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Impact of Underwater Explosion and Bubble on Submerged Cylinder

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Abstract—*This paper describes the numerical simulation of a cylinder submerged under water subjected to explosion using MSC.Dytran. The cylinder is modeled using a Lagrangian mesh. Multiple Euler domains are used to the air inside the cylinder, the surrounding air, water and the explosive. Since the model includes air, water and explosive, a multi- material Euler solver is required. A fast general coupling is used to simulate the interaction between the Lagrangian mesh and Euler mesh. When by the impact of the shock wave and subsequent gas bubble, the cylindrical structure deforms, fails and water flow into the cylinder.*

Keywords: *Numerical simulation; Lagrangian mesh; Euler mesh; multi-material Euler solver; shock wave; Structural deformation.*

1. INTRODUCTION

When a submerged structure subjected to under water explosion (UNDEX) loading, it is important to predict the structural response to the shock wave. Furthermore, in the case of the explosion occurring close to the structure, a high velocity water jet penetrating the gas bubble occurs. This water jet is extremely efficient in producing damage.

Fig. 1 [4] illustrates the pressure-time history, which is observed in the water at a fixed distance from the point of explosion. Upon arrival of the shock wave, the pressure rises instantaneously to the peak value and decreases at nearly exponential rate. Subsequent to the shock wave, other pressure pulses occur. These pulses arise from a much slower phenomenon, namely the pulsating of the gas bubble, which contains the gaseous products of the explosion. The high pressure of the gas causes an initially rapid expansion of the bubble and the inertia of the outward moving water carries it far beyond the point of pressure equilibrium. The outward motion stops only after the gas pressure has fallen substantially below the ambient pressure. Now the higher surrounding pressure reverse the motion. Again the flow overshoots the equilibrium and when the bubble reaches its minimum size, the gas is recompressed to a pressure of several hundred atmospheres. At this point we have effectively a second “explosion” and the whole process is repeated. The bubble oscillates in this way several times. The position and the size of the bubble are shown in Fig. 1 for a few specific moments, which correspond to the pressure-time curve as indicated above.

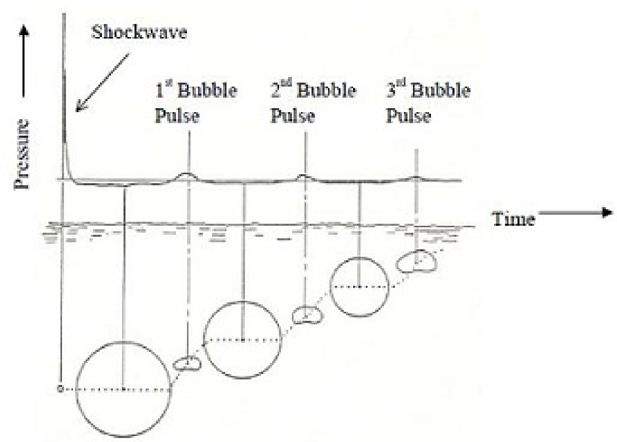

Fig. 1: Pressure waves and bubble phenomena of UNDEX

The pressure-time history reflects the low gas pressure during the phase where the bubble is large and it shows the pressure pulses, which are emitted from the bubble near its minimum. The period of the bubble pulsations is very long when compared with the shock wave portion of the pressure-time history of an explosion. In particular, this duration is long enough for gravity to become effective. Such a bubble has great buoyancy and, therefore, migrates upward. However, it does not float up like a balloon, but shoots up in jumps.

In order to be able to predict structural behavior under UNDEX loading without going into destructive testing, a lot of finite element computer analysis have been made. MSC.Dytran [1] is a commercial software package for short-term transient analyses that involve structural parts and computational fluid dynamics (CFD) parts. The CFD solver of MSC.Dytran uses an Eulerian approach and employs a finite volume method to discretize the governing equations. These equations are the conservation laws and are integrated in time by a first-order explicit dynamic procedure. The Euler mesh is stationary in the space while the fluid can flow through the mesh. CFD simulations provide fluid velocity, pressure fields and other variables.

