Stone Skipping Simulation by ALE and SPH

Mitsuhiro Makino
Dynapower Corporation
makino@dynapower.co.jp

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 φ between stone and water
2. Impact angle θ of the velocity **v**

The other parameters are the rotational velocity **n** of stone and the translational velotity **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.

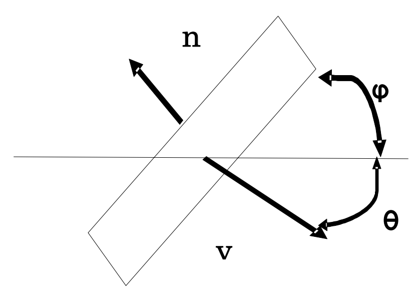

Fig 1. The parameters of stone

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, -150mm $< y < 150$mm, and $0 < z < 100$mm for water and 100mm $< z < 200$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
$    slave    master     sstyp     mstyp     nquad     ctype     direc     mcoup
         7         1         1         0         4         4         2        -1
$    start       end      pfac      fric    frcmin      norm   normtyp      damp
    0.0001.0000E+10  0.100000  0.300000  0.500000         0         0     0.000
$       cq      hmin      hmax     ileak     pleak   lcidpor     nvent  blockage
     0.000     0.000     0.000         0  0.100000         0         0         0
$   iboxid   ipenchk   intforc   ialesof    lagmul    pfacmm      thkf
         0         0         0         0     0.000         0     0.000
```

Model of SPH

The water is modeled by SPH particles with the region of 0 < x < 1000mm, -150mm < y < 150mm, and 0 < z < 100mm surrounded by the shell box with 0 < x < 1000mm, -150mm < y < 150mm, and 0 < z < 300mm. 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 (part8) are defined by the following 2 contact cards.

