

# Meshless Methods in Workbench LS-DYNA

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## 1 Introduction

CADFEM Germany GmbH is working to create an open library of Ansys LS-DYNA [1] industrial use cases. Two new Industrial Use Cases for Ansys LS-DYNA have been developed by CADFEM in 2023. They focus on using meshless methods and the Eulerian approach for real-world applications: SPG usage with GISSMO damage model to simulate material separation and SPH/S-ALE solver usage for inertia-dominated fluid-structure interaction (FSI).

## 2 Model and Methods

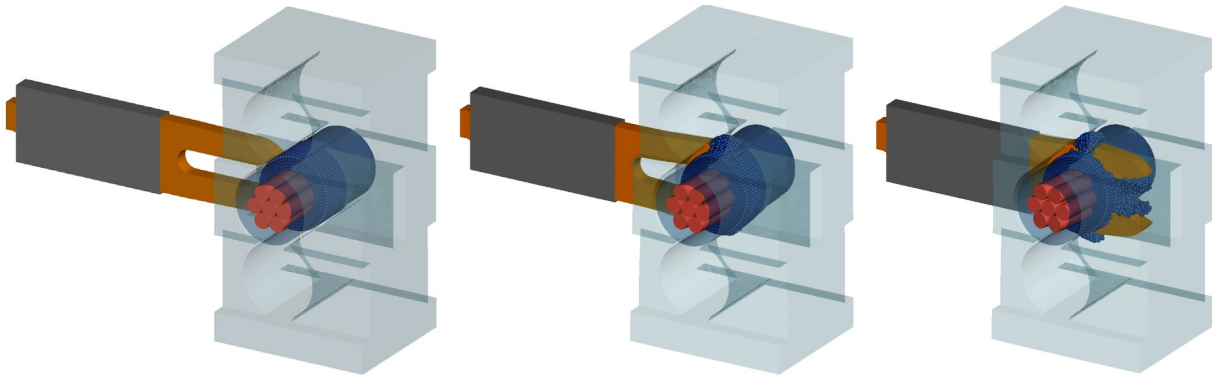
Best practice guides with detailed descriptions of the settings used and solutions adopted have been developed for both topics under consideration.

- As far as possible, the models were created within the Ansys Workbench and Mechanical environments.
- Most features are already implemented here, which makes these challenging applications much more user-friendly to set up.
- Command snippets can be used to insert some missing functions.
- For some special postprocessing, leaving the Ansys Mechanical environment is necessary.
- These examples serve multiple purposes. It shows how to set up these applications for simulation with the best possible outcome. Identifying the missing functionality helps further enhance the LS-DYNA system in Mechanical.

## 3 SPG usage with the GISSMO damage model to simulate material separation

### 3.1 Simulation case overview

The first example of meshless methods in LS-DYNA Workbench considers cutting the isolator from a set of wires during installation with a connector (see Fig. 1).



*Fig.1: Some steps during cutting wire isolator simulation with SPG process, with kind permission of ERNI Deutschland GmbH, a TE Connectivity Ltd. company*

The motion of the connector is conditioned by setting the velocity of its end face. All bodies in the model, except for the connector guide, are deformable. Contact interaction between all bodies is considered.

### 3.2 GISSMO Support in Workbench LS-DYNA

GISSMO (Generalized Incremental Stress State dependent damage Model) is one of the most advanced damage accumulation models for LS-DYNA. The model simulates material failure behavior by considering the material data through the definition of (sets) of curves. Thus, GISSMO allows us to consider the complex stress-strain state of material by using:

- triaxiality  $\eta = \frac{\sigma_m}{\sigma_{eq}}$  (see Fig. 2), where:
  - $\sigma_m = -p$  – hydrostatic stress,
  - $\sigma_{eq}$  – equivalent Von Mises stress;

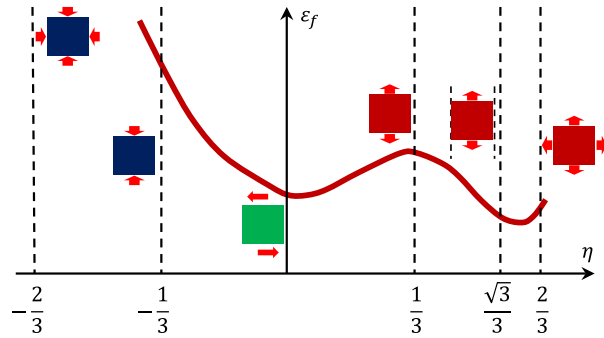


Fig.2: Dependence of failure strain on triaxiality

- Lode parameter  $\xi = \frac{27 J_3}{2 \sigma_{eq}^3} = \cos(3\theta)$  (see Fig. 3), where:
  - $J_3$  – third invariant of the stress deviator,
  - $\theta$  – Lode angle.

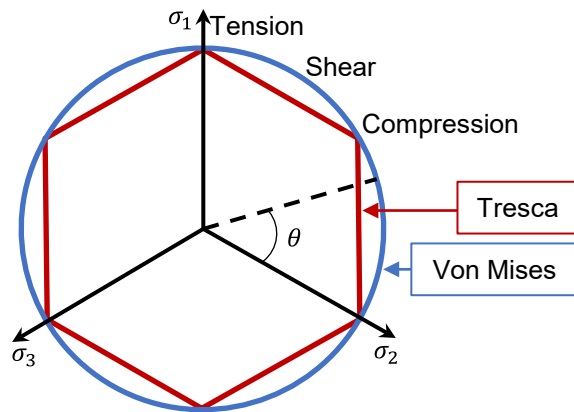


Fig.3: Stress state in the deviatoric plane

Incremental accumulation of damage gives the model knowledge not only about the current state of the material, but also about the history of loading:

$$\dot{D} = \frac{n}{\varepsilon_f(\eta, \xi)} \varepsilon_p D^{(1-\frac{1}{n})},$$

where:

- $D$  – Damage value,
- $n$  – Exponent for nonlinear damage accumulation,
- $\varepsilon_p$  – Equivalent plastic strain increment,
- $\varepsilon_f$  – Equivalent plastic strain to failure.

The model can also consider the instability of the plastic flow of the material, which allows a better estimation of failure dynamics in situations like "plastic hinge" or "necking". Finally, the model has a built-in regularization mechanism that minimizes the influence of mesh size on the obtained result.

This GISSMO material model (**\*MAT\_ADD\_DAMAGE\_GISSMO** card) is supported in the Ansys Workbench Engineering Data module from version 2022R2 onwards. This allows automatic conversion to the desired Unit System for the simulation (see Fig. 4).

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.75E-09	tonne mm <sup>-3</sup>		
3	Isotropic Elasticity				
9	*MAT_PIECEWISE_LINEAR_PLASTICITY				
37	*MAT_ADD_DAMAGE_GISSMO				
38	Definition				
39	Damage Type	Damage is Accum...			
40	Mid-plane Failure Option for Shell Elements	Inactive			
41	Option to use a Bending Indicator Instead of the Lode Parameter	Inactive.			
42	Reduction Factor for Regularization for Biaxial Stress States, biaxf	0			
43	Damage Threshold Value, dcrit	0.5	mm mm <sup>-1</sup>		
44	Exponent for Nonlinear Damage Accumulation, dmgexp	3			
45	Critical Plastic Strain, ecrit	0	mm mm <sup>-1</sup>		
46	Exponent for Damage-related Stress Fadeout, fadexp	5			
47	History Variable used to Evaluate the 3D Table LCSDG, hisvn	0			
48	Number or Percentage of Failed Integration Points Prior to Element Deletion, numfp	1			
49	Reference Element size, refsiz	0.02	mm		
50	Reduction Factor for Regularization for Shear Stress States, shrf	0			
51	Softening Reduction Factor for Failure Strain in Crashfront Elements, soft	0			
52	Failure Strain Function, lcsdg	Tabular			
53	Scale	1			
54	Offset	0	mm mm <sup>-1</sup>		

Fig.4: GISSMO model parameters overview in Workbench Engineering Data

In addition, model parameters are automatically recognized when loading legacy models into the project via the External Model system. It should be realized that the Workbench environment inevitably has some limitations in supporting all possible data types and dependencies that GISSMO can accommodate. Thus, there are limitations considering temperature dependence and processing data in the form of **\*DEFINE\_TABLE** and **\*DEFINE\_FUNCTION**. However, such limitations can be bypassed by using command inserts with the required input portions from the k-file.