In simulations with fluid-structure interaction the fluid inside a finite volume domain is bounded by a surface that represents the interacting structure. This surface is called a coupling surface and enables the fluid to exert a force on a deformable structure.

A unique "Adaptive Multiple Euler Domains" [6, 7] technology had been developed in MSC.Dytran for single and multi-material Euler solvers. Multiple Euler domains are automatically generated around a coupling surface, and each Euler domain automatically adapts itself when the coupling surface moves and deforms. The Euler materials can be either hydrodynamic or have shear strength. Material in- and out-flow can be defined, as well as flow between the Euler domains across porous or open areas in the coupling surfaces. When the structure fails, the Euler materials flow through the holes, failed surfaces and ruptured areas. This Adaptive Multiple Euler Domains technology makes efficient modeling of UNDEX using MSC.Dytran possible.

The purpose of this paper is to demonstrate the application of Multiple-material Euler solver with Adaptive Multiple Domains to the UNDEX process. The problem simulates a cylinder submerged under water subjected to explosion using MSC.Dytran. The cylinder is modeled using a Lagrangian mesh. Multiple Euler domains are used to the air inside the cylinder, the surrounding air, water and the explosive. A fast general coupling is used to simulate the interaction between the Lagrangian mesh and Euler mesh. When by the impact of the shock wave and subsequent gas bubble, the cylindrical structure deforms, ruptures due to plastic strain failure and water flow into the cylinder.

2. EMPIRICAL FORMULATION

In a typical UNDEX simulation there are air water, explosive and the metal of the cylinder.

The air is assumed to be ideal and to satisfy the equation of state:

$$\mathrm{P} = (\gamma - 1)\rho e \tag{1}$$

Here p, ρ and e are respectively the pressure, density and specific internal energy and γ is the ratio of the heat capacities of the gas. The explosive is modeled as a compressed hot gas in this simulation.

The water is assumed to be compressible but inviscid and irrotational. It is modeled with a polynomial equation of state as follows:

$$\mathrm{P} = k\left(\frac{\rho}{\rho_0} - 1\right) \tag{2}$$

Here k is bulk modulus

ρ and ρ_0 are respectively the overall density and reference density.

The material flow is described by the conservation laws for mass, momentum and energy that read:

$$\frac{d}{dt}\int_V \rho dV + \int_A \rho(u \times n)dA = 0 \tag{3}$$

$$\frac{d}{dt}\int_V \rho u_i dV + \int_A \rho u_i(u \times n)dA = -\int_A p n_i dA \tag{4}$$

$$\frac{d}{dt}\int_V \rho e dV + \int_A \rho e(u \times n)dA = -\int_A u_i p n_i dA \tag{5}$$

Here V is a volume, A is the boundary of this volume, n is the normal vector along the surface A, u denotes the velocity vector in the volume.

In applying the conservation law of mass, mass is transported from one element to the other. Both the donating element as well as the receiving element can have multiple materials. Euler elements can contain up to five materials in one element. First the materials common to both elements are transported out of the donating element and if no common material is left in the donating element other materials are transported as well. This approach minimizes unphysical mixing and preserves material interfaces between air and water as much as possible.

To apply the conservation laws for Euler elements that are only partially inside the coupling surface the boundary of that part of an Euler element that is inside the coupling surface has to be determined. This boundary consists of the interfaces between Euler elements and the intersection of the coupling surface with the Euler element. These intersections are called polpacks. The conservation laws are applied to that part of the Euler element that is inside the coupling surface and surface integrals are computed by summing across the Eulerian interfaces and the polpacks. Flow and other communication from one Euler mesh to the other take place through porous shell elements that are common to both coupling surfaces [3].

The pressure computation in elements that contain a mixture of air and water is based on one of the thermodynamic equilibrium principles that amounts to pressure equilibrium. In an Euler element with both air and water there is a distinct pressure inside the air and a distinct pressure inside the water. Although masses are fixed during the pressure computation the volume of the air and the volume of the water are not fixed and they are adjusted iteratively until the pressure in the water equals the pressure in the air.

