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Penetration Behaviour Simulation of Shaped Charge Jets in Water Filled Targets

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ABSTRACT:

In this paper penetration behavior of shaped charge jet in water filled targets has been simulated by using AUTODYN software. Velocity of jet, process of crater formation in water due to movement of high velocity jet, consumption of jet and orientation of jet particles during penetration of water have been successfully simulated. The simulated results match very well with the experimental data for residual penetrations obtained in steel plates after penetration of water column for stretching, fully stretched and particulated jets.

1.Introduction:

The shaped charge jets are generally designed and evaluated for their performance against hard targets like penetration of monolithic, composite and explosive reactive armors. Very few experimental studies have been conducted in the past for the penetration of shaped charge jets in underwater targets like submarines, which contain a column of water sandwiched between two armor plates. In the absence of adequate experimental data, validation and improvement of the penetration models for compressible materials like water becomes very difficult. Recently one such extensive experimental study was carried out by the authors by using Flash Radiography as a diagnostic tool. It was observed that the water which acts as a low density armour, shows more penetration resistance, particularly at higher jet velocities, than predicted by the existing hydrodynamic theories. Karlsson has simulated formation, elongation and fragmentation of shaped charge jet by peripheral- initiation as well as center point ignition of explosive charge by using Autodyn software and compared the effect of initiation point on the quality of jet [1,2]. In case of centre point initiation, the velocity of jet tip was reduced in comparison to peripheral initiation and large jet tip fragment was formed instead of elongated fragment. The results indicate that qualitatively Autodyn reproduces experimentally observed results. The effect of yield strength of jet material on jet break-up time was also found in line with the experimental results of Chou and Carleone [3]. Following the method of Karlsson [2], we have modeled the shaped charge warhead which was earlier studied experimentally [4]. The Autodyn simulation reproduced the jet having parameters similar to the actual jet recorded by flash radiography. Further simulations were carried out to reproduce the experimental results of penetration of confined water targets by this jet. Simulation methodology so developed will be used in future to predict the results of shaped charge experiments.

2.Shaped Charge:

Shaped charge is a special type of cylindrical explosive device in which a conical cavity is made at one face and lined with metal. The detonation of explosive cylinder at the central point of the face opposite to the cavity makes the liner collapse towards the axis. A metal jet moving at very high velocity is thus produced due to collision of liner material along the axis of the cone. The projectile so produced has two distinct parts moving with high and slower velocities which are called jet and slug, respectively. There is constant velocity gradient through out the length of the jet which causes the jet to elongate and then break into a number of small fragments. It has been observed from the experiments that penetration of the jet in the target is maximum when it is fully stretched and just starts breaking. The other main parameters which affect the jet velocity and its penetration capability include charge caliber and explosive to metal mass ratio, liner material and cone angle, target stand off etc. The sketch of the shaped charge warhead used in this study is given in Fig.1.

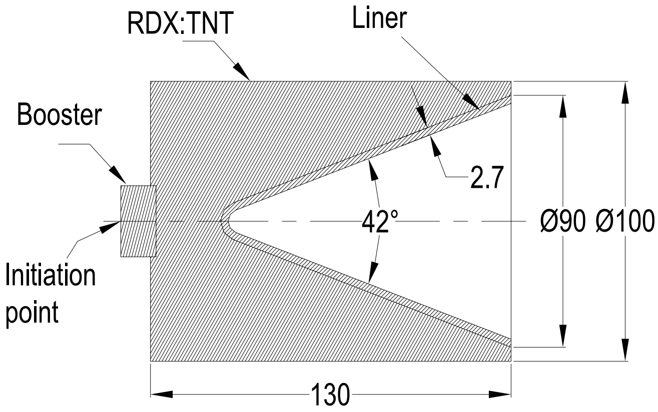

Fig.1: Sketch of the shaped charge warhead

3.Method of Simulation:

Autodyn is very useful simulation software for wide variety of nonlinear physics problems such as explosive detonation, projectile impact and penetration etc. It is an integrated package with the preprocessing, post processing and analysis modules which uses finite difference, finite volume and finite element technique for the solution of the problems. The package includes Euler, Lagrange, ALE and SPH processors which can be selected separately to model different parts of the problem as per their suitability. But most commonly used solvers are Lagrange and Euler. In Lagrange solver the material is fixed but the grid is moving. Due to high strain rate, Lagrange grid suffers from the problem of excessive distortion and self- entangling. As a result, cell dimensions tend to become zero, leading to zero cell volume and zero time step, thus, halting the simulation. On the other hand, in Euler solver the grid is fixed and the material flows along the grid, therefore no cell distortion occurs in the grid. Therefore, in high strain rate phenomena Euler is preferred over Lagrange. Multiple materials are handled either through a volume fraction technique or an interface technique. As all the variables are cell centered, this allows arbitrary shaped control volumes to be formed at the interface between Lagrange and Euler grids. This facilitates the computation of gas-structure and fluid- structure interaction problems as in the present case study.

