Stone Skipping Simulation by ALE and SPH

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Abstract

Stone skipping is the play at sea shore and river. The flat stone, which is thrown, skips on the surface of water. This phenomena is simulated by ALE and SPH capability of LS-DYNA®. The dependency of the parameters such as the angle between stone and water, incident angle of stone will discuss.

Introduction

Stone skipping is the play at the seashore and river. The flat stone, which is thrown, skips on the surface of water, and the number of stone skip is count. Clonet et al (1) made experiment of this phenomena, and Nagahiro did SPH simulation and theoretical analysis (2). He also wrote the review paper in Japanese (3).

By Nagahiro’s review paper I motivated to simulate this phenomena by LS-DYNA. Since stone skipping is the familiar example of fluid structure interaction (FSI), I would like to understand and test LS-DYNA’s FSI capabilities by this phenomena. LS-DYNA V971 has two formulation of FSI. One is Arbitrary Lagrangian and Eulerian (ALE), and the other is Smooth Particle Hydrodynamics (SPH). This paper describes preliminary results of stone skipping phenomena by MPP971R4.2.1 for ALE and LS971R4.2.1 for SPH.

Stone

There are two angles related to stone and water surface;  
1. Attack angle $\phi$ between stone and water  
2. Impact angle $\theta$ of the velocity $v$

The other parameters are the rotational velocity $n$ of stone and the translational velocity $v$. The stone is circular plate rigid body with 25mm radius and 6mm thickness. The mass density is 3e-9 tonne/mm$^3$. The gravity load is $-z$ direction.

Model of Water and Air by ALE

The water and air is modeled by ALE multi-material. The water and air are in the region $0 < x < 1000$mm, $-150$mm $< y < 150$mm, and $0 < z < 100$mm for water and $100$mm $< z < 200$mm for air, and size of each ALE solid element is 5x5x5mm.
The coupling between stone (part 7) and water and air (part_set 1) by the following card.

*CONSTRAINED_LAGRANGE_IN_SOLID

\[
\begin{align*}
\text{slave} & : \text{master} \quad \text{sstyp} \quad \text{mstyp} \quad \text{nquad} \quad \text{ctype} \quad \text{direc} \quad \text{mcoup} \\
7 & : 1 \quad 1 \quad 0 \quad 4 \quad 4 \quad 2 \quad -1 \\
\text{start} & : \text{end} \quad \text{pfac} \quad \text{fric} \quad \text{frcmin} \quad \text{norm} \quad \text{normtyp} \quad \text{damp} \\
0.0001.0000E+10 & : 0.100000 \quad 0.300000 \quad 0.500000 \quad 0 \quad 0 \quad 0.000 \\
\text{cq} & : \text{hmin} \quad \text{hmax} \quad \text{ileak} \quad \text{pleak} \quad \text{lcidpor} \quad \text{nvent} \quad \text{blockage} \\
0.000 & : 0.000 \quad 0.000 \quad 0.100000 \quad 0 \quad 0 \quad 0 \\
\text{iboxid} & : \text{ipenchk} \quad \text{intforc} \quad \text{ialesof} \quad \text{lagmul} \quad \text{pfacmm} \quad \text{thkf} \\
0 & : 0 \quad 0 \quad 0 \quad 0.000 \quad 0 \quad 0.000 \\
\end{align*}
\]

Model of SPH

The water is modeled by SPH particles with the region of \(0 < x < 1000\)mm, \(-150\)mm \(< y < 150\)mm, and \(0 < z < 100\)mm surrounded by the shell box with \(0 < x < 1000\)mm, \(-150\)mm \(< y < 150\)mm, and \(0 < z < 300\)mm. The SPH particles put in water region with 5mm distance in each direction, that is, 200x60x20 particles.

The coupling among stone (part 7), shell box (part 9) and water (part 8) are defined by the following 2 contact cards.