The cylinder consists of shell elements that deform under stresses and support failure models. An explicit finite element solver solves the shell dynamics, and an explicit Euler solver models the material inside and outside the cylinder. The interaction between these two solvers takes place in two steps:

(1) The mass in the Euler elements exerts a pressure load on the cylinder surface. These loads constitute the boundary conditions for the finite element solver, resulting in new grid point accelerations and velocities for the cylinder. From the updated plastic strain or updated stresses of the shell elements it is determined which elements are failing. Finally the cylinder grid points are moved with the new velocities.

(2) The cylinder grid points move and so the Euler mesh has a new boundary. Consequently, the volume of mass in each element may change. Since density is mass divided by the volume of the mass, densities also change, and so pressure.

3. NUMERICAL MODELS

The relative position of the cylinder, water surface and explosive is shown in Fig. 2. To model the fluid inside and outside of the cylinder, two Euler domains are used. The outer domain has the cylinder surface as part of the boundary, material is outside the cylinder surface and there is no material inside the cylinder surface. The contents inside the cylinder are modeled in the inner domain and this domain is also enclosed by the cylinder surface. Material of the inner domain is inside the cylinder surface and there is no material outside the cylinder surface. Therefore both Euler domains use the cylinder surface as part of their enclosure.

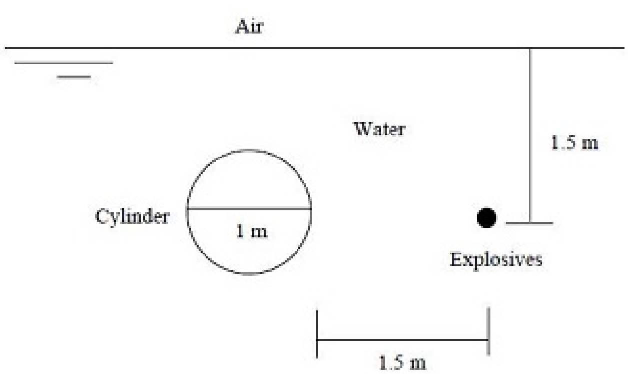

Fig. 2: Positions of cylinder, water surface and explosive

The outer Euler domain and its enclosing surface are shown in Fig. 3. The outer boundary of the outer domain is given by a sufficiently large fixed box. Pressure at the outer boundary is set to the hydrostatic pressure. This behaves like open boundary.

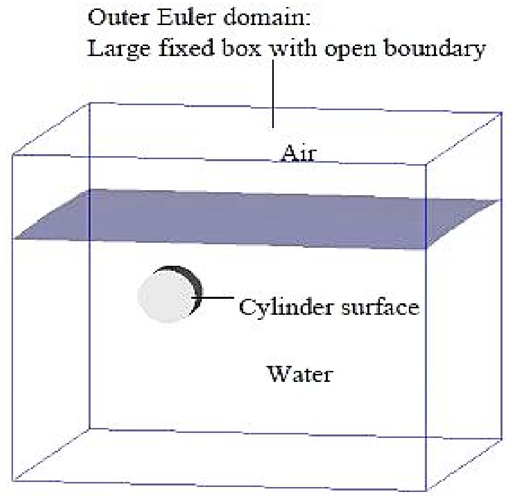

Fig. 3: Outer Euler domain and its enclosing surface

The Euler mesh contains the water and the air on the top of the water. The density of water is 1000 Kg/ m^3. The bulk modulus is taken as 2.2E9 Pa. Water hydrostatic pressure is defined starting from 1.0E5 Pa at the surface and increasing going down. A minimum pressure of zero is defined for the water, so that if a portion of water got a negative pressure, all of the water would flow out of that region and a void would be created. The density of air is 1.1848 Kg/ m^3. The ratio of the heat capacities of the gas is constant as 1.4. Specific internal energy is taken as 2.14E5 Kg-m^2/s^2. Initial air pressure is set to 1.0E5 Pa.

