Study of the SPH Method for Simulation in LS-DYNA

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Abstract: ***The aim of this paper is to presentthe capabilities of Smoothed Particle Hydrodynamics (SPH) method in LS-DYNA.A new particle element has been added to LS-DYNA. It is based on Smoothed Particle Hydrodynamics theory. SPH is a meshless lagrangian numerical technique used to model the fluid equations of motion. SPH has proved to be useful in certain class of problems where large mesh distortions occur such as high velocity impact, crash simulations or compressible fluid dynamics. First, we introduce the basis principles of the SPH method. Then the coupling of this technique to LS-DYNA is presented and the input needed for such analysis is provided. Two types of simulations have been comducted and show once again good capabilities of this new technology for both applications***

Keywords: SPH, LS-DYNA, Simulation

1. Introduction

The Smoothed Partice Hydrodynamics (SPH) method has been developed by Livermore Software Technology Corporation (LSTC) in LS-DYNA since 1998.This method is called a meshfree method because traditional finite elements are replaced by particles which are not physically connected but mathematically linked [1,2]. It is an alternative to the classical Lagrangian Finite Elements method and is used to simulate problems where materials are submitted to hydrodynamic deformation modes, such as high velocity impacts. This paper presents the SPH contribution to simulate the impact model test. Two cases to illustrate SPH capabilities in LS-DYNA .Until now, there was a lot of research on the ability of SPH method in LS-DYNA software. For example, Martin Madaj et al [3] presents some results of the SPH orthogonal cutting simulations of A2024-T351 aluminium alloy compared to the experimental and FEM simulation. Niclas Stenberg et al [4] use the SPH simulation technology to predict the thermal and mechanical loads on the rake face of aturning tool. Mohammad Sarfaraz, Ali Pak[5] present numerically-derived tsunami wave loads on bridge superstructures using smoothedparticle hydrodynamics (SPH), which is a type of mesh-free methods. D.H. Zhang [6] used SPH method with applications of oscillating wave surge converter. Jian-YuChen[7] using the Smoothed Particle Hydrodynamics to tackle explosion in soil with extremely large deformation and the effects of blast on structures. RuiYan et al [8] simulate the motion of rigid bodies bouncing from the surface of water in two dimensions using SPH method.

Nowadays computers have become more powerful and popular. As a result, computer simulation has become a reliable tool for many designers, engineers and scientists in the investigate performance of mechanics impact models. This study performs analysis of mechanics testing by using SPH method in LS-DYNA software. With taking into account verification and validation (V&V) of road safety barrier simulation, this paper presented an approach to build a reasonable and exactly model. The results of the present model confirmed the capabilities of Smoothed Particle Hydrodynamics (SPH) method.

2. Smoothed Particle Hydrodynamics (SPH)

Smoothed Particle Hydrodynamics (SPH) is an N-body integration scheme developed by Lucy, Gingold and Monaghan [1977]. The method was developed to avoid the limitations of mesh tangling encountered in extreme deformation problems with the finite element method. The main difference between classical methods and SPH is the absence of a grid. Therefore, the particles are the computational framework on which thegoverning equations are resolved. This new model requires a new calculation method, which is briefly explained in the following.

2.1. SPH formulation

The particle approximation of a function is:

$$\Pi^h f(x) = \int f(y) W(x-y,h) dy \qquad (1)$$

Where W is the kernel function i

The Kernel function W is defined using the function θ by the relation:

$$W(x,h) = \frac{1}{h(x)^d}\theta(x) \qquad (2)$$

Where d is the number of space dimensions abd h is the so-called smoothing length which varies in time and in space W(x,h) should be centrally peaked function . The most common smoothing kernel used by the SPH community is the cubic B-spline which is defined by choosing θ as:

$$\theta(x) = C \times \begin{cases} 1-\frac{3}{2}u^2+\frac{3}{4}u^3 \;\; for \; |u| \le 1 \\ \frac{1}{4}(2-u)^3 \;\; for \; \le |u| \le 2 \\ 0 \;\; for \; 2 < |u| \end{cases} \qquad (3)$$

where C is a constant of normalization that depends on the on the number of space dimensions.

