FINDING OUT THE EFFECTS OF DEPTH ON THE UNDER-WATER BLAST USING AN EXPLICIT DYNAMIC ANALYSIS METHOD

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Abstract - *This project deals with assessment of lethality of underwater blast on target plates representing double hull submarine. Safety of submarines during to underwater explosions is a multiphase phenomenon, comprising of series of events which are difficult to predict without the use of numerical methods. Detonation of explosion causing expansion of gases inside the water, which in turn gives rise to high velocity shockwaves in water that have potential of damaging the underwater structures. In order to study impact of these waves effectively a numerical model has to be generated to which correlates the physical phenomenon with mathematical formulations. To numerically model these undulations in water, a heretic approach, SPH, having capability to deform with high velocity is being employed. Smoothed Particle Hydrodynamics (SPH), a mesh free Lagrangian method is used instead of most common Eulerian approach in finite element analysis that involves both nodes and elements. SPH is incorporated as uniformly distributed particles in the domain as nodes to represent the fluid. These particles expand due to detonation of explosives and travel with high velocities imparting the pressure on plates placed in water that represents the hull of the submarine. By determining this pressure that is being acted on the submarine its safety can be determined.*

***Key Words*: Underwater blast, Submarine, Explosion, SPH, Detonation**

1.INTRODUCTION

Underwater explosion is a serious threat when a ship or submarine passes within a close proximity. Shock waves propagated due to the underwater blast may not cause same level of damage and are different than that of air or land explosions. However, it may result in potential failures that will make the system weak and inoperable.

Physical prototype testing of this scenario is not always possible. This is an extremely complex non-linear application and needs careful understanding of physics and engineering materials. This signifies the importance of virtual prototype simulation in time domain to evaluate the damage and performance. This can be achieved by modelling ship, explosive and water using LS-PrePost and analysis is carried out using LS-DYNA (explicit dynamic finite element analysis code). This effort is done in order to check the damage and make the necessary conclusions in underwater explosion test case.

1.1 Objective

The objective of this project is to assess the lethality of underwater blast on target plates representing single hull submarine.

1.2 Scope of work

- FE modelling of simulation studies for water depth of 10m.
- Assigning material properties.
- Assigning boundary conditions.
- Result extraction and interpretation.

2. LITERATURE REVIEW

This literature review shows the abundance of submarine impact studies for open water explosions. Much important information was obtained from this literature review. However, this review shows little reported work on underwater explosions, which included the influence of detonating 4 explosives below the mud line and confinement of the explosives pile. Connor's (1990) study showed a reduction in explosive efficacy in the development of a water shock. The measured pressure, momentum and energy flow density were lower than would be expected from a free water explosion for medium-scale experiments and large-scale offshore structure removal operations. The lack of a robust method to take into account the real conditions encountered in the removal of offshore structures led us to select a series of parameters for a numerical study that may permit the determination of a good explosive weight supported the operational atmosphere of the explosive.

Jae-Hyun Kim, Hyung-Cheol Shin in the year 2008 they performed simulation on liquified oxygen tank to investigate the survival capability of this tank while under water explosion. This study is done by the ALE (Arbitary Langrangian Eulerian) approach. It is used to study the fluid structure interaction. By their study they confirm that the ALE approach is the best method for simulation of underwater explosions. They found that the mesh size can alter the results as the smaller the mesh size means better the results as compared to the larger mesh size. While blast happens, they found that the shock waves produced are in spherical hence they concluded that the shock waves produced while simulating are spherical waves not like plane waves. They considered shock acceleration to find effects based on this static analysis is performed. After seeing all results, they concluded that the ALE technique can be used to test the structural damage of the structure after explosion.

Vasile Nastasescu, Silvia Marzavan in 2016 these two people presented a paper which represents theoretical and practical analysis of underwater explosion. This numerical analysis on submerged structure is achieved by using smoothed particle hydrodynamic method (SPH) it is also known as free particle method. They also showed some types of explosions which took at under water and also tried to explain damage mechanisms which are created by underwater explosions on immersed structures. In their study they concluded that the SPH (smoothed particle hydrodynamic) is practically and theoretically validated to get results automatically solving by fluid structure interactions.