*CONTACT_AUTOMATIC_NODES_TO_SURFACE_ID

\[
\begin{align*}
\text{#} & \quad \text{cid} \quad \text{title} \\
1 & \quad 1 \\
\text{ssid} & : \text{msid} \quad \text{sstyp} \quad \text{mstyp} \quad \text{sboxid} \quad \text{mboxid} \quad \text{spr} \quad \text{mpr} \\
8 & : 7 \quad 3 \quad 3 \quad 0 \quad 0 \quad 0 \\
\text{fs} & : \text{fd} \quad \text{dc} \quad \text{vc} \quad \text{vdc} \quad \text{penchk} \quad \text{bt} \quad \text{dt} \\
0.300000 & : 0.300000 \quad 1.000000 \quad 0.000 \quad 20.000000 \quad 0 \quad 0.0001.0000E+20 \\
\text{sfs} & : \text{sfm} \quad \text{sst} \quad \text{mat} \quad \text{sfst} \quad \text{sfmt} \quad \text{fsf} \quad \text{vsf} \\
1.000000 & : 1.000000 \quad 2.500000 \quad 0.000 \quad 1.000000 \quad 1.000000 \quad 1.000000 \quad 1.000000 \\
\text{soft} & : \text{sofscl} \quad \text{lcidab} \quad \text{maxpar} \quad \text{shopt} \quad \text{depth} \quad \text{bsort} \quad \text{frcfreq} \\
1 & : 0.100000 \quad 0 \quad 1.025000 \quad 2.000000 \quad 2 \quad 0 \quad 1 \\
\end{align*}
\]

Results of Simulation

Figure 2 shows the results with the stone of \(\theta=20^\circ\), \(\varphi=20^\circ\), rotation \(65\)round/s, and \(|v|=4900\)mm/s. The left column is ALE and the right is SPH, and by both method the stone is skipping.
Fig. 2 side view of results (left: ALE, right: SPH)
Figure 3 shows the same parameters of Fig.2 except for \(|v|=1000\text{mm/s}\). By this slow velocity, the stone does not skip. This indicates that there is the minimum velocity of stone skips.

![Figure 3](image)

Figure 3 \(|v|=1000\text{mm}\)

Figure 4 shows the stone of \(\theta=50^\circ\), \(\phi=40^\circ\), rotation 45round/s, and \(|v|=4900\text{mm/s}\). By this large impact angle \(\theta=50^\circ\), the stone does not skip, however, for the small impact angle such as \(\theta=20^\circ\) or \(30^\circ\), the stone skips.

![Figure 4](image)

Figure 4 large impact angle \(\theta=50^\circ\)

**Conclusion and Discussions**

1. Both ALE and SPH can simulate the stone-skipping phenomena.
2. General behaviors of ALE and SPH are similar, however in detail there are several differences.
   One of examples is the z-velocity and z-displacement of center of gravity of stone as shown in Fig.5 and Fig. 6. In each figure, sign x is ALE results and sign □ is SPH. The difference may be comes from the interaction between stone and water, but at present I could not adjust the difference.

In the future work, I would like to compare the LS-DYNA results and the experiment of Clonet et al and the theory of Nagahiro and Hayakawa.
Execution time

The calculation was done by AMD Phenom IIx4 965 (3.4GHz) with DDR2 (800Mhz 2GBx4). LS-DYNA is single precision of V971R4.2.1 and MPP971R4.2.1. Typical timing information is summarized in Table 1. Endtime is 0.25sec. The number of element of ALE is 480468, and the number of element of SPH is 240000 SPH particles, 55200 shell and 468 solid. SPH does not model the air part, and the number of elements of SPH is half of ALE. For SPH, MPP version does not work.

<table>
<thead>
<tr>
<th></th>
<th>Elapsed time</th>
<th>CPU time/Zone cycle</th>
<th>Clock time/Zone cycle</th>
</tr>
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<tbody>
<tr>
<td>ALE(SMP)</td>
<td>34h34m25s(87936cycle)</td>
<td>5478nanosec</td>
<td>2942nanosec</td>
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<tr>
<td>ALE(MPP)</td>
<td>14h19m44s(87936cycle)</td>
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<td>SPH(SMP)</td>
<td>9h50m·8s(58913cycle)</td>
<td>7863nanosec</td>
<td>2028nanosec</td>
</tr>
</tbody>
</table>

Table 1 summary of calculation (each calculation was done by 4 Cores)

Acknowledgement

I would like to acknowledge the Dr. Ian Do of LSTC for his helpful suggestions of ALE method.

References

(3) S. Nagahiro, BUTSURI 64(2009)763 in Japanese