### 3.3 SPG Support in Workbench LS-DYNA

The Smoothed Particle Galerkin method is a unique meshless method developed especially for material separation and fragmentation simulation. In contrast to element erosion with standard finite elements, a failure in SPG does not remove material. Failure in SPG preserves mass and volume, which is a significant advantage.

Most meshless methods can simulate co-called mathematical-based material failure. So, with SPH material simulation, material failure is typically driven by a purely mathematical quantity like kernel support size. That means the material fails if the distance between some particles is large enough that the radiuses of their support kernels don't intersect. Often, this leads to a wrong description of material degradation, e.g., this effect leads to pre-vermilion degradation of polymers and rubbers.

The SPG method can capture physical-based material failure. Only the quantity from material constitutive law can influence material failure. SPG also has a direct interface to interact with the GISSMO model, which is especially convenient in the considered case. The user does not need additional customization of the solution model. When the appropriate criterion for failure is met, the bonds between the particles are cut, and we can see separation. At the same time, mass and even momentum are preserved (when using the option of Momentum Consistent SPG).

SPG is supported starting with Workbench LS-DYNA 2023R1. Users have access to the full scope of **\*SECTION\_SOLID\_EFG** card values (see Fig. 5). The only command snippet for correct bond-failure simulation that should be added is **\*CONTROL\_TIMESTEP, ERODE=0**.

Although working with SPG models differs from traditional FE models, it is essential to consider some peculiarities of contacts when targeting to simulate fragmentation. SPG parts in contact should be addressed as nodal sets containing all (external and internal) nodes in the part (**SSTYP=4**). If the part is addressed by part ID only, the solver will only extract the nodes on the outer surface of the part, which will lead to missed contact detection. These settings can easily be performed in the LS-DYNA Workbench interface (see Fig. 6) employing the Named Selection infrastructure (analogous to the **\*SET** card family in the LS-DYNA keyword file).

Details of "SPG"	
<b>Geometry</b>	
Scoping Method	Geometry Selection
Geometry	1 Body
<b>Definition</b>	
Method	SPG
Formulation	Program Controlled
LS-DYNA ID	47
Type	Section Solid SPG
<b>SPG Controls</b>	
Dilation X	1.8
Dilation Y	1.8
Dilation Z	1.8
Kernel Function	Cubic
Kernel Scheme	Eulerian
Time Steps for Displacement Smoothing	5
Smoothing Scheme for Momentum	Regular Smoothing
<b>Advanced SPG Controls</b>	
Bond Failure Mechanism	Program Controlled
Critical Failure Value	10000000000
Critical Relative Deformation	10000000000
Option of Stabilization	Fluid Particle Approximation
Quadrature Factor	1
Self-Contact Indicator	Program Controlled
Box	
Particle-to-Particle Damping Coefficient	-0.001

Fig.5: SPG section definition in Workbench LS-DYNA

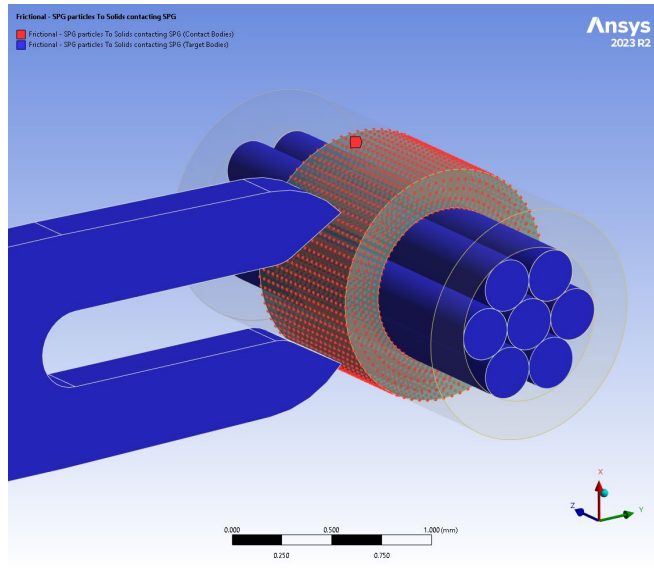


Fig.6: Contact Scoping for SPG

### 3.4 Material separation simulation

In summary, SPG coupling with GISSMO to simulate material separation, for example the simulation of cutting a wire isolator, turns out to be a standard task for the Workbench LS-DYNA environment (see Fig. 7).

Time [s]	Minimum [min/man]	Maximum [min/man]	Average [min/man]
1	0	0	0
2	4.9999e-005	0	0
3	9.9999e-005	0	0
4	1.4999e-004	0	0
5	1.9999e-004	0	0
6	2.4999e-004	0	0
7	2.9997e-004	1.0034e-002	5.6678e-006
8	3.4996e-004	3.1627e-002	1.8137e-005
9	3.9996e-004	5.4813e-002	3.2566e-005
10	4.4995e-004	6.9763e-002	4.6991e-005
11	4.9995e-004	9.1039e-002	6.7125e-005
12	5.4994e-004	0.11428	9.5591e-005
13	5.9994e-004	0.14353	1.2866e-004

Fig.7: SPG and GISSMO work in Workbench LS-DYNA

The user can access all basic settings of the GISSMO material model and the SPG solver settings. The simulation can be defined, solved, and processed in Workbench with minimal use of command objects.

## 4 S-ALE and SPH for inertia-dominated FSI with a very flexible container

### 4.1 Simulation case overview

A fluid-filled flexible container, like an infusion bag is a common type of packaging for food and medical products (see Fig. 8). Typically, the filling starts with an empty container with no internal volume.

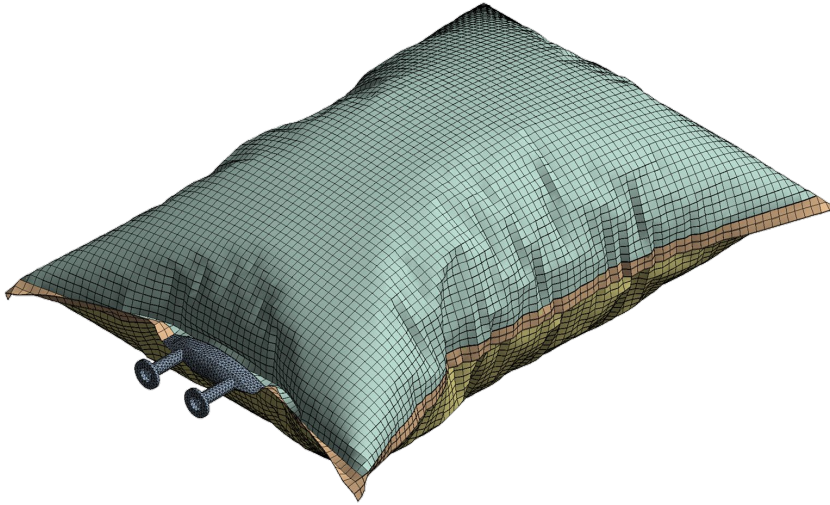


Fig.8: The bag model after deployment

To fill the bag, two approaches are considered. The first approach will first simulate the inflation of a shell bag model by means of internal pressure. Subsequently, a liquid is generated in the inner volume of the inflated bag geometry, and a drop test of the resulting model is performed. A second approach is the most complete and more complex by considering the full problem: filling an uninflated bag with liquid is directly modeled. The fluid is modeled using the S-ALE or SPH approach. Each method has its pros and cons:

- S-ALE:
  - The high-precision volume filling (no gaps and void areas)
  - Uniform and smooth pressure fields on the FSI interface
  - Internal pressure generation without additional simulation
  - Cons: Interface leakage for long-time processes/shell container/alternating pressure
- SPH:
  - The FSI interface is robust,
  - Overall higher stability simulation, especially with global motion,
  - Simulation of the filling process via injection is easier,
  - Cons: Volume filling is not perfect and initial particles packing requires compaction,
  - Cons: Internal pressure generation requests additional simulation,
  - Cons: Non-uniform and sharp pressure fields on the FSI interface. Each particle is a concentrated nodal load to the structure. Therefore, there should be more than one particle per structural element.

### 4.2 Creating and deploying a bag driven by internal pressure

Standard Workbench environment tools, like SpaceClaim, can easily create the bag model. The bag model consists of two shell-part sets:

1. top surface part with 0.26 mm thickness,
2. bottom surface part with 0.26 mm thickness and flange stripe part with 0.52 mm thickness.