D. Ho-Minh, Jian Tong and Danielle S. Tan they published a paper in the year 2016 in their paper they presented dispersion process in a simplified version by simulating this as a numerical model. To conduct these numerical simulations, they used smoothed particle hydrodynamics (SPH) means spherical sized uniform particles which represents the sedimental water mixture and pure water. They compared the simulation results which are obtained from smoothed particle hydrodynamic method (SPH) with experimental results. Here they examined two types of fluids one is dilute mixture and other one is highly concentrated fluids. Suspension viscosity model is used to calculate the viscosity of heavier fluid.

Rouhollah Amirabadi, Reza Ghazangian they conducted a comprehensive study on explosion takes place in an identical submarine in the year 2018. They conducted numerical study on effects of the explosions on submarine by using ABAQUS software. In this paper researcher tries to explain about phenomena of underwater blast and how blast affects the structure, explains theories that governs fluid dynamic propagation, interaction of shock wave with structures. Here they investigated on the spherical and cylindrical shells which are subjected to different types of shock waves which are generated during under water blast. By this test they obtained some results as responses of structures for various frequencies, hydrodynamic pressure.

3. METHODOLOGY

Procedure of this starts with creating a container having significantly large dimensions that represents the water body wherein submarines are located. This tank would be sufficiently large enough so that the water waves reflecting back will not affect the cylindrical shell. In this model fluid is assumed as infinite and homogeneous acoustic field. This container is meshed using 2D shell elements, and is given rigid material properties as it has no vital role to play in the simulation besides holding the nodes.

SPH nodes are created with inputs of box size that holds the SPH particles, filling directions and ratio of filling the volume. Density of particles was also given considering both the solving time and appropriate resolution of simulation using nodes only. Multiple SPH nodes are enclosed in this container by incorporating the properties that define water, which include density, viscosity coefficient, bulk viscosity, and a governing equation of state (EOS_MURNAGHAN).

A catastrophic detonator is positioned at the centre of these SPH particles that generates pressure waves when triggered. This detonator is also modelled using the same SPH particles. In order to pass on waves generated by this detonator component to water component, appropriate contact between these SPH particles was given. The same contact of Automatic_nodes_to_surface must be given between water particles and hull of the submarine. SPH particle are defined as slaves while the hull plates were the master component. The values of coefficients of friction, damping coefficient are provided to incorporate more reliability.

Plates representing the double hull of the submarine should be placed in the container at various specified distances from the detonator in various iterations, on which pressure values are measured during the post processing of the simulation. These pressure values are found carrying out simulations, at all the intervals with an increment of 8m, 9m, 10m covering all the region that a submarine travels through, to simulate the effect of additional hydrostatic pressure due to the depth of water. The more the depth of water is, the more pressure it will exert on the cylindrical shell to increment in hydrostatic force.

Termination time of the simulation was decided according to the time required for the water wave to travel to the farthest plate from the detonation point. Timestep decided by the LS-Dyna was scaled down in order to make the simulation more reliable. RCFORC card is deployed to find out reaction forced being exerted by the components on each other. Gravity is defined ubiquitously using body Z acceleration card, which is a must to get accurate results. Particle approximation theory used is enhanced fluid formulation.

Parameters and effects of this underwater explosion are modelled using this mesh free method in CAE. Graphs of pressure values against distance and time, energy plots are to be drawn to determine the safety of the hull.

4. METHOD APPLIED: -

- Modelling of blast analysis is on the basis of (SPH) Smooth particle hydrodynamics or Arbitrary Lagrange and Eulerian Approach (ALE) method.
- SPH methodology has proven to be a reliable and economical methodology for modelling the blast response of the vehicles and alternative structures and it's a time economical methodology.
- SPH method is more accurate as compare to ALE method.
- Blast analysis need equation of state for its analysis.