The explosive TNT is created in this Euler mesh, too. The density of the explosive is 1700 Kg/ m^3 and the mass is 0.445 Kg. The specific internal energy is 4.765E6 Kg-m^2/s^2. The explosive can be modeled by a JWL or IG (Ignition and Growth) equation of state in MSC.Dytran. However if we assume that the explosive is a ball, the radius of the ball is only 0.04 m. A finer

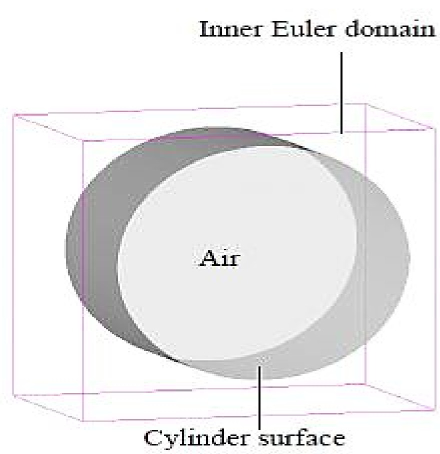

Fig. 4: Inner Euler domain and its enclosing surface

mesh has to be created to simulate this small ball. In this simulation the explosive is defined as a compressed hot gas (γ=1.4). The mass and specific internal energy are those of the explosive charge. The radius of the gas ball is taken as 0.1m and the density is adjusted to 105 Kg/ m^3 to keep equivalent mass of the explosive. Initial air pressure is calculated from Eq. (1) to be 2.0E8 Pa.

The inner Euler domain is shown in Fig. 4. The surface presents the outer boundary of the domain. The inner domain is initialized by air.

The outer and the inner domains have meshes that do not coincide. The element size for each domain is the same as 0.1 m in this simulation.

Since the purpose of this paper is just to demonstrate the new technology in MSC.Dytran, the model has been simplified and no details of the cylinder are modeled. The cylinder is modeled with Lagrangian shell elements incorporating both a plasticity model as well as a failure model. It is 0.6 m long with diameter of 1.0 m. The end covers are modeled as rigid bodies having the appropriate mass and center of gravity. Once any of these elements exceeds some failure criterion it fails. Since the boundary of the finite volume domain is provided by the shell elements of the cylinder, once shell element fail flow takes place between the inner Eulerian domain and the outer Eulerian domain. Gravity load is applied to the whole model.