Geometric model of the problem was generated by using in-built preprocessor of Autodyn. Selection of most appropriate material model and associated input data is the prerequisite requirement of predicting the response of materials used in the problem. The composition-B explosive, copper liner material, steel casing and target materials all were modeled in Euler for the shaped charge jet formation and penetation. The various parameters used for simulation of shaped charge jet are given in Table-1.

TABLE-1: Material models used in simulation

Material	Equation of State	Strength Model	Failure Model
RDX/TNT(60/40)	JWL	None	None
Cu(OFHC)	Shock	Piecewise JC	None
Steel-1006	Shock	Johnson-Cook(JC)	None

4.Results and Discussions:

A simulation of shaped charge jet in air was first carried out to compare with the experimentally recorded jet by flash radiography. The simulated jet at 130 µsec and 194 µsec along with recorded jet is shown in Fig.2. As far as length and velocity of simulated jet are concerned, they compare very well with the experimentally recorded jet. However, fragmentation of simulated jet starts early which is a numerical artifact due to numerical perturbation caused by the oblique movement of copper liner through the rectangular Euler grid[2]. The model of Shaped charge and steel-water-steel sandwich target is shown in Fig.3. The simulation of penetration of jet through this target is shown in Fig.4. Effect of water stand-off on residual penetration of second steel target was also studied by simulation. The simulation results are in good comparison with the experimental results as shown in Table-2.The jet tip velocity at the entry and exit of water column of different lengths as obtained from simulations are in close agreement with the experimentally recorded velocities in each case. Similarly, the experimental results of residual penetration in the steel target kept at the end of water column is also reproduced by the Autodyn simulation in all the three target formations.

Fig2(a): Flash X-ray records of jets in air at130µsec and 194µsec as produced from shaped charge of Fig.1.

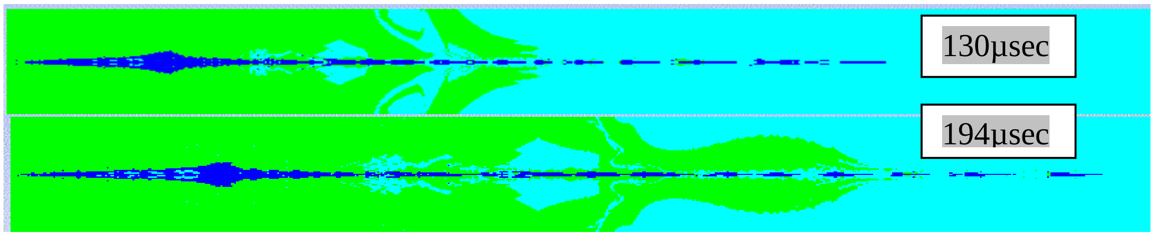

Fig2(b).: Simulated jets in air at130µsec and 194µsec as produced from shaped charge of Fig. 1.