4.1 About smooth particle hydrodynamic: -

- SPH particles are not actual particles.
- They are really fluid samples of constant mass.
- Particles are placed inside a container to represent a fluid.
- Every particle is then assigned a set of initial properties.
- After every time step (a few milliseconds), update the properties of all particles.

4.2 GOVERNING EQUATIONS: -

The underwater explosion is governed by physical law of conservation. The water and the gas created during high explosive is assumed as inviscid because of rapid explosive velocity and shock propagation velocity in water. Therefore, this entire process represents the adiabatic process. The underwater explosion process is modelled by using Euler equation with the help of equation of state

$$D\rho/Dt = -\rho\nabla.v$$

$$Dv/Dt = -1/\rho \ \nabla p$$

$$De/Dt = -p/\rho \ \nabla v$$

$$P = p(P,e)$$

Where v, t, ρ, e and p are velocity, time, density, internal energy and pressure respectively.

When high explosive detonates it produces explosive gas here the standard Jones-Wilkinns-Lee equation is implemented for equation of state. As per the JWL EOS the pressure of the detonated explosive gas is

Here A, B, R1, R2 are experimental coefficients obtained by analysis. e is the internal energy of the explosive per unit mass. η is the ratio of the density of the explosive gas to the initial density of the original explosive.

5. DESCRIPTION OF MODELS

5.1 Characteristics of explosive:

- High TNT explosive filled with insensitive composition PBHE 102 or PBX 140 or TGAG5

$$p = A(1-\frac{\omega\eta}{R_1})e^{-\frac{R_1}{\eta}} + B(1-\frac{\omega\eta}{R_2})e^{-\frac{R_2}{\eta}} + \omega\eta\rho_0 e$$

- Weight of high explosive: 2 kg
- Initiation: Time mechanical fuse
- Depth of functioning: 10m

PARAMETER OF EXPLOSIVE: -

The parameters of explosive are given as per the JWL standard as shown below

(cm-g-μs-Mbar)	Comp B	C-4	PETN	TNT	NM	Octol 78/22	Tetryl	HMX
ρ_o	1.717	1.901	1.500	1.630	1.128	1.821	1.730	1.891
P_{CJ}	0.295	0.280	0.220	0.210	0.125	0.342	0.285	0.420
V_d	0.798	0.8193	0.745	0.693	0.628	0.848	0.791	0.911
K_{bulk}	0.10			0.077	liquid	0.113	0.052	
G_{shear}	0.05			0.03	liquid	0.05	0.026	
σ_{yield}	0.01			0.00711	liquid	0.01	0.0216	
A_p	5.242	6.0977	6.253	3.712	2.092	7.486	5.868	7.783
B_p	0.07678	0.1295	0.23290	0.03231	0.05689	0.13380	0.10671	0.07071

C	0.01082	0.01043	0.01152	0.01045	0.00770	0.01167	0.00774	0.00643
r_1	4.2	4.5	5.25	4.15	4.40	4.50	4.40	4.20
r_2	1.1	1.4	1.60	0.95	1.20	1.20	1.20	1.00
ω	0.34	0.25	0.28	0.30	0.30	0.38	0.28	0.30
E_o	0.0850	0.090	0.0856	0.07	0.0510	0.0960	0.0820	0.1050
Ref.	[11], [12]	[11]	[11]	[11], [12]	[11]	[11], [12]	[11], [12]	[11]