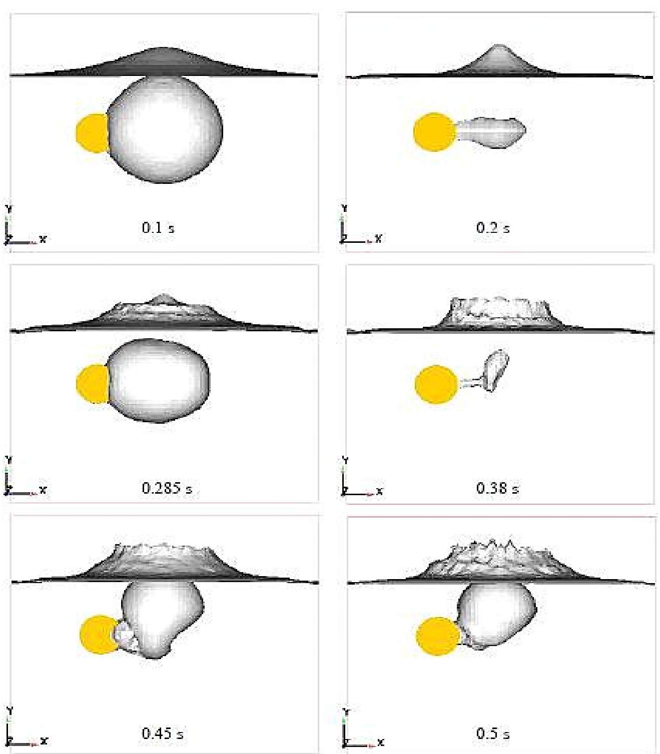

Fig. 5: Isosurfaces of material fractions

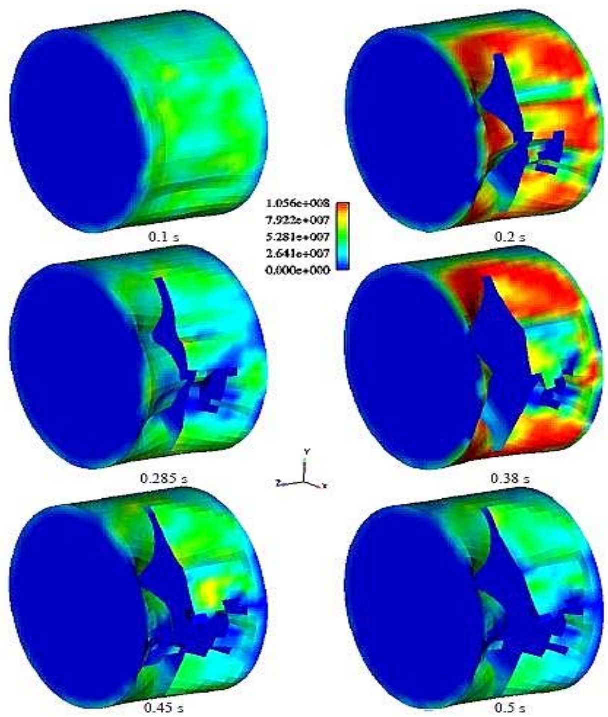

Fig. 6a: Effective stress plotted on the deformed shapes of the cylinder

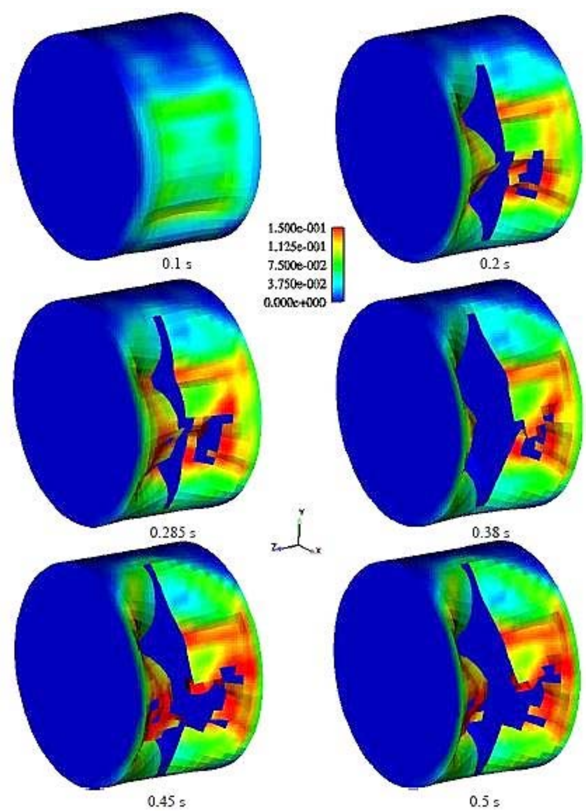

Fig. 6b: Effective plastic strain plotted on the deformed shapes of the cylinder

4. RESULTS AND DISCUSSION

The simulation is carried out 0.5 seconds for the duration of the formation and collapse of the first and second bubble until beginning of formation of the third bubble. Plots of the water bubble shapes are shown in Fig. 5. The first bubble came in touch with the structure and collapsed on causing a bubble jet. Damages on the cylinder caused by this jet are observed. Then the second bubble collapsed on the cylinder and the formed bubble jet enlarge the damages. The effective stress and plastic strain are plotted on the deformed and damaged shapes of the cylinder as shown in Fig. 6. Fig. 7 shows velocity distribution of the fluid. The first and second bubble jets emitted near the bubble minimum radius are clearly seen in the plot at 1.2 s and 0.38 s, respectively.