These part sets are stitched together around the perimeter. This stitching can be done by means of bonded (tied) contact, Node Merge operation or the Mesh Connection tool. The approach taken here utilizes the Mesh Connection tool (see Fig. 9) to avoid creating unnecessary contact pairs. This tool is specifically designed for local cross-linking of shell bodies. It merges nodes with the given tolerance and allows for local remeshing.



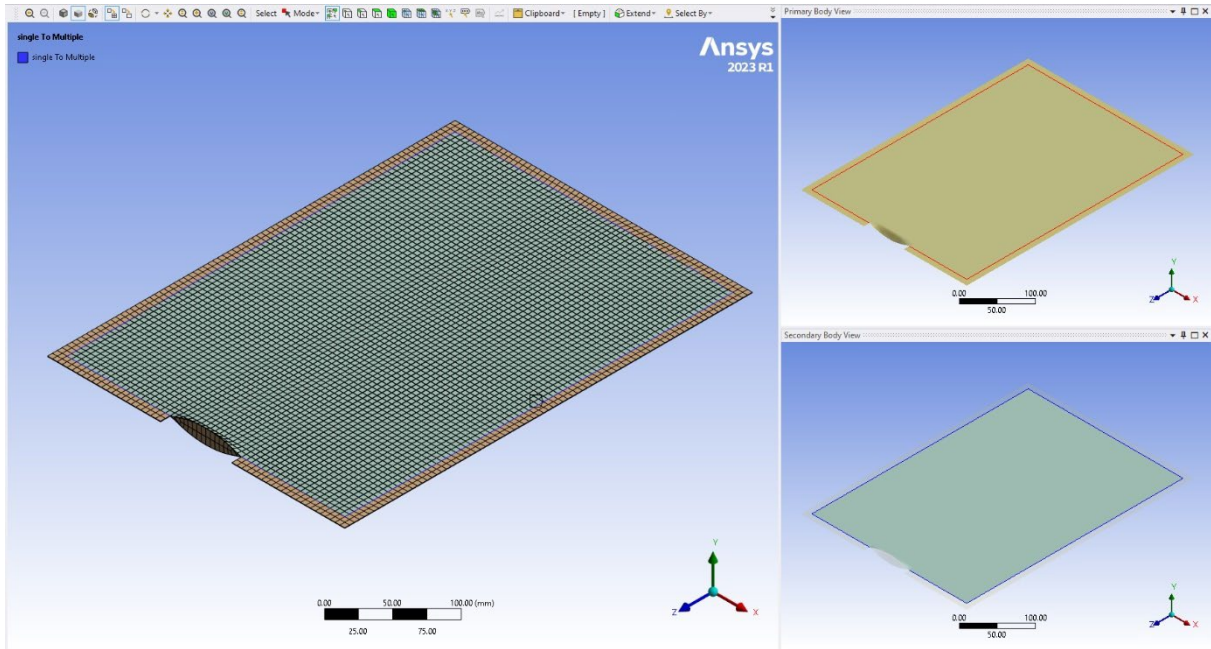


Fig.9: Mech Connection overview

The bag model uses fully integrated `*SECTION_SHELL`, `ELFORM=16` elements with a characteristic element size of about 5 mm. On the one hand, such elements will give greater accuracy in calculations of the plane-stress state of the model and the absence of hourglass effects; on the other hand, they will not behave as membrane elements. A benefit of this type of element is that it does not impose restrictions on the bag material models used.

Although the bag shell material should mainly work in the elastic zone, `*MAT_PLASTIC_KINEMATIC` is the material of choice. A small kinematic hardening definition is set for the material. This stabilizes the calculation when local stress peaks occur.

It is important to know that this type of element has an underestimated warping stiffness by default. The full projection warping stiffness for the shell element can be activated by assigning `*HOURLASS`, `IHQ=8`. Warping stiffness correction avoids severe creases and large folds in the final geometry of the unfolded bag (see Fig. 10).

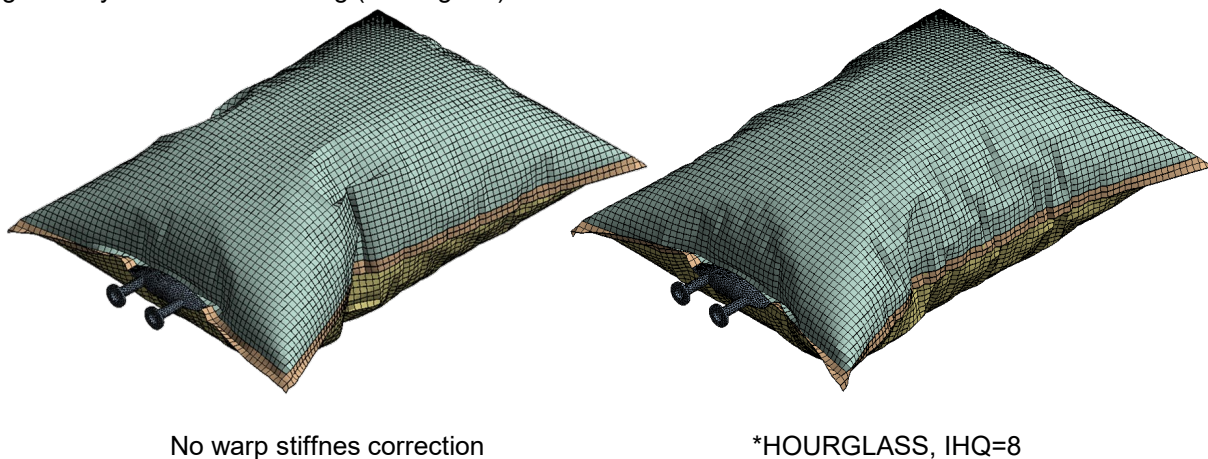


Fig.10: Correction of warping stiffness

This setting improves both the accuracy and stability of the calculation. At the same time, the increase in the computational cost of shell elements is insignificant compared to the cost of running the fluid interface in the following steps.

In the process of deformation, the elements of the bag will distort significantly. We can improve the stability of the solver by introducing `*CONTROL_SHELL`, `NFAIL4=0` (disable highly distorted fully integrated shell elements erosion), `WRPANG=90` (disable warnings about highly warped shell elements).

**\*CONTACT\_AUTOMATIC\_SINGLE\_SURFACE** (FS=0.2, SFS=SFM=4.0, SOFT=2, SOFTSCL=0.1, SBOPT=5, DEPTH=35) is used for defining bag parts self-contact. Access to all these options is possible in Workbench LS-DYNA via Body Interaction type of contact with an additional Contact Properties object in the model tree. To stabilize the deployment process, it is recommended to include a stiffness damping **\*DAMPING\_PART\_STIFFNESS\_SET**, COEF=0.2 for all the shell parts.

The internal pressure should inflate the bag without causing significant strain on the material. The easiest way to set the internal pressure is with the **\*AIRBAG\_LOAD\_CURVE** card. This card allows not only to set the pressure but also to measure the internal volume of the bag via **ABSTAT** ASCII results (see Fig. 11).