5.2 Characteristics of water tank: -

Diameter of water tank: -2500 cm

Depth of tank: -1000 cm

Depth of charge: -500 cm

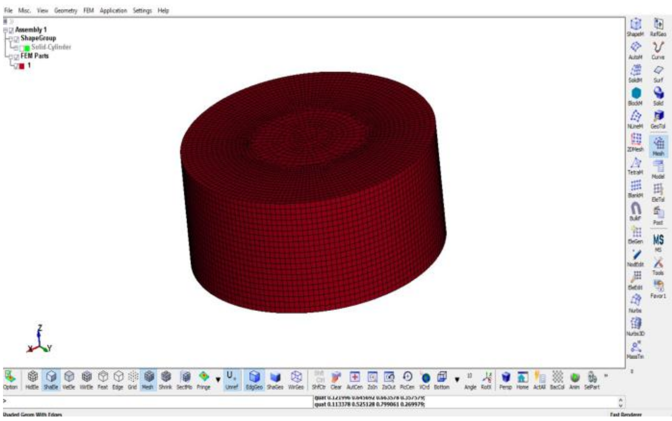

Fig 1: -Water model

PARAMETERS OF WATER: -

Density: - 1 g/cm^2

Dynamic viscosity of water: - 8.90*10^-4 Pa sec

Viscosity: - 0.0091 poise

5.3 Target plate:

- Type of hull: Double hull submarine
- Material of hull: Steel HY80 / HY100
- Inner hull thickness: 10mm
- Length: 2m X 2m.

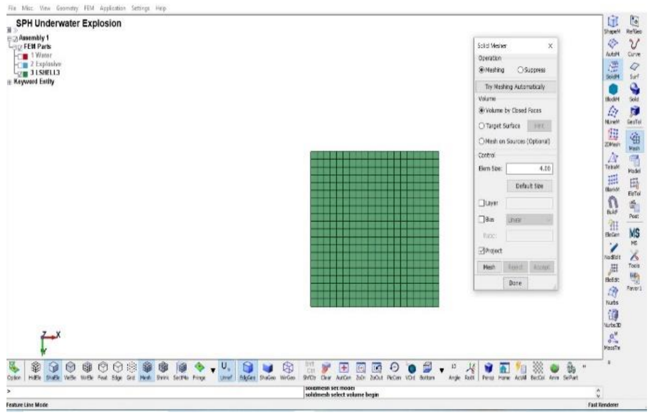

Fig 2: -Hull plate

PARAMETERS OF TARGET PLATE: -

Mass density: - 7.81 g/cm^3

Youngs modulus: - 2.09 g/cm^2

Poison's ratio: - 0.3

5.4 Model set-up: -

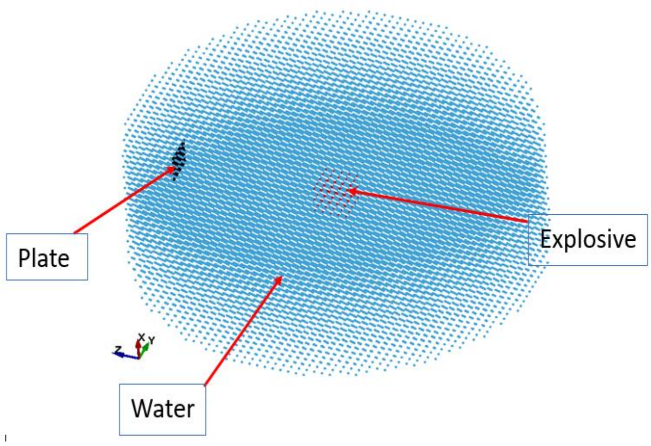

Fig 3: -Final model setup

The final model set-up is done as shown above. The explosive is placed at the Centre of the water model at depth of 5m. The water and explosive model also converted to SPH particles and the plate is placed in the tank at certain distances (8m, 9m, 10m) in 3 iterations.

6. Contacts and conditions given: -

The complete model set up of water, a catastrophic detonator and hull plate is shown above. The detonator is placed between the water to pass the waves generated by the detonator component to water an appropriate contact must be given between these two SPH particles.

To get the effects of wave on plate the contact of Automatic_nodes_to_Surface must be given between the SPH nodes and plate surface. Here during contact plate is defined as master component while SPH particles are defined as slave.

The pressure is going to exert on the plate as per the depth of water, as the more depth of water more the pressure is exerted on the plate as there is increase in hydrostatic force.