The SPH method is based on a quadrature formula for moving particles ($x_i(t) \in \{1..N\}$, where$x_i(t)$ is the location of particle i, which moves along the velocity field v.

The particles approximation of a function can now be defined by:

$$\Pi^h f(x_i) = \sum_{j=1}^{N} w_j f_{(x_i)} W(x_i - x_j, h) \quad (4)$$

Where $w_j = \frac{m_j}{\rho_j}$ is the "weight" of the particles. The weight of a particle varies proportionallyto the divergence of the flow

2.2. SPH meshing technique

SPH meshing technique avoids all the problems associated with the regular Lagrangian meshing technique. The SPH uses a Kernal approximation based on randomly distributed interpolation points, with no assumptions about which points are neighbors to calculate spatial derivatives.

In the SPH method, the location of neighboring particles is important. The sorting consists of finding which particles interact with which others at a given time. A bucket sort is used that consists of partitioning the domain into boxes where the sort is performed. With this partitioning the closest neighbors will reside in the same box or in the closest boxes. This method reduces the number of distance calculations and therefore the CPU time.

The time step is determined by the expression

$$\partial_t = C_{CFL} min_i \left(\frac{h_i}{c_i + |v_i|}\right) \quad (5)$$

Where C_{CFL} is a numerical constant

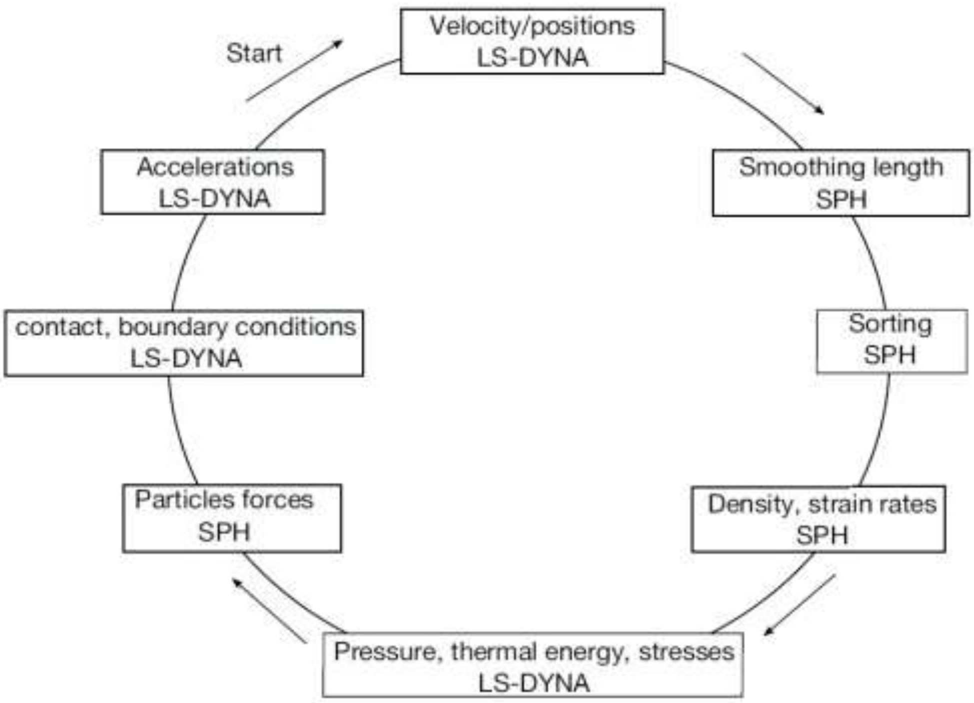


Figure 1: Calculation cycle for SPH particles

3. Implementation in LS-DYNA

3.1. Material Definitions

SPH elements consist of only one node, on which all element properties are centered. Their initial density needs to be specified and from the initial particle spacing the elements are given a certain mass. This mass stays constant throughout the simu- lation, whereas particle density and occupied volume may deviate from the initial value. The SPH processor in LS-Dyna uses a variable smoothing length [22]. The initial smoothing length h_0 is computed for each particle by taking the maximum of the distances between neighbouring particles. The smoothing length then varies in time according to following equation:

$$\frac{dh(t)}{dt} = h(t)\nabla v \quad (6)$$

The smoothing length decreases when particle concentration is high and increases when few particles are around. Thus, h varies to keep the same number of particles within its support domain.