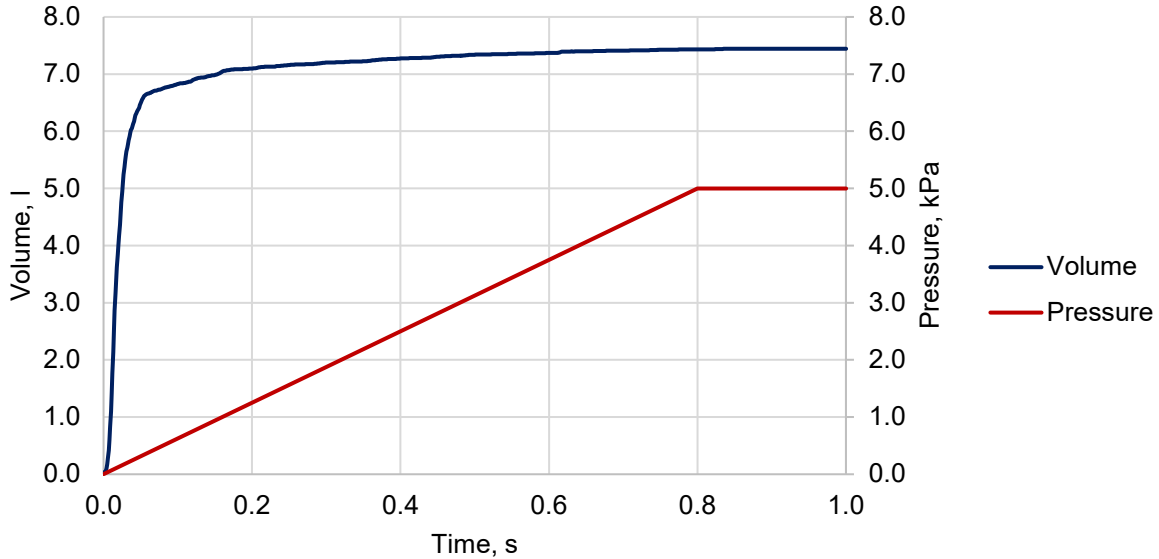


Fig. 11: Applied internal pressure curve and the bag volume history

Consideration of the stress state of the bag shell material is not essential for this problem. This allows the usage of the internal Workbench data transfer mechanisms instead of DYNAIN usage. Inflated bag geometry will be used in further simulation stages (see Fig. 12).

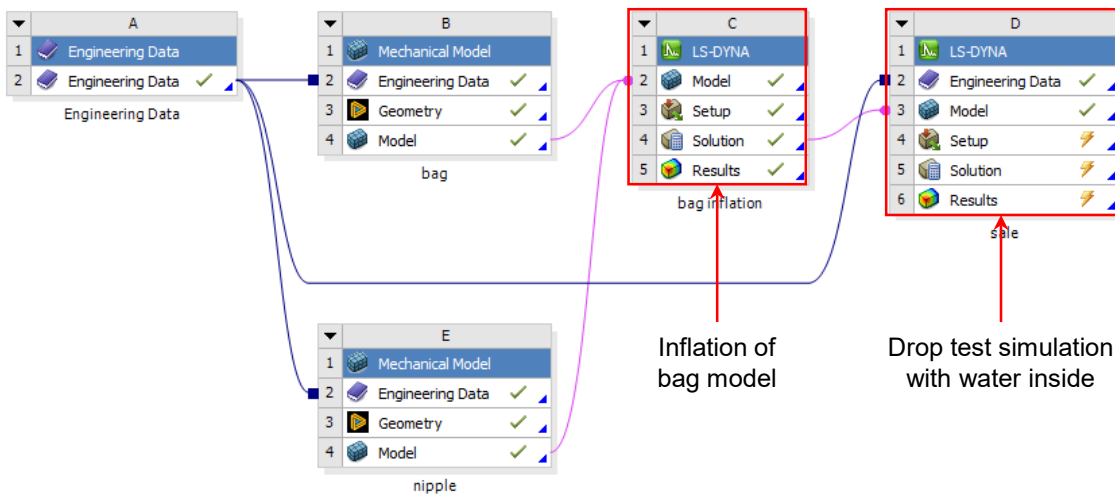


Fig. 12: Workbench project schematic with data transfer lines

### 4.3 Generating fluid inside bag deformed shape and drop test

#### 4.3.1 S-ALE Approach

Workbench LS-DYNA provides multiple options for S-ALE 3D simulation setup and postprocessing but no options for filling the shell-element bag with fluid. Therefore the fluid generation and the bag drop test will be performed based on command objects and postprocessing available in LSPP only.

The following describes the basic setup for robust ALE simulation in Workbench LS-DYNA:

- **DCT** = -1 – use alternate (improved) advection logic,
- **METH** = 1 – donor cell with Half Index Shift (HIS) advection method, first-order accurate,
- **AFAC** = -1 – turn ALE smoothing weight factor off.

Additionally, the value of the Time Step Safety Factor is set to 0.6 – the best practice value of explicit time step reduction when working with ALE.

The next process steps are simulated for the current simulation stage and approach (see. Fig. 13).

1. Deformed bag geometry is filled with water and keeps **\*MAT\_VACUUM** outside the bag – this is the standard for ALE initial volume filling.
2. Subsequently the external pressure on the bag is simulated: the pressure linearly increases from 0 to 0.1 MPa during the first 0.1 s.
3. Then, the external atmospheric pressure is kept constant for the following 0.1 s.
4. Finally, starting at time 0.2 s, we define an initial velocity of -4.4 m/s (equivalent to a 1-meter fall) and enable standard earth acceleration. At the same time, the effect of external atmospheric pressure is maintained. The calculation is completed at time 0.3 s after the first bounce of the bag from the Rigid Wall.

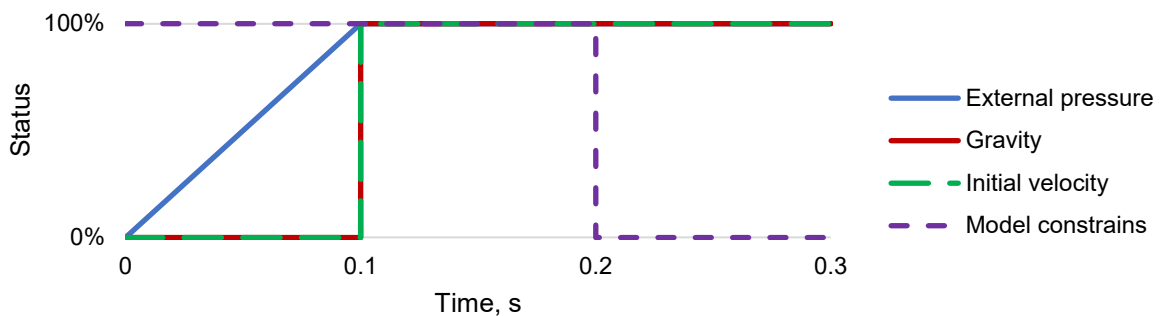


Fig.13: Load and b.c. application timeline

The possibility of considering the small compressibility of the fluid, even by a linear law, gives the possibility to obtain a more stable and predictable result than using the incompressibility hypothesis. So, since the fluid is simulated under loading by an external pressure, it is preferable to use a standard combination of **\*MAT\_NULL** with **\*EOS\_LINEAR\_POLINOMIAL** instead of **\*EOS\_MURNAGAN**.

The main challenge in solving the current S-ALE problem is correctly selecting and setting up the FSI interface. Two solvers can be chosen to do FSI processing with S-ALE. **\*ALE\_STRUCTURES\_FSI** is a modern version of FSI with minimalistic settings and much user-friendly automation, while **\*CONSTRAINED\_LAGRANGE\_IN\_SOLID** directs a mature solver, allowing experienced users to take full advantage of the richness and flexibility of its settings. Both cards are natively available in the Workbench LS-DYNA interface. Let's compare the work of these solvers (see Fig. 14 – 15).

**\*ALE\_STRUCTURES\_FSI** (mentioned as ASF) results in a solver crash of about moment 0.215 s (15% of the drop stage simulation). However, in the first stages of the calculation, it shows a very good conservation of bag volume. The results do not improve by adjusting the PFAC parameter or using the penalty pressure curve instead of the static PFAC value. The algorithm does not cope well with the situation when small volumes of liquid are trapped by the bag's folds, which result from deformations during the drop.

The interface **\*CONSTRAINED\_LAGRANGE\_IN\_SOLID** with **ILEAK=0** or **ILEAK=1**, **FRCMIN=0.5** settings has been evaluated next (mentioned as CLIS ILEAK 1). This interface allows you to complete the calculation to the end, however it cannot keep the internal volume of the bag constant due to significant leaks. Moreover, the S-ALE domain is filled with many water droplets – not caused by leaking – but being drawn in from outside through the boundaries of the domain.

The best results are obtained when switching to the interface **\*CONSTRAINED\_LAGRANGE\_IN\_SOLID** with **ILEAK=2**, **FRCMIN=0.3** (mentioned as CLIS ILEAK 2). This interface works as robustly as possible. Leaks in the model are negligible. The only remark to the work of this interface is that it does slightly overestimate the volume of fluid in the bag. Besides this these settings show the best results.