The termination time of simulation was decided by the time required to travel the wave to the farthest plate from the centre.

To make more reliable simulation the time step was decided by LS Dyna.

To get the accurate results we use Z – acceleration card where the gravity is defined.

7. RESULTS AND DISCUSSION

In fir 8 the explosive is surrounded by the water in the form of explosive particles, the plate is also placed at a certain distance with respect to the explosive. This explosive is filled with TNT particles.

When the cylindrical shaped explosive detonates the hull plate is get affected by the shock wave propagated in the water. The results for 3 iterations are shown below

7.1 For 8m plate: -

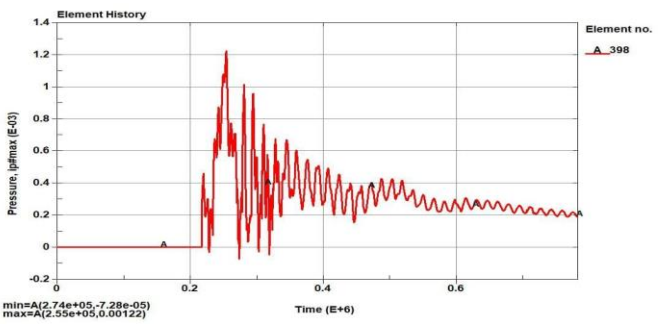

Fig 4: -Shows pressure variation on 8m plate

Above figure shows that how the pressure is going to exert on the plate at the different time intervals on the plate which is located at a distance 8m. When the detonator explodes the pressure created is going to effect on the plates. The pressure variation on a plate is shown in the above figure. By observing the pressure graph, we can see that the wave pressure reaches the plate after 0.22 Secs. The maximum pressure of about 0.00122 Mbar is created on plate of about 0.25 Secs after the detonator explodes. After reaching maximum pressure limit the pressure is going to attain a constant level. Here in this case pressure reaches constant level of 0.002 Mbar.

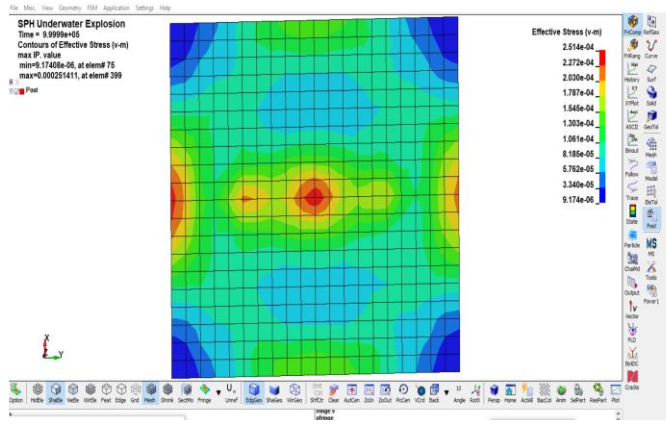

Fig 5: -Contour plot of von-mises stress on 8m plate

Above figure shows the von-mises stress which represents the equivalent stress effects on a plate which is located at a distance 8m from the detonation point. For this distance the maximum stresses are concentrated on the centre of the plate. The maximum von mises stress developed on the centre of the plate is 0.0002514 g/cm-s at element number 399 and the minimum von mises stress recorded is 9.17408e-06 on the element number 75.

