
Lead	*EOS*	*Shock*	*Strength*	Steinberg Guinan
	Reference density	11.34 (g/cm^3)	Shear Modulus	8.6 x10^6 (kPa)
	Guneisen coefficient	2.74	Yield stress	8.0 x10^3 (kPa)

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 4 Issue 8, August 2017
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Table 2: Parameters of failure model for all materials

Material	*Model*/Parameter	Value
Concrete (35MPa)	*Failure Model*	*RHT Concrete*
	Damage Constant, D1	0.040
	Damage Constant, D2	1.000
	Minimum strain to Failure	0.010
	Residual Shear Modulus Fraction	0.130
	Tensile failure	Hydro (P min)
Steel 4340	*Failure Model*	*Plastic Strain*
	Plastic strain	0.002
	Crack softening	No
Lead	*Failure Model*	Non
Copper	*Failure Model*	Non

Table 3: Parameters of the erosion model for RC panel components

Material	Model/Parameter	Value
Concrete (35MPa)	*Erosion Model*	*Geometric Strain*
	Erosion Strain	0.5, 1.0, 1.25, 1.5, 1.75, 2.0
	Type of Geometric Strain	Instantaneous
Steel 4340	*Erosion Model*	*Geometric Strain*
	Erosion Strain	2
	Type of Geometric Strain	Instantaneous
Lead	*Erosion Model*	Non
Copper	*Erosion Model*	Non

Three different types of mesh sizes were used to simulate the concrete panel and to investigate the mesh size effect on numerical results. Mesh 1, which represents the course mesh, is consisted of 11250 Lagrangian elements. In mesh 2 (fine mesh) and mesh 3 (very fine mesh), the concrete panel are discretized into 18,000 and 34650 Lagrangian elements respectively, while the reinforcement steel bars are represented by 1920 beam elements. In all meshes, the geometry of the concrete panel was defined to have fine grids at the center (where the bullet hits the panel) and coarser grids away from its center.

3. Results and Discussion

Finding the proper erosion values for concrete panel subjected to high speed impact using different mesh sizes was made. The obtained AUTODYN results in terms of penetration depth, bullet residual velocity and damage depth at front and rear faces of RC panel for all meshes were compared with the experimental results [8] in Tables 4 and 5.

Table 4: Experimental and numerical results for mesh 1.

Response	Experimental Results [8]	Numerical Results (AUTODYN) Erosion Values			
		0.5	1.0	1.5	2.0
Penetration depth (mm)	100	70	58	50	46
Bullet residual velocity (m/s)	110	0	0	0	0
Depth of damage at front face (mm)	40	32	38	42	42

Table 5: Numerical and experimental results for meshes 2 and 3.

Response		Numerical Results (AUTODYN) Erosion Values							Exp. Results [8]
		0.5	**0.75**	**1.0**	**1.25**	**1.5**	**1.75**	**2.0**	
Penetration Depth (mm)		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Bullet residual velocity (m/s)	Mesh 2	**536**	**448**	**320**	**252**	**160**	**117**	**82**	**110**
	Mesh 3	**505**	**396**	**264**	**177**	**130**	**100**	**56**	
	%	**6**	**11**	**17**	**29**	**18**	**14**	**31**	**-**
Damage Depth at front and rear faces (mm)	Mesh 2	**21 13**	**23 15**	**28 21**	**29 24**	**40 29**	**41 37**	**46 -**	**40 45**
	Mesh 3	**17 13**	**20 24**	**21 33**	**30 30**	**35 30**	**42 40**	**46 -**	

Table 4 represents the comparison between numerical and experimental results for mesh 1 in terms of penetration depth, bullet residual velocity and damage depths at front face of the concrete panel. The erosion values for mesh 1 varied between 0.5 to 2.0 with an interval of 0.5. It can be seen from Table 4 that the penetration depth is decreased as the erosion value is increased and the bullet did not fully penetrate the concrete panel and reached zero velocity (stopped) at different penetration depths. Figure 4 illustrates the damage depth for mesh 1 with erosion value of 1.5. It is evident that, the numerical results of penetration depth and bullet residual velocity for the course mesh do not agree with experimental results. The discrepancy in results is obviously due to the insufficient refinement of the mesh. Nevertheless, the front damage depth obtained by AUTODYN was converged with the experimental results when the erosion values exceeded 1.0.