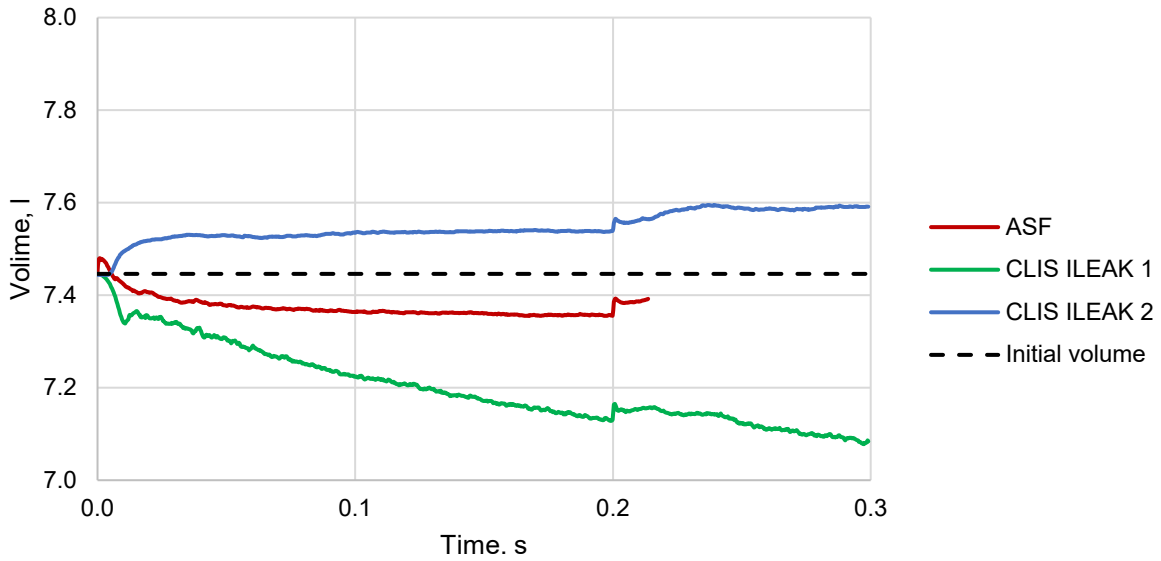


Fig.14: Preserving liquid volume inside the bag with different FSI interface



Fig.15: Model state at time 0.215 s: ASF has crushed at that time, CLIS ILEAK 1 shows enormous leakage, CLIS ILEAK 2 works near ideal

#### 4.3.2 SPH Approach

We now consider the same process using the SPH instead of the S-ALE solver (see Fig. 13). As noted above, the S-ALE method requires attention when tuning the FSI interface. At the same time, SPH uses contact algorithms that are simpler and easier to configure. It must be noted however that the initial filling of an arbitrary volume with spherical particles is difficult to accomplish to be perfect. An additional step is always required to eliminate voids by applying external pressure which will be a source of undesired bag folds.

As in the case of S-ALE, Workbench LS-DYNA does not provide the functionality to fill an arbitrary shell-container with SPH particles. So, the best strategy for SPH in bag generation is to use the **\*DEFINE\_SPH\_MESH\_BOX** card. The card allows offloading the SPH generation process directly to the solver, with the advantage that the size of the model can be significantly reduced. Also **\*DEFINE\_SPH\_MESH\_BOX** with option **SFSP** allows to generate particles with a given bag interference. Let's take a closer look at this option.

Reducing SFSP (increased initial penetration of particles) allows the user to increase the number of particles in the volume. The solver eliminates interference at initialization by filling the voids with particles.

Next the phase of filling a spherical bag with liquid particles is solved. The setup works with **\*CONTACT\_AUTOMATIC\_NODES\_TO\_SURFACE**, **FS = 0.3**, **SFS = SFM = 1e-6**, **SOFT = 1**,

$SFSP = 0.9$ . With `*CONTROL_SPH, ITHK=1`, the contact algorithm will consider real particle radii. In this case, the finite coefficient of friction between the fluid particles and the bag shells is particularly important. It stabilizes the contact, reducing undesirable oscillations of the particles along the normal of the contact surface.

The effect of the SFSP coefficient value on the residual volume of the bag after compaction is shown in Figure 16. The relationship between the SFSP coefficient value and the residual volume is linear for the model problem. However, the dependence may be different for a real complex geometry and a different particle size, and the coefficient value should be selected individually. This improves the filling and reduces the number of folds, resulting in a better bag shape. Due to the smoother bag outer surface, there are no unbalanced resulting pressure forces. But as can be seen on the right side in picture 16: a SFSP value of 1.0 (no initial shell-particle penetration, default filling) can cause the contact to become unstable because of too large penetrations.

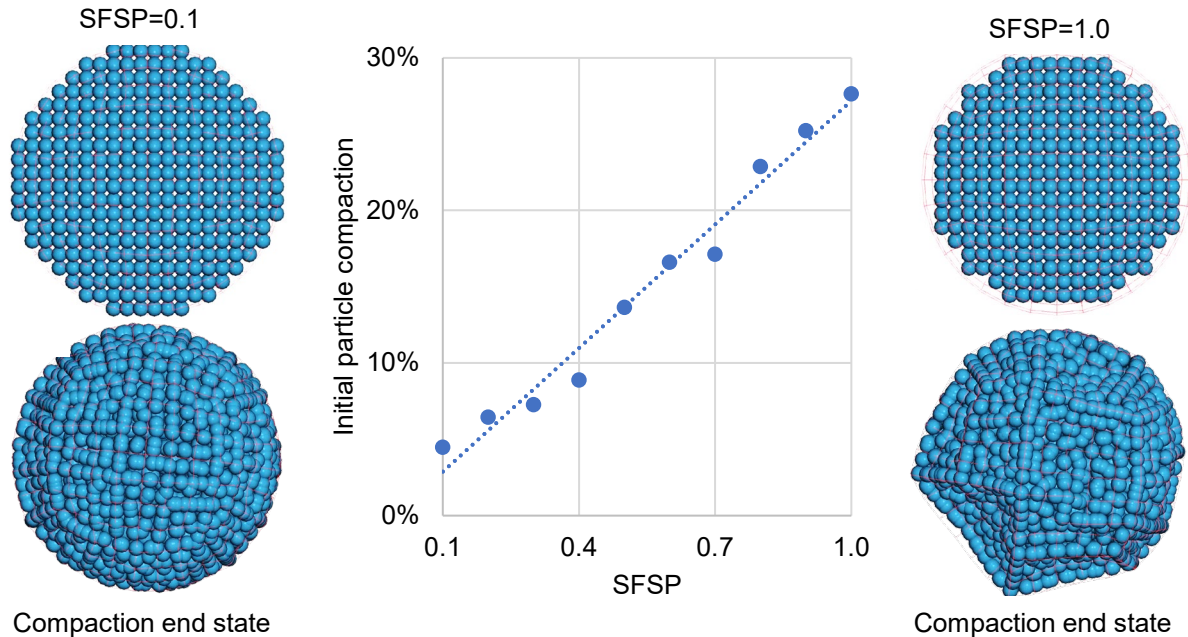


Fig.16: SFSP influence of particle filling: particles compaction visualization

In addition to the challenge of eliminating non-ideal volume filling, additional adjustments to the SPH solver settings are made. Enhanced fluid formulation (`*CONTROL_SPH, FORM=15`) is used since the enhanced fluid formulation with renormalization (`*CONTROL_SPH, FORM=16`) showed less stable and more noisy results in terms of internal material pressure evaluation.

The simulation uses a Monaghan-type artificial viscosity formulation (`*CONTROL_SPH, IAVIS=0`). The results of the simulations confirm the remarks from solver documentation: the solver overestimates fluid viscosity with default settings. To reduce the viscosity, using the `*HOURLGLASS` card with  $Q1=0.001$  and  $Q2=1E-7$  for SPH parts is necessary. Alternatively, the “default” viscosity formulation can be recommended (`*CONTROL_SPH, IAVIS=1`), where there is no need for an additional `*HOURLGLASS` card.

In this case, delayed application of initial velocity is used via `*INITIAL_VELOCITY_GENERATION_START_TIME`. It was found that the delayed initial velocity initiation for the SPH part requires special model settings. First, `*INITIAL_VELOCITY_GENERATION, PHASE=1` should be used for the SPH part and any other deformable part. But, additionally, `*INITIAL_VELOCITY_GENERATION, PHASE=0` should also be added to the model. Only with double usage of `*INITIAL_VELOCITY_GENERATION` on the SPH part it is possible to initialize delayed initial velocity correctly.