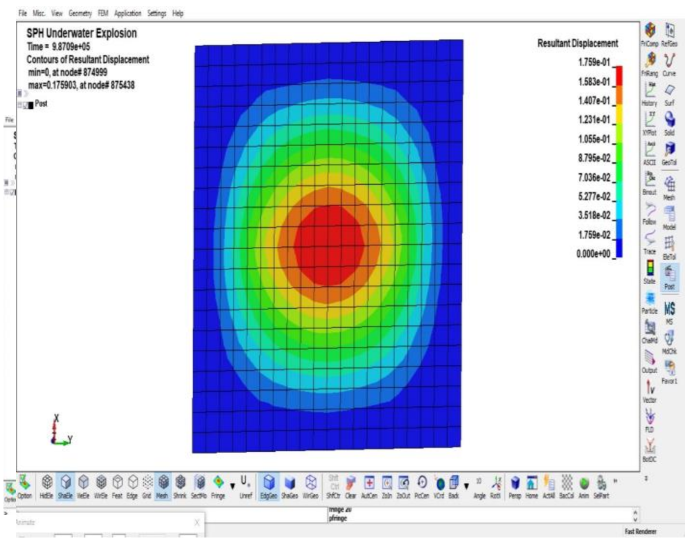

Fig 6: - Contour displacement plot of 8m plate

When the detonator explodes shock, waves are produced in the form of waves then these waves are going to collide on the plates because of this some elements on the plates are going to displace. Here in this case some elements of the plate which are located at the centre of the plate as shown in the figure are going face the maximum displacement about 0.27783 cm.

7.2 For 9m plate: -

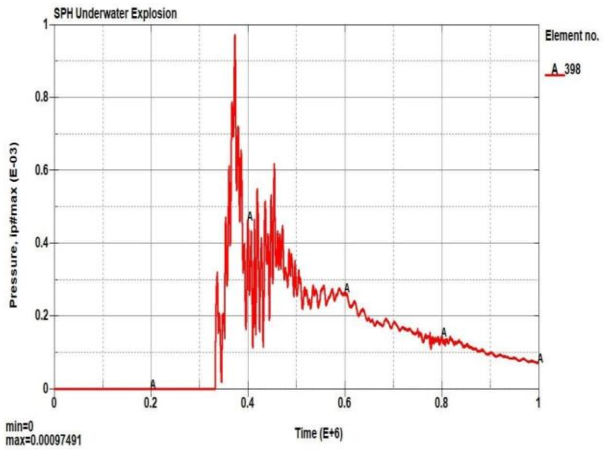

Fig 7: - Shows the pressure variation on 9m plate

Above figure shows the pressure variation on the plate due to explosion at a distance 9m. After 0.33secs of explosion the pressure starts to develop on this 9m plate. In the beginning the pressure variation takes place at the different lower levels then at 0.38secs pressure reaches the value 0.000974Mbar it is the maximum pressure that is affected by the detonator on the place which is located at a distance 9m. After reaching maximum value pressure variation decreases to lower level then it reaches to a constant level.

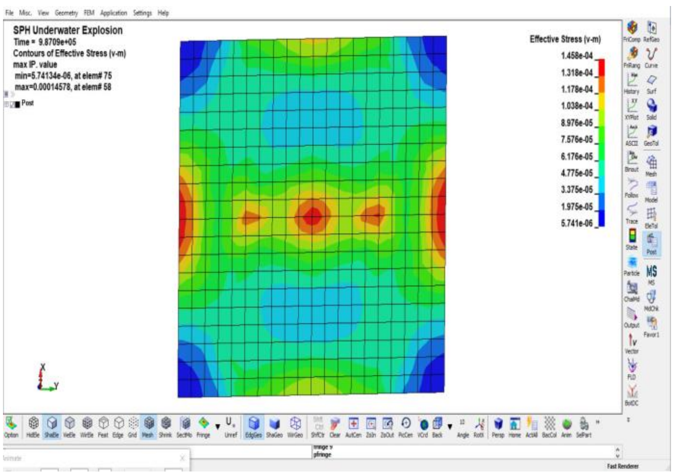

Fig 8: -Contour plot von-mises stress on 9m plate

The maximum von-mises stress affected by the explosion on this plate is 0.0001457g/cm-s. because of the larger distance than the previous one the stress values are less compared to 8m distance plate.