3.2. Material model

For the SPH elements, modelled as water, air the choice is down to two material cards. Either MAT_001_ELASTIC_FLUID can be used, which is designed to model fluids, or the MAT_009_NULL. The null material can be used to model any type of homogeneous and isotropic fluid and solid. An equation of state needsto be assigned in conjunction, for which a limited number of options are available. The Gruneisen equation of state is a good choice

3.3. Contact definitions

In the classic SPH technique a laborious composition of boundary particles and ghost points is used. Within LS-Dyna there is no need for such a construction. The software allows mesh-based and mesh-free methods to co-exist and interact in one simulation.

Since the SPH particles are not interconnected, only one-way type of contact definitions are applicable in which the

SPH is always defined to be the slave and the elements are defined to be the master. The interaction between the SPH and other elements is defined using penalty based contact algorithms. An appropriate con- tact type is the simple *CONTACT_NODES_TO_SURFACE card, where the slave nodes are checked for penetration through the master surface. When a node is in contact with the surface, a restoring force is applied to prevent further penetration. This force is proportional to the penetration distance into the shell or solid element and acts in the direction normal to the master surface.

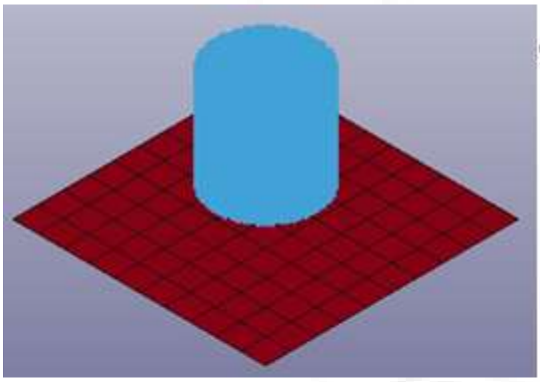
The restoring force is defined by:

$$f = k\ d\ n$$

In this equation, d is the penetration distance, n is the surface normal vector and k is a penalty factor, comparable to a spring constant. The constant k should be set large to minimise penetration.

3.4. Simulation of impact test

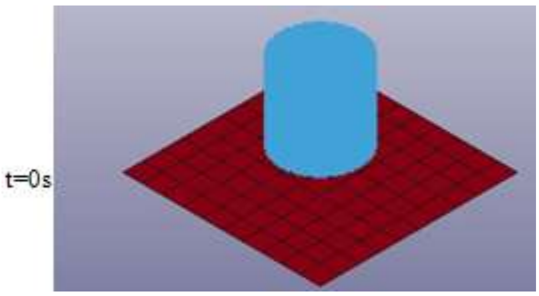
Figure 2present initial condition the first simulation test. The impact test model consist of the cylinder and the plate. The cylinder was set 100m/s with impact angle 90^0as shown in Figure 2 This model was useful method to simulate the bird strike impact model.



(7)

Figure 2: The impact test simulation

The model using 126400 number of particles SPH The time analysis was set 300 ms. The time analysis approximately3 minutes with using share memory parallel (SMP) on one computer with 16 GB RAM, Intel Core i7- 6700 HQ(8 CPUs).