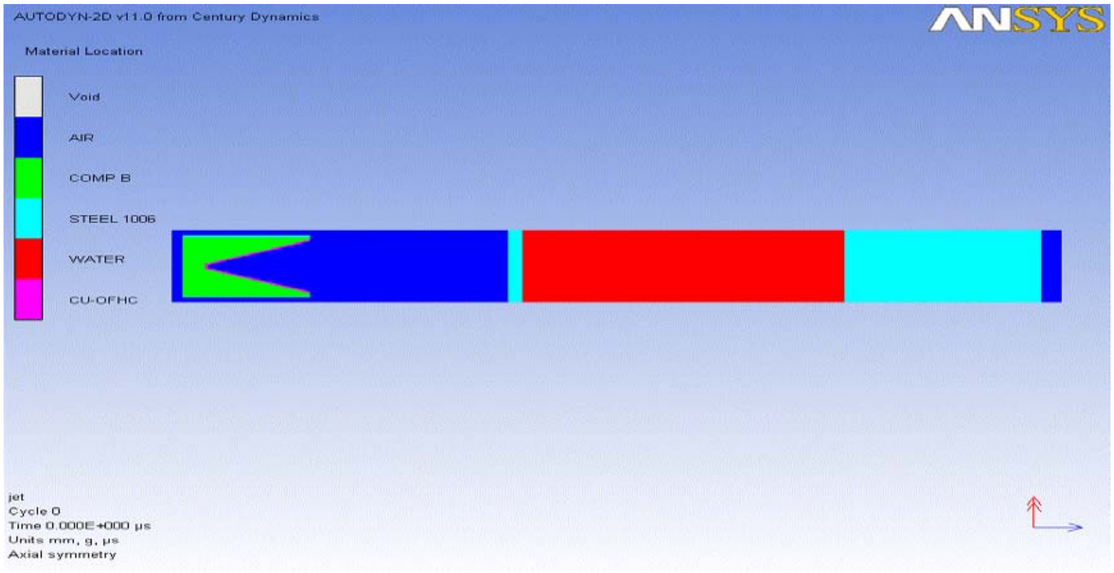

Fig.3: Model of shaped charge jet and target

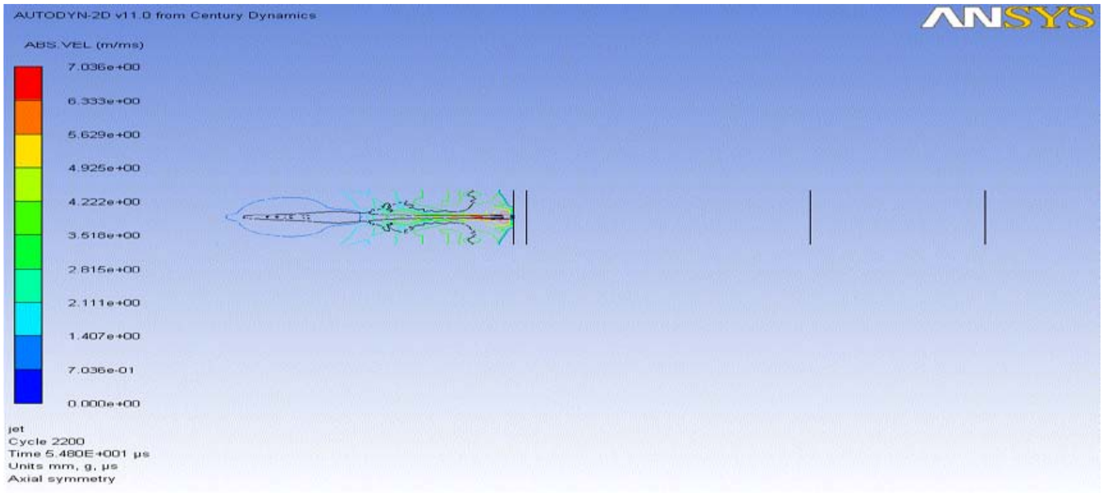

Fig.4(a): Jet striking the first steel target just before entering the water column.

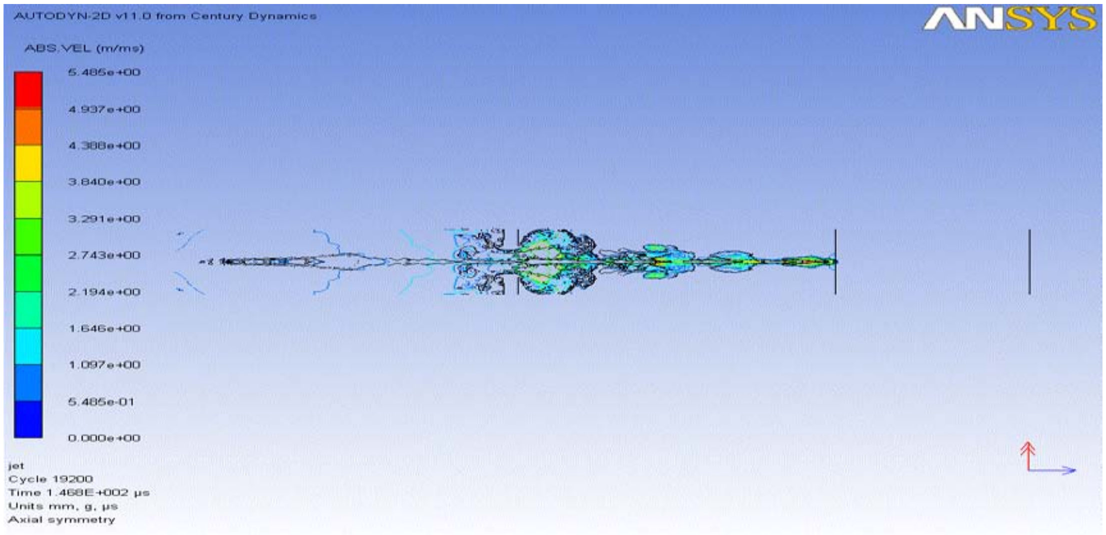

Fig.4(b): Jet striking the second steel target just after penetrating through the water column.