With a shell element size of 10mm and a particle distance of 5 mm the solver produces a relatively smooth pressure with four particles per one shell element.

Application of all these additional tips and settings allows us to perform calculations using the S-ALE analytical loading sequence (see. Fig. 13).

#### 4.3.3 S-ALE and SPH results comparison

The results of the very-flexible bag with fluid drop test are compared. The results obtained from both simulation approaches are in good agreement with each other (see Fig. 17).

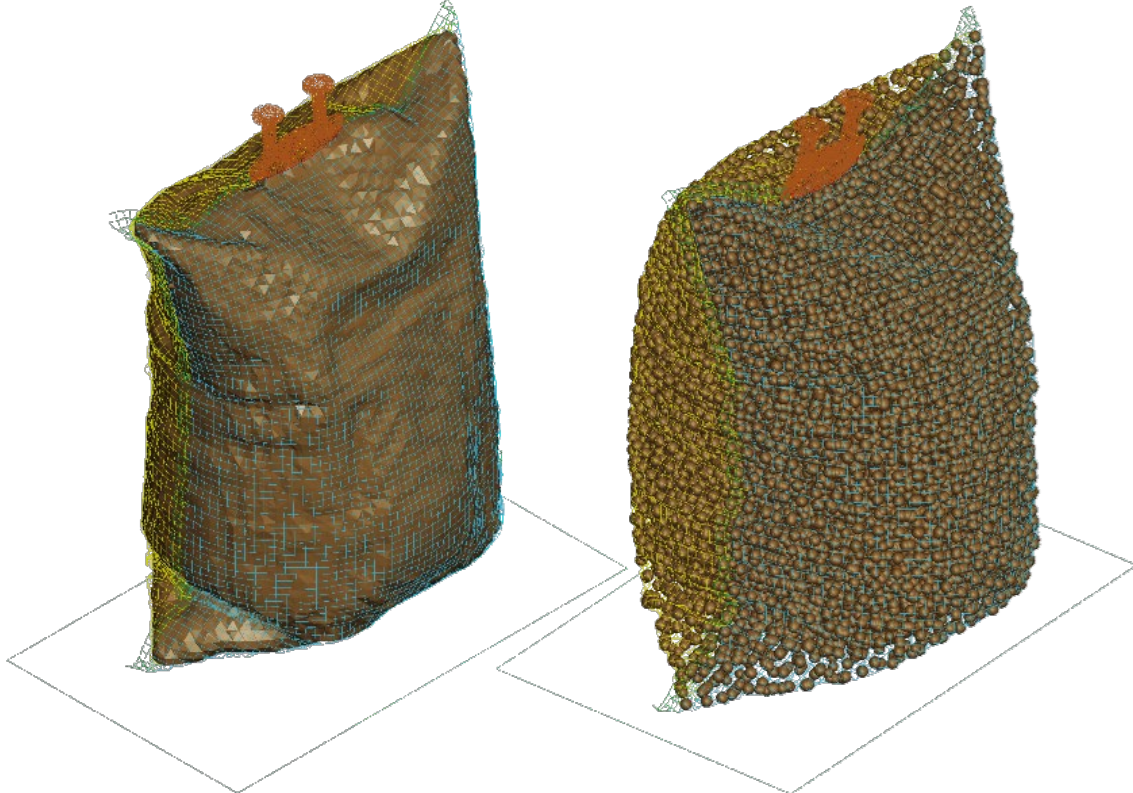


Fig.17: Deformed shape of the fluid bag using S-ALE (left) and SPH (right) approaches.

Let us compare the normal force curves in the contact between the bag and Rigid Wall (see Fig. 18). They are similar, but the amplitude of the curve in SPH calculation is slightly lower than in S-ALE. This is explained by the non-ideal filling of the bag with particles, which leads to a smaller volume and mass of water inside the bag.

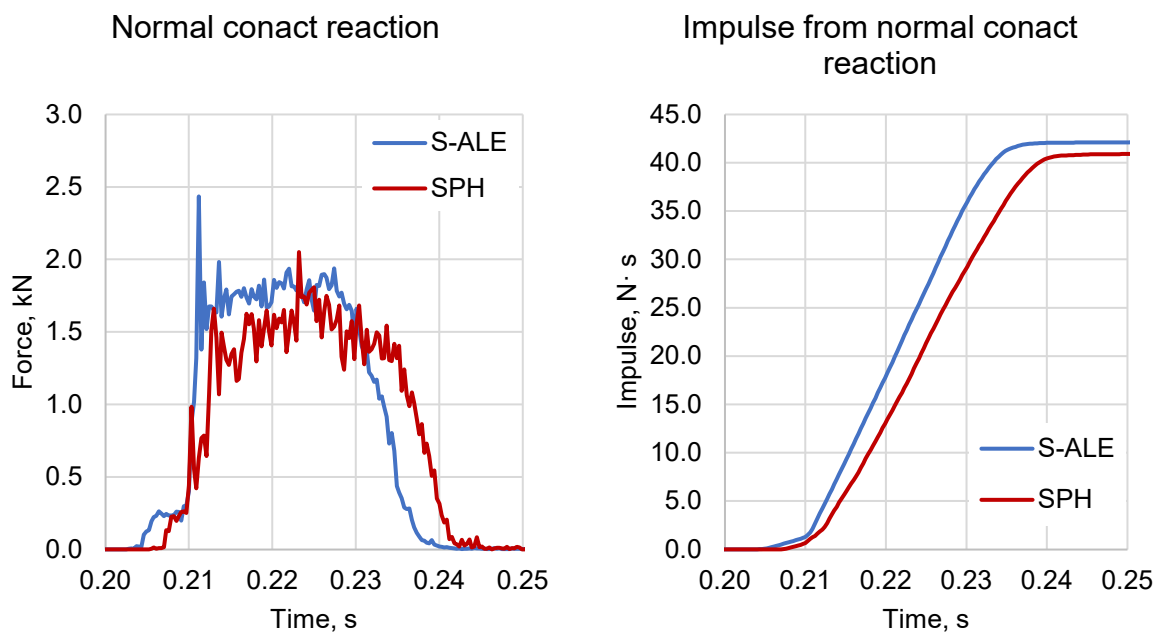


Fig.18: Normal contact reactions between the bag and Rigid Wal – force and impulse

It is interesting to compare the computational performance of the methods (see Tab. 1). The SPH simulation runs with 5 mm particles, and the S-ALE domain element size is 5 mm. The above calculations were performed with Ansys LS-DYNA R13.1.1 MPP DP solver running on CPU 20 cores via INTEL MPI 2019.6.166. The server configuration is Windows Server 2019, Intel Xeon Gold 6266C x2, and 280 Gb RAM.

Parameter	S-ALE	SPH
WCT, hh:mm:ss	5:55:35	11:46:18
Memory to start, word	memory = 7202K memory2 = 589K	memory = 2004K memory2 = 80K
Cycles number	408035	271465
Time step safety factor	0.6	0.9

Table 1: S-ALE and SPH performance comparison.

The S-ALE approach shows a two times better simulation performance even though the time step safety factor is 30% lower for the method. S-ALE solver needs 3.5 times more memory for solution initialization than SPH.

#### 4.4 Simulation of bag filling driven by fluid injection

The project's last and most advanced stage is the direct fluid injection simulation of the bag-filling process. The modeling of this process with S-ALE is extremely time-consuming. FSI interfaces are not designed to handle tangential loads. In addition, a significant denser mesh is required to ensure fluid flow, increasing the problem's resource intensity. Thus, using S-ALE does not provide a workable solution and makes the problem too resource-intensive. However, for SPH, modeling such a process is not very difficult.

In addition, SPH supports multistage handling of the results with DYNAIN. The calculation results can produce a ready-to-use model of the fluid in the shell in DYNAIN format, which can be further used for various drop test scenarios.

##### 4.4.1 SPH injection driven by velocity

If creating a pre-determined internal fluid pressure in the bag is not a priority, particle injection utilizing the **\*DEFINE\_SPH\_INJECTION** card is possible. The underlying algorithm of this card received many new features in R14.0. In addition, it was with R14.0 that the algorithm gained a higher stability. The card allows to realize inlet boundary conditions with constant velocity. A known limitation of the definition of this card is that already active SPH particles must not pass through the defined injection surface. If this happens, the resulting interference between the already active and newly created particles leads to an unphysical energy jump and possible crash of the computational scheme.