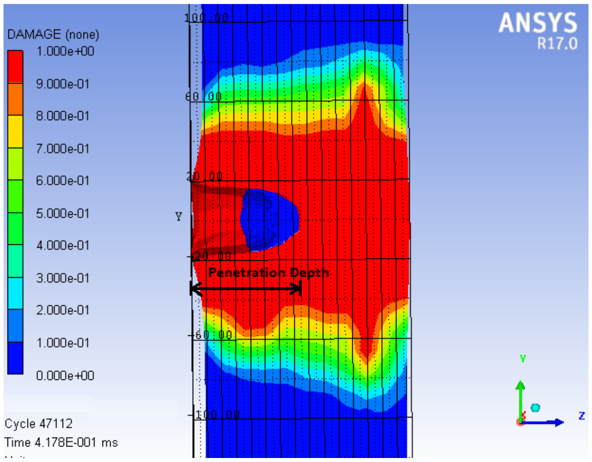


Figure 4: The damage depth for mesh 1 with erosion value of 1.5

In Table 5, when fine meshes were used (i.e. meshes 2 and 3), it can be observed that as the erosion values are increased, the residual velocity of bullet is gradually reduced while the damage depth is increased. The numerical simulations for both meshes with erosion values below 1.0 have a high residual velocity compared with experimental results and the resulting damage patterns do not clearly show the scabbing and spalling of the concrete panel. When erosion values below 1.0, AUTODYN solution underestimated the values of damage depths at front and rear faces compared with experimental results. The resulting damage profile for mesh 2 using erosion value of 0.5 is shown in Figure 5.

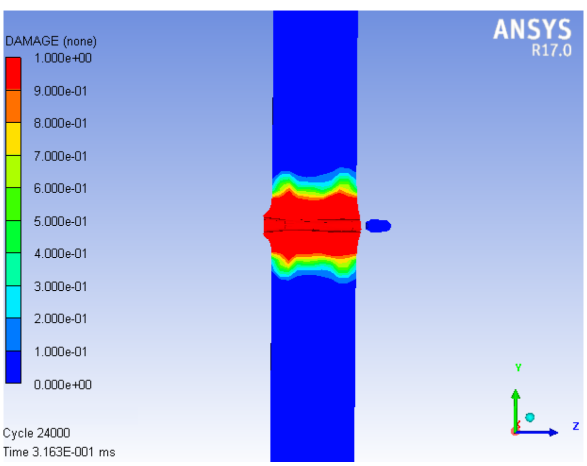
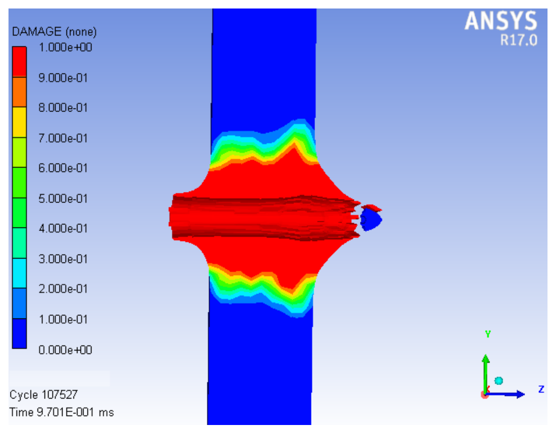


Fig. 5: Damage profile for mesh 2 with erosion value of 0.5

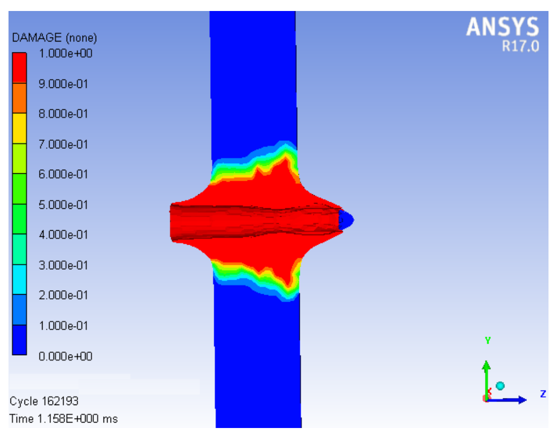
For simulations with erosion values of 1.0 and 1.25, the bullet residual velocity was considerably reduced compared with experimental results, i.e. the differences in residual velocities for meshes 2 and 3 were 29% and 18% respectively. However, the resulting damage patterns for these erosion values were better than those obtained by erosion values below 1.0. In all cases (i.e. erosion values ≤ 1.25), the bullet completely penetrated the whole panel and the penetration depth was 100 mm.

For the erosion value of 1.5 (i.e. elements are eroded by 150%), the bullet residual velocities for meshes 2 and 3 are reduced to 117 m/s and 100 m/s respectively, with differences of 6% and 10% when compared with experimental results. The corresponding damage depth at front and rear faces are approaching those values obtained from experimental results. The damage profiles of meshes 2 and 3 for erosion strain value of 1.5 are illustrated in Figure 6.

For this particular erosion value of 1.5, it can be concluded that using very fine mesh does not significantly improve the accuracy of the numerical results, however, using very fine mesh can increase the computational time and computer memory. The maximum difference in bullet residual velocity between fine and very fine meshes was 14%.