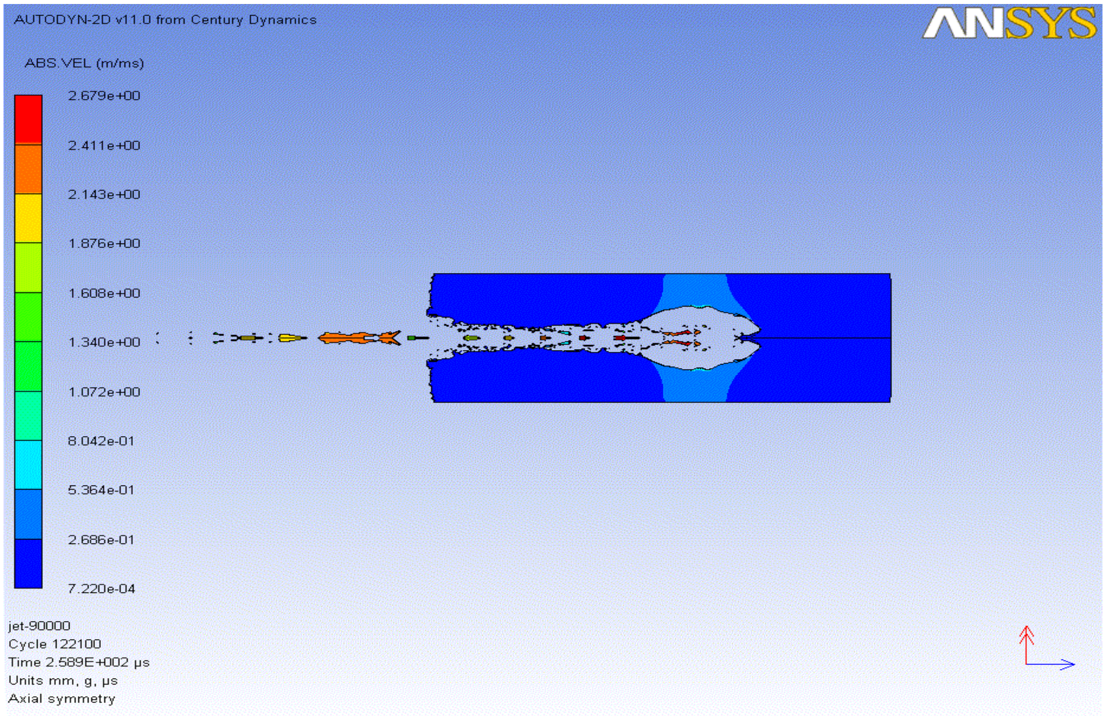

Fig.4(c): Jet penetrating through the second steel target just after coming out of the water column.

TABLE-2: Comparison of simulated and experimental results of target penetration

Stand-off between shaped charge and water column (mm)	Water stand-off (mm)	Average jet tip velocity Vjen(mm/ µs) at the enterance of water column		Average jet tip velocity Vjex(mm/ µs) at the exit of water column		Residual penetration in RHA(mm)	
		Exp.	Sim.	Exp.	Sim.	Exp.	Sim.
200 (2 CD)	325	7.43	7.20	4.65	4.58	170	161
	650	7.20	7.01	2.44	2.38	102	96
	1000	7.65	7.47	2.12	2.15	15	12
400 (4 CD)	325	7.60	7.52	5.11	5.15	230	235
	650	7.72	7.70	2.80	2.85	135	145
	1000	7.50	7.55	2.28	2.32	30	35
800 (8 CD)	325	7.02	7.15	1.82	2.01	10	16

5.Conclusion:

The Autodyn software has been used to simulate shaped charge jet formation, elongation and its penetration of water filled metal target. The simulated jet tends to break into fragments early in comparison to the experimentally recorded jet which may be numerical artifact due to oblique movement of copper liner through the rectangular Euler grid. The simulation results of penetration of jet in steel-water-steel target closely match with the experimental data.

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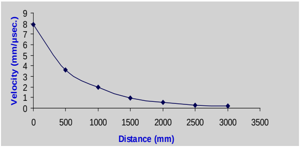

Fig.2. Velocity-distance profile of jet in water