The general model setup for the case is shown in Figure 19. We inject particles through a small rigid pipe. This pipe or neck creates a small column of water, which will have internal pressure due to gravity. The SPH particles from this column will fill the bag.

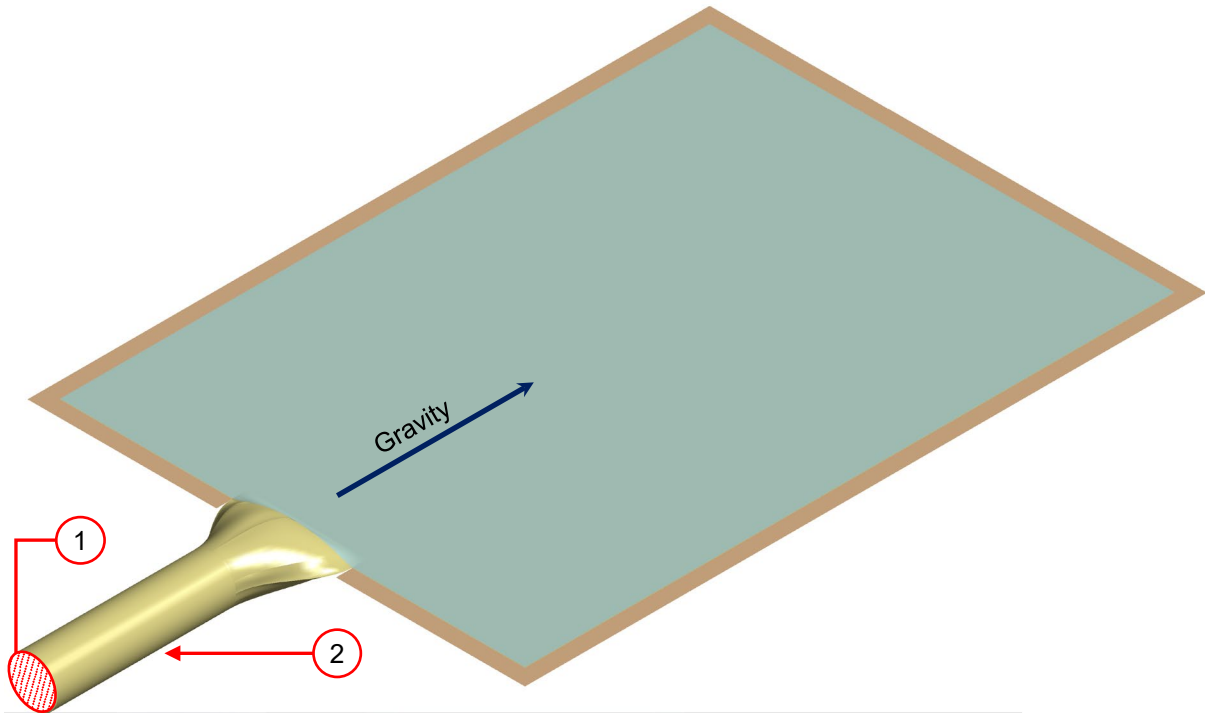


Fig. 19: Bag model with SPH injection driven by velocity: 1 – injection surface, 2 – rigid bag neck.

From the physics point of view of the described process, it is very important to introduce external atmospheric pressure on the bag. Without this pressure, the model has no forces to bring the particles together, and the bag is filled with many voids (see Fig. 19).

When solving this filling problem, the previously made settings of the SPH contact with thin shell elements are insufficient, resulting in penetration of many particles through the shell surface, in the order of tens of percent of the total internal volume.

To eliminate this observed phenomenon, increasing bucket sorting frequencies is necessary. By default, sorting occurs once every 200 cycles. However, stable behavior of the contact is achieved by sorting once every 5 cycles. This setting can be done in the corresponding contact card; for MPP by means of **BCKT** and for SMP by means of **BSORT**.

As discussed earlier, consideration of the external atmospheric pressure acting on the bag of SPH particles is essential. It is this pressure that keeps the particles together. When modeling particle injection, one can see that a model without external pressure immediately accumulates many voids, and the particle volume distribution turns out to be unphysical (see. Fig. 20). In addition, in the absence of external pressure, it becomes difficult to predict the time of calculation and the volume of liquid inside the bag. The bag's volume is more than equivalent to the volume of liquid inside, which means too many voids, as seen in the corresponding curves (see. Fig. 21).



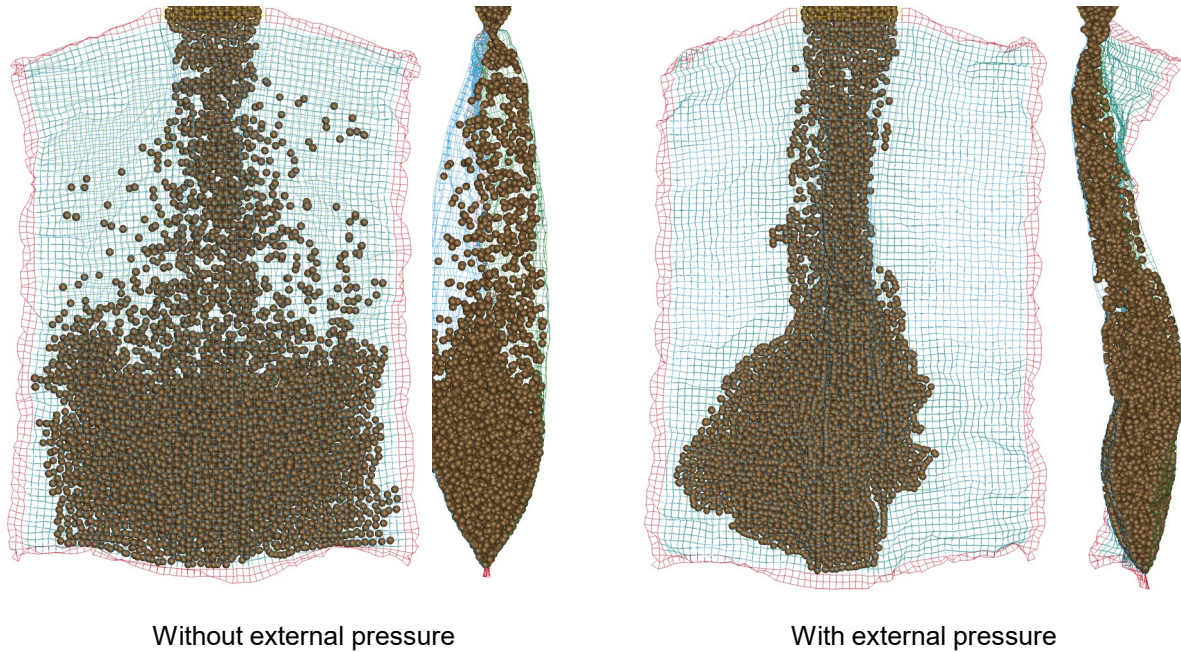


Fig.20: Particles in the spatial distribution at time 0.25 s

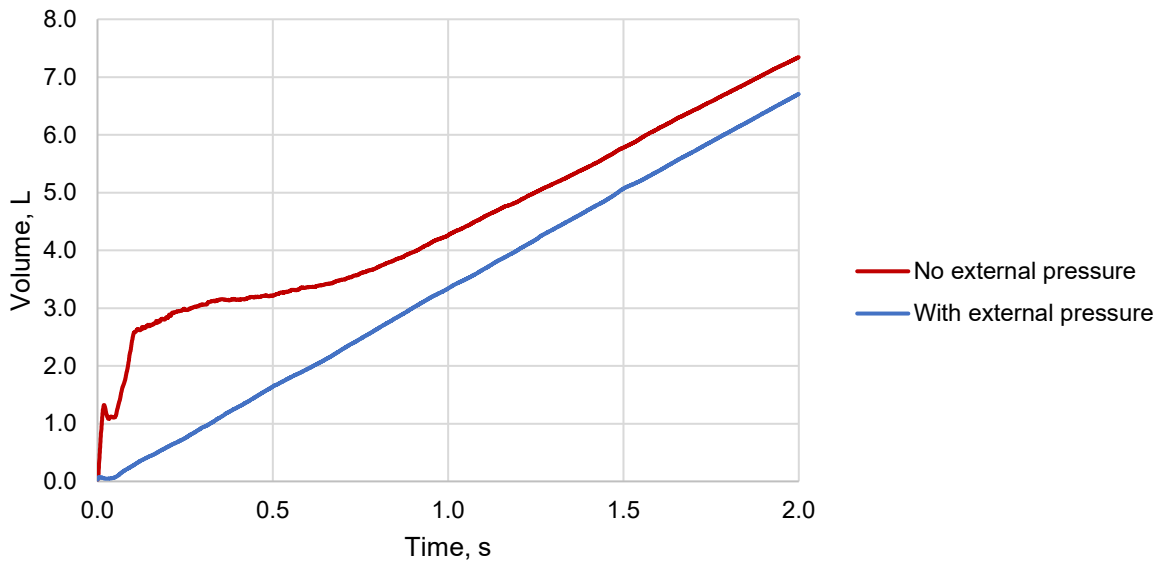


Fig.21: Filling the bag with and without external pressure consideration

#### 4.4.2 SPH injection driven by pressure

If it is important to create a certain internal pressure in the bag, the card `*DEFINE_SPH_INJECTION` is unsuitable. In this case, it is necessary to simulate injecting particles from an external reservoir using a piston (see Fig. 22).