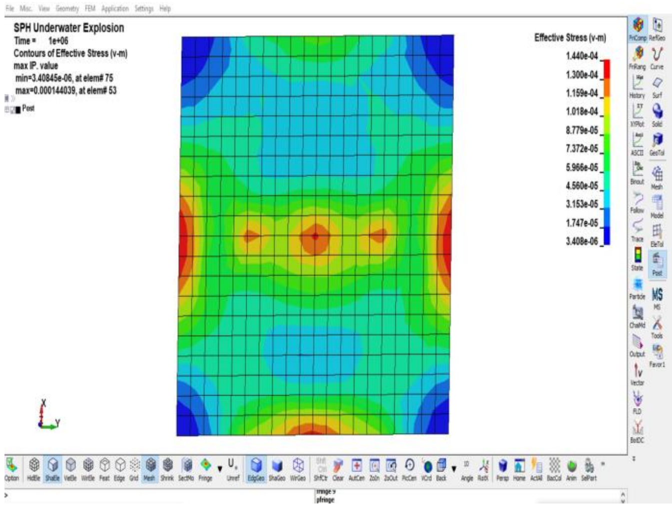

Fig 9: -Contour displacement plot of 9m pate

Above figure shows the displacement of plate which is located at the distance 9m from the detonator point. In this case the centre portion of the plate got displaced maximum as compared to other portion the plate. The maximum displacement of the plate portion is 0.1759cm.

7.3 For 10m plate: -

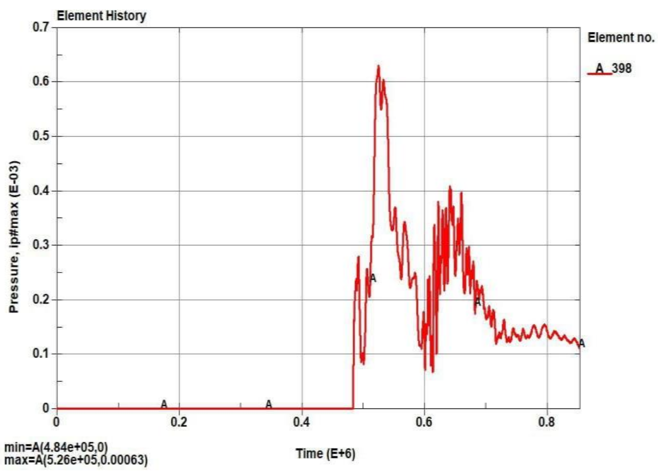

Fig 10: -Shows pressure variation graph for 10m plate

It is the last iteration of this analysis and here it will take a longer time to affect the plate from explosive than the previous iteration. Here the pressure starts varying on plate at 0.49 secs after explosion. In this case the maximum pressure applied on the plate is noted as 0.00063Mbar at time interval 0.53 secs.

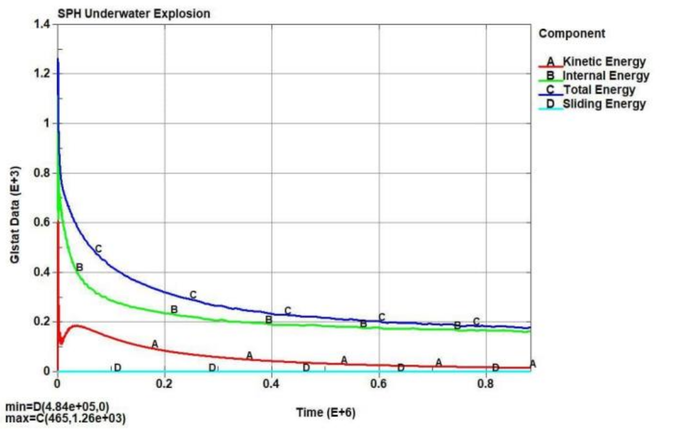

Fig 11: -Contour von-mises stress plot on 10m plate

Von-mises stresses or the effective stresses for a plate which is located at a distance 10m apart from the detonation point is shown in the above figure. The maximum stress is concentrated at the centre of the plate which is 0.000144g/cm-s at element number 53. The minimum stress recorded on the plate is 3.406e-06 g/cm-s at the element number 75. This plate is affected less as compared to the other plates as this plate placed at a longer distance than the previous plates.