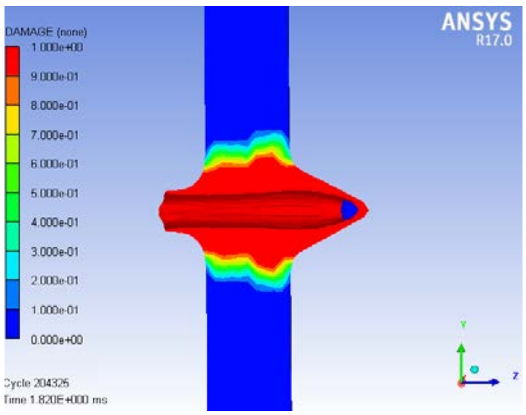
a) Mesh 2



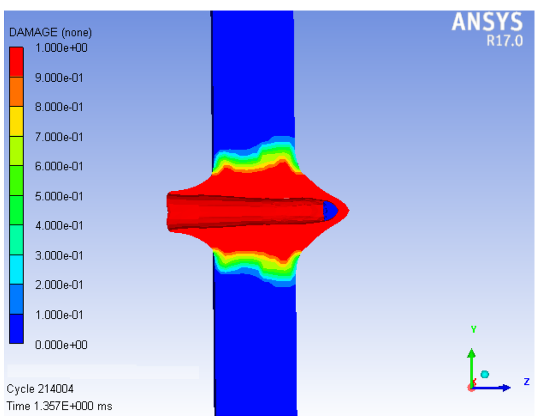
b) Mesh 3

Fig. 6: Damage profiles for meshes 2 and 3 with erosion value of 1.5

When the erosion values are exceeded 1.5 (i.e. 1.75 and 2.0), excessive and unrealistic distortion is developed at the rear face of the panel for meshes 2 and 3. Figure 7 shows the distortion induced at rear face for both meshes at erosion value of 2.0. It can be observed from Figure 7 that the bullet did not completely penetrate the panel and reached constant velocity with more computational time and cycles. The corresponding bullet residual velocities for these erosion values were recorded as 82 m/s and 63 m/s for mesh 2, and 56 m/s and 69 m/s for mesh 3. The bullet residual velocity vs. time for both meshes at erosion value of 2.0 are shown in Figure 8.

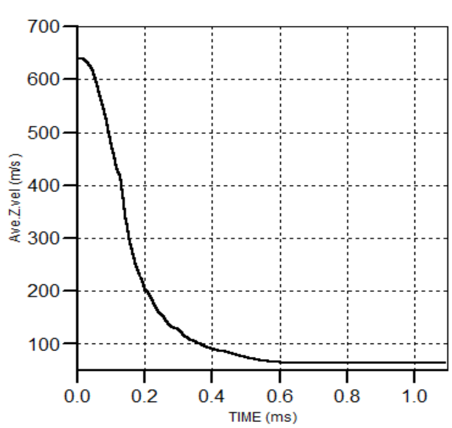


a) Mesh 2

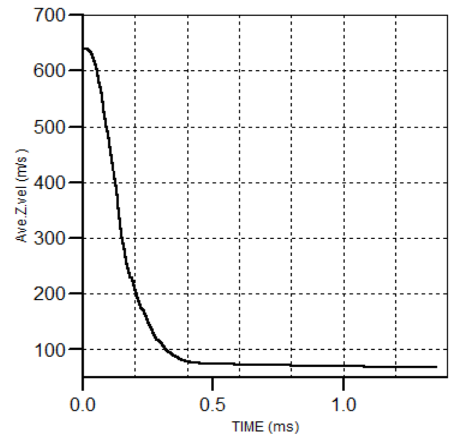


b) Mesh 3

Fig. 7: Excessive distortion at rear face using erosion value of 2.0



a) Mesh 2



b) Mesh 3

Fig. 8: Bullet residual velocity vs. time for erosion value of 2.0

3. Conclusion

Different results are obtained when the same problem is solved with different erosion values and mesh sizes. It should be observed that the bullet residual velocity and damage pattern of concrete panel are strongly dependent not only on erosion value but also on mesh size. The residual velocity of bullet is remarkably reduced as the erosion strain value is increased. However, using large erosion values in the numerical model could resulting in an excessive mesh distortion.

Based on the results obtained in this study, a fine mesh must be used in the numerical model using AUTODYN to obtain more accurate results and realistic damage pattern for the concrete panel. Moreover, it is recommended to use an erosion value of 1.5 as erosion criterion in AUTODYN for the numerical simulation of concrete structures subjected to high speed impact.

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ISSN (Online) 2348 – 7968 | Impact Factor (2016) – 5.264

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