```
*CONTACT_AUTOMATIC_NODES_TO_SURFACE_ID
$#     cid                                                                 title
         1
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         8         7         3         3         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
  0.300000  0.300000  1.000000     0.000 20.000000         0     0.0001.0000E+20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
  1.000000  1.000000     2.500     0.000  1.000000  1.000000  1.000000  1.000000
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         1  0.100000         0  1.025000  2.000000         2         0         1
*CONTACT_AUTOMATIC_NODES_TO_SURFACE_ID
$#     cid                                                                 title
         2
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         8         9         3         3         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
  0.000000  0.000000  1.000000     0.000 20.000000         0     0.0001.0000E+20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
  1.000000  1.000000  2.500000     0.000  1.000000  1.000000  1.000000  1.000000
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         1  0.100000         0  1.025000  2.000000         2         0         1
```

Results of Simulation

Figure 2 shows the results with the stone of $\theta=20^o$, $\varphi=20^o$, rotation 65round/s, and $|v|=4900$mm/s. The left column is ALE and the right is SPH, and by both method the stone is skipping.

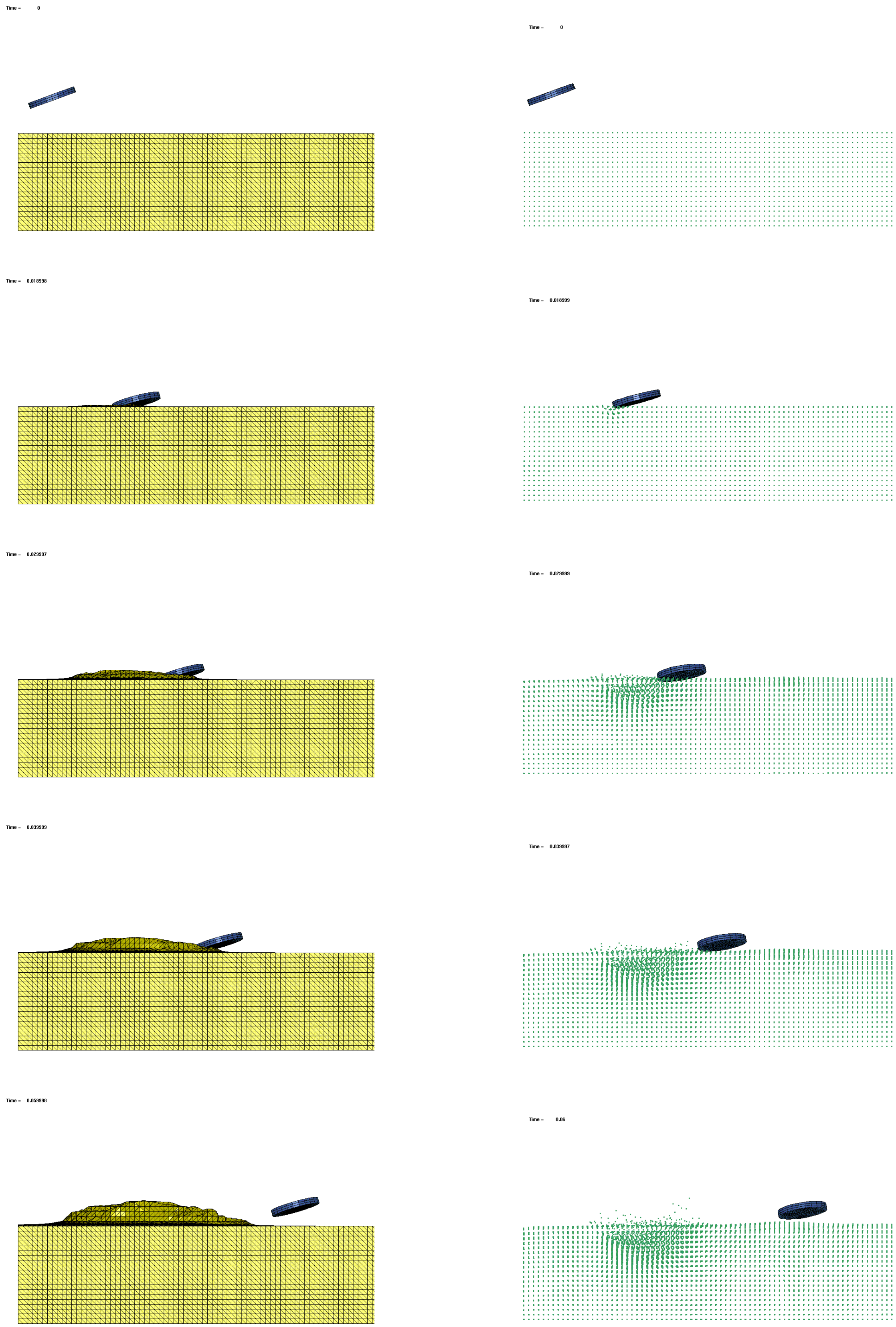

Fig.2 side view of results(left: ALE,right:SPH)

Figure 3 shows the same parameters of Fig.2 except for |v|=1000mm/s. By this slow velocity, the stone does not skip. This indicates that there is the minimum velocity of stone skips

Figure 3 |v|=1000mm

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

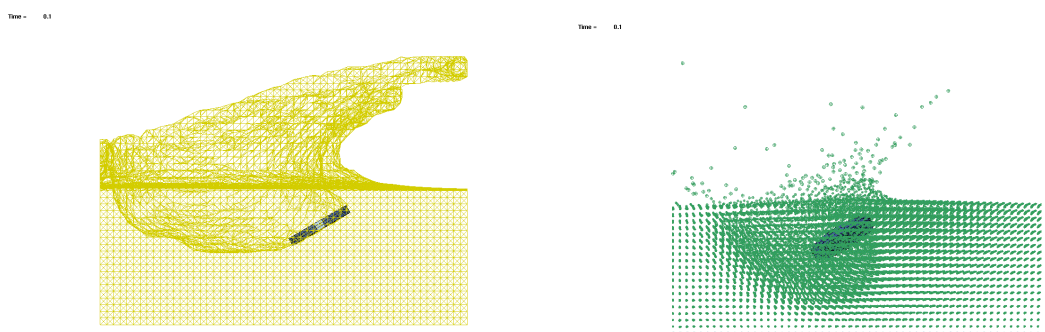

Figure 4 large impact angle$\theta=50^o$

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.

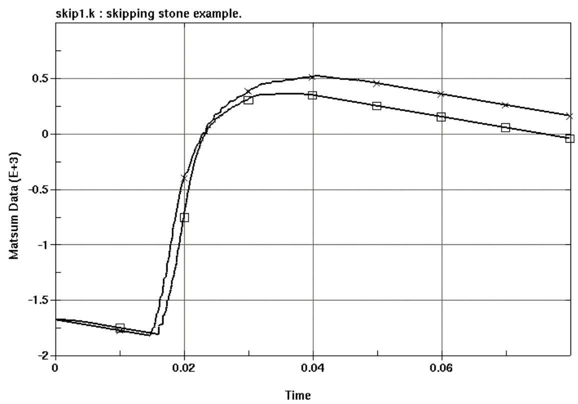

Fig. 5 z-velocity of c.g. of stone

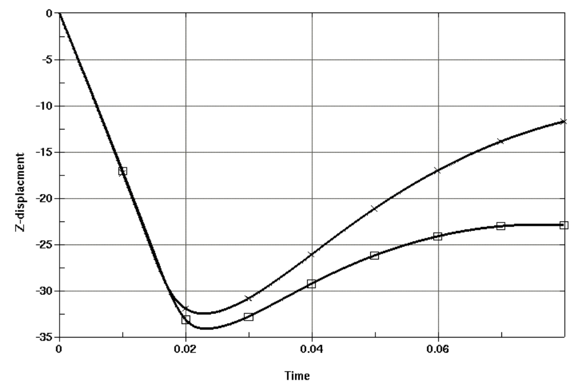

Fig. 6 z-displacement of c.g. of stone

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.

	Elapsed time	CPU time/Zone cycle	Clock time/Zone cycle
ALE(SMP)	34h34m25s(87936cycle)	5478nanosec	2942nanosec
ALE(MPP)	14h19m44s(87936cycle)	1161nanosec	1221nanosec
SPH(SMP)	9h50m 8s(58913cycle)	7863nanosec	2028nanosec

Table 1 summary of calculation(each caluculation 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

(1) C. Clonet, F. Hersen and L. Bocquet, Nature, 427(2004)29
(2) S. Nagahiro and Y. Hayakawa, Physical Review Letters 94(2005)174501
(3) S. Nagahiro, BUTSURI 64(2009)763 in Japanese