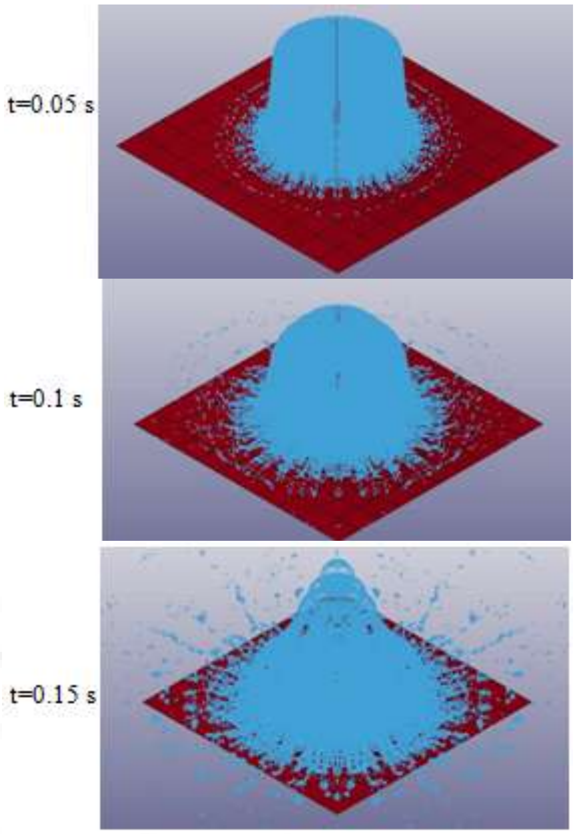
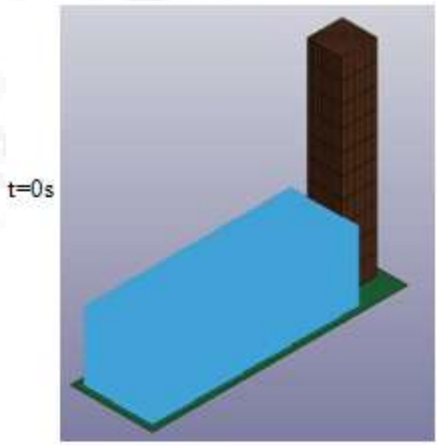


Figure 3: Sequential from water drop test

Figure 4 presents the breaking waves impact with rigid column. This case simulates the impact of a water column on a rigid rectangle shape obstacle. The model using 192600 number of particles SPH The time analysis was set 500 ms. The time analysis approximately15 minutes with using share memory parallel (SMP) on one computer with 16 GB RAM, Intel Core i7- 6700 HQ(8 CPUs).



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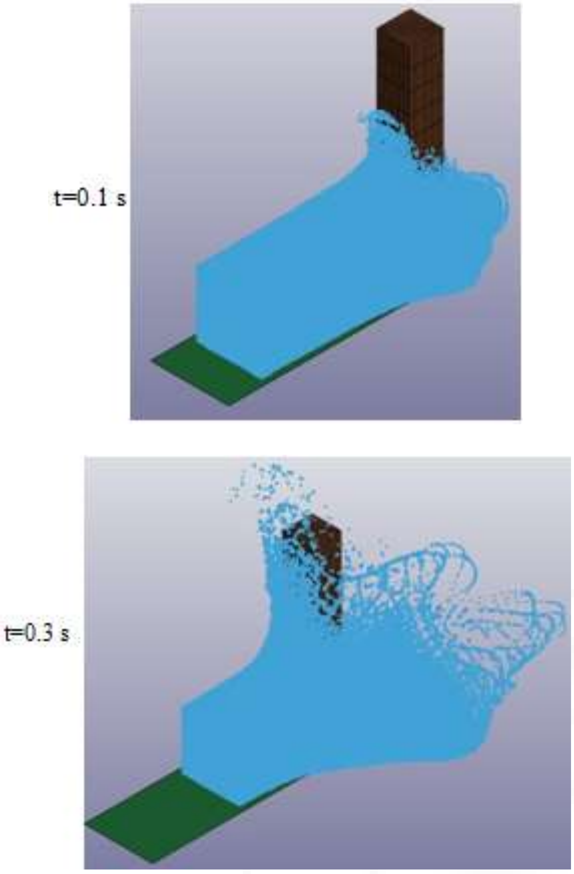

Figure 4: Dam break simulation

4. Conclusion

This paper aims to investigate the different new features appeared in recent versions of LS-DYNA and related with SPH method. Different tests were done to bring some elements in order to evaluate capabilities of these new technologies: SPH formulations based on a Lagrangian kernel and Hybrid SPH/Solid Elements. Results obtained allow to be enthusiastic, first because new SPH formulations shown good qualities concerning tensile instabilities which stays one of the major problems with SPH nowadays. Other limitations with this calculation method concern physical transitions with classical Solid Elements on the one hand, and calculation times on the other hand. That's precisely on that fields that new Hybrid elements are very interesting since we saw different types of applications where this kind of element bring obvious improvements. Large studies still have to be done to carry on the investigation of these options which should permit to SPH method to develop its applications possibilities in future years.

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