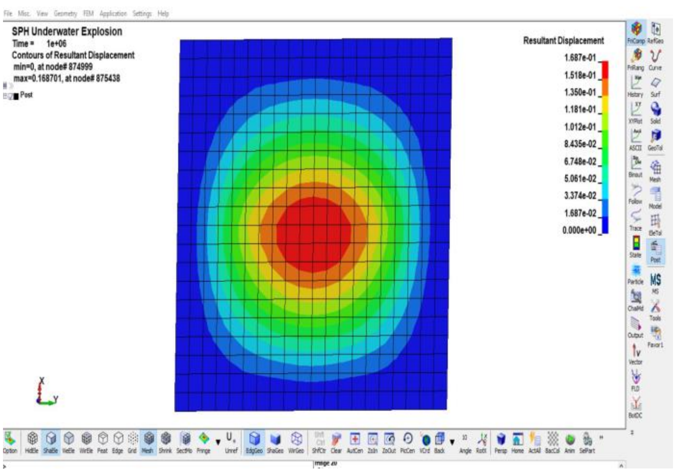

Fig 12: - Contour displacement plot of 10m plate

The above distribution figure shows the displacement of plate which is located at a distance 10m from the explosion. The maximum displacement of the plate is going to take place at the centre portion. The maximum displacement recorded is 0.168 cm due to explosion. Here the elements which are located at centre are more displaced.

7.4 Energy plots: -

When the detonator explodes the explosion takes place. Here in this case underwater explosion the detonator is placed at the centre of the SPH water particles and the plates are located at different location. When the explosion takes place, the energies are created because of shock wave propagation in underwater. The energies which are produced in this case are kinetic energy, Internal energy, Total energy.

By using TNT explosive in the underwater explosion, we got total energy 1.26 KJ which is the highest energy recorded among other energies. Then it is gradually decreases with the time and then the energy level reaches constant level. After total energy the second most energy recorded is internal energy, when explosion takes place it recorded 0.6KJ of energy then it suddenly increases to 1.12KJ of energy then it also decreases gradually with respect to time and then it reaches constant energy level. Here kinetic energy is produced when the detonation takes place and the value of the kinetic energy spikes from zero to 0.6KJ and decreases suddenly then increases some value and then decreases slowly to zero.

Table-1: - Energies produced due to explosion

Type of Energy produced	Amount of energy produced in KJ	
	Min	Max
Total energy	0.17	1.26
Internal energy	0.157	1.12
Kinetic energy	0.0	0.604

8. CONCLUSIONS

For underwater explosion we use SPH method which is validated in fluid mechanics theoretically and practically which helps in solving the structure and fluid interaction. Water, explosive, hull plate interactions can be determined in one run only but it takes more time to solve.

In this simulation TNT is used as high explosive which is placed at the centre of the water tank and hull plate is located at the same depth but placed at different distances here, we take three iterations as 8m, 9m, 10m. The TNT explosive parameters are taken as per the JWL regulation and it gave the proper results.

When the detonator explodes it produces energies, the highest energy recorded is 1.26KJ which is Total energy then internal energy produced is 1.12KJ and at last the kinetic energy produced is 0.6KJ.

The nearest plate which is the pate located at a distance 8m from the detonation point is highly affected by the explosion. The maximum effective stress is seen on the nearest plate which is located at a distance 8m from the centre which is about 0.0002514 g/cm-s and the maximum pressure is 0.00122 Mbar and maximum displacement recorded is 0.27783cm which is higher than the other two plates.

By observing the graphs, we come to know that the energies and pressure values reaches a maximum limit and then after some time interval it reaches the constant level and does not change with time. Here we use LS-Dyna explicit solver to solve this problem. As shown above we applied SPH method for water and explosive to get proper results. As compared to ALE method SPH method gives the best results.

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