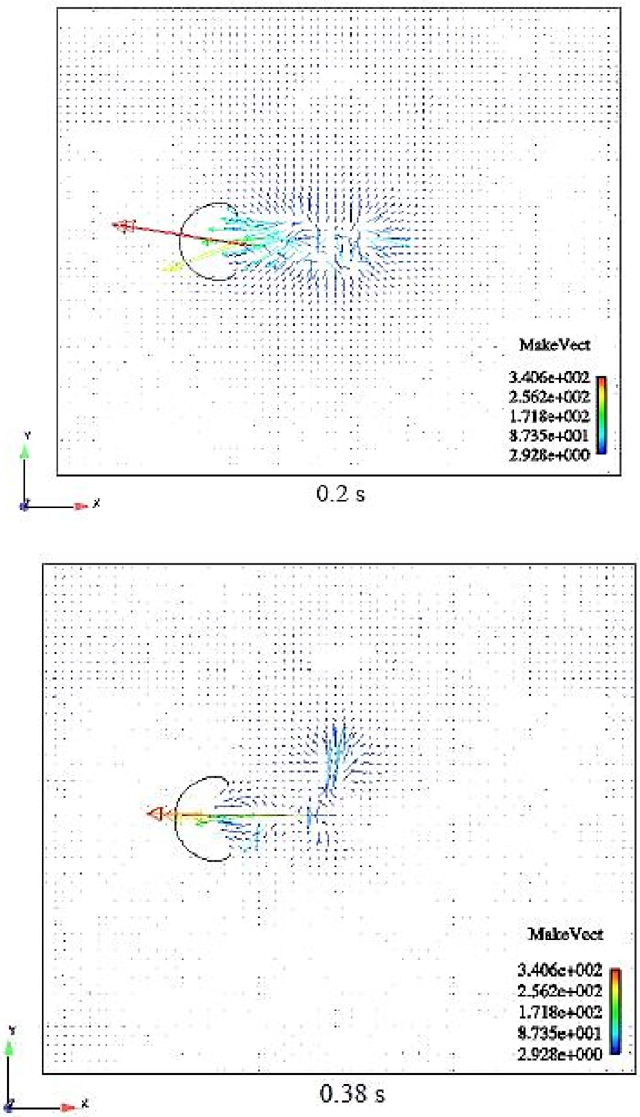

Fig. 7: Velocity distribution of fluid

Since the explosive is defined as a compressed hot gas, it may affect the shock wave characteristics. However, it models the bubble formation and collapse correctly together with bubble pulse loading. With regard to the purpose of this simulation, no attempt is made to study effect of the shock wave on the structure, which is also very important. However, the method presented does not put any restriction on this kind of simulation.

5. CONCLUSIONS

It is now possible to accurately simulate UNDEX, using the Multi-material Euler Solver of MSC.Dytran. The unique "Adaptive Multiple Euler Domains" technology makes it possible to model efficiently. Although experimental data is not available, the simulation results confirm expectations.

6. ACKNOWLEDGEMENT

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REFERENCES

[1] A link to the website of MSC.Dytran can be found at the following URL: *http://www.mscsoftware.com*.

[2] Chisum, J.E. and Shin, Y.S., "Explosion Gas Bubble near Simple Boundaries," *Shock and Vibration*, 1997, Vol. 4, No. 1, pp. 11-25.

[3] Hirsch, C., 1990, *Numerical Computation of Internal and External Flows*, John Wiley & Sons.

[4] Swisdak, M. M., 1978, "Explosion effects and properties: PART II - Explosion effect in water," Naval Surface Weapons Center.

[5] Umemoto, K., Sakaue, H. and Gefken, P., "A Comparison of Numerical Simulation by a Multimaterial ALE Fluid-structure Interaction Analysis Code with Interface Pressure Measurements", *the 70th Shock and Vibration Symposium*, 1999.

[6] Van der Veen, W.A., "Simulation of a compartmented airbag deployment using an explicit, coupled Euler/Lagrange method with adaptive Euler domains," *NAFEMS*, March 2003, Florida.

[7] Van der Veen, W.A., "Crushing simulation of a partially filled Fuel Tank beyond failure," *2005 SAE World Congress*, April 2005, Detroit.