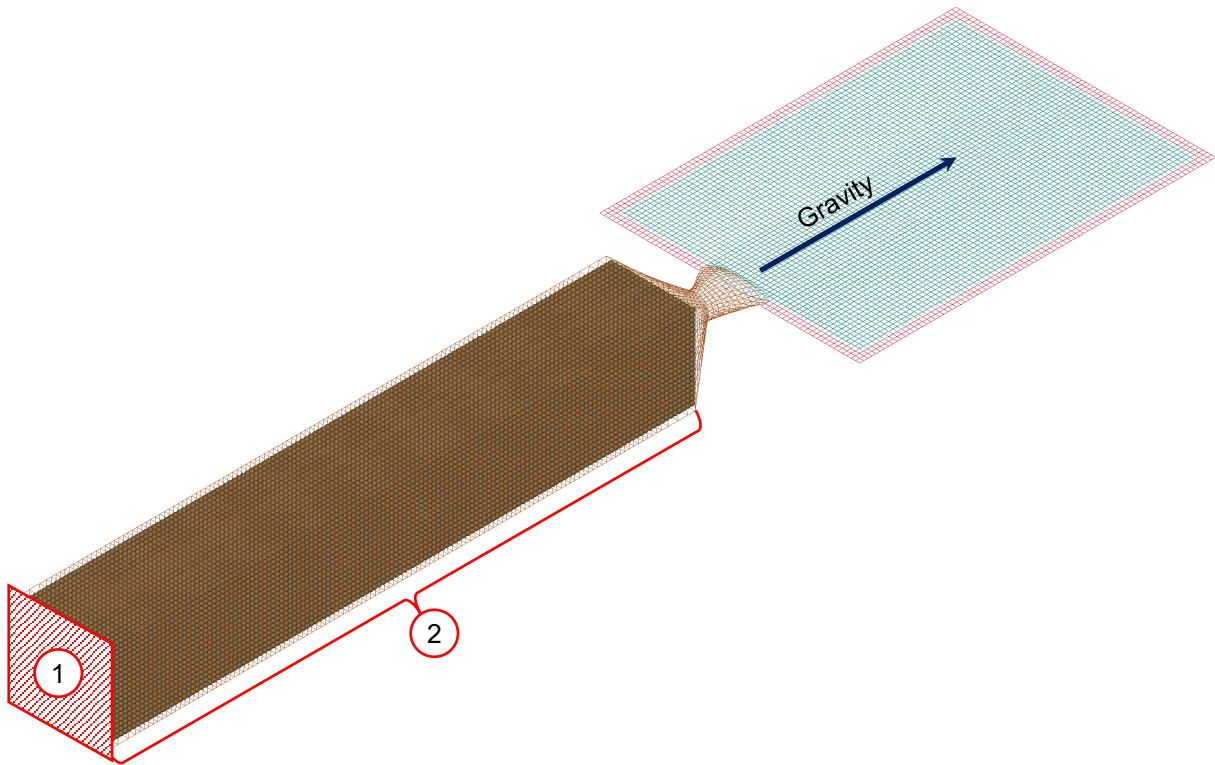


Fig.22: Model for injection of pre-generated particles from the tank (2) using a piston (1)

The movement of the rigid piston is set using a constant pressure of 0.2 MPa. Also, we should not forget the effect of the external atmospheric pressure of 0.1 MPa on the bag surface. In addition, the maximum piston speed is limited to 5 m/s by the `*CONSTRAINED_RIGID_BODY_STOPPERS` card. The reservoir of initially pre-generated particles has a square cross-section that is a multiple of the particle diameter. This allows knowledge of the exact volume of the injected liquid in advance.

Some intermediate computational results (see Fig. 23) show the importance of properly adjusting the bucket sorting frequency for particles to prevent penetrations of particles outside the deformable bag surface. The default settings result in particles finding contact with other particles, rather than moving through the bag due to gravity.

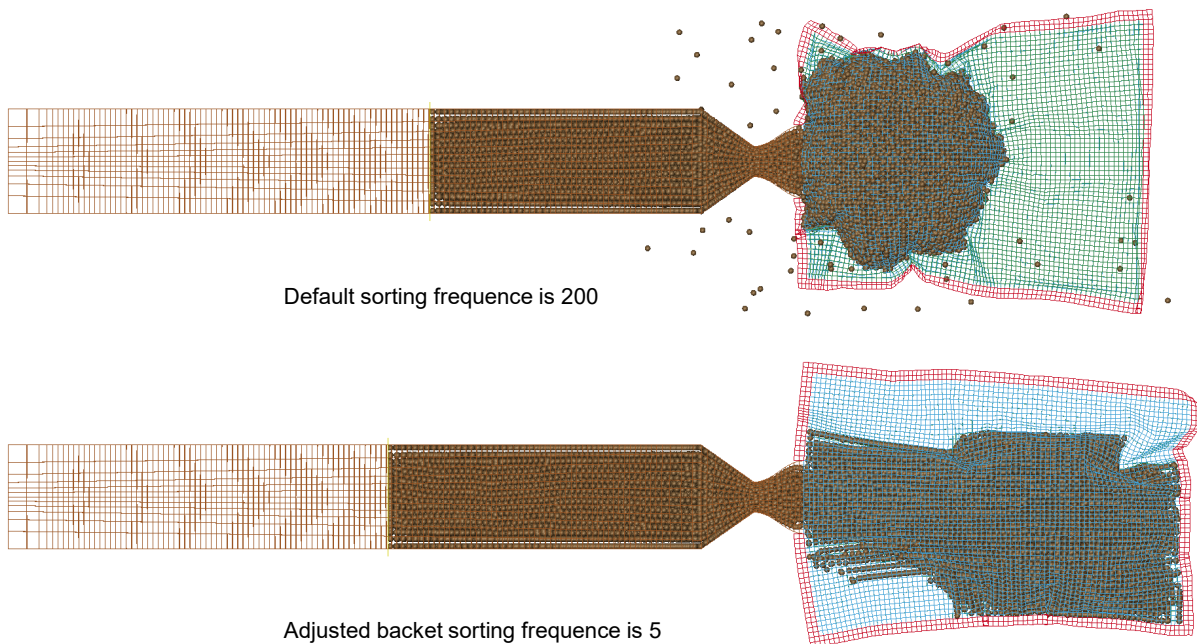


Fig.23: Importance of basket sorting adjustment for the model

## 5 Conclusions

The examples of two real industrial applications of the Workbench LS-DYNA environment are analyzed in detail during the project.

The first application describes how the SPG mesh-less method can be coupled with the GISSMO damage model for material separation simulation. This simulation can be completely reproduced inside Workbench with minimal command snippets usage.

The second application compares S-ALE and SPH for inertia-dominated FSI with a very flexible container. A complete multi-case study has been performed: different scenarios of container deployment have been considered, drop test results for S-ALE and SPH have been compared and finally the fluid injection procedure driven by velocity or pressure has been described.

Developing these test cases for real industrial applications of Ansys LS-DYNA highlights two critical aspects: first and foremost, users get ready-made examples and detailed recommendations on how to use the software. This helps to lower the bar for new users to enter the advanced simulation world. Secondly, developing such examples is an excellent stress test of software availability. It allows developers to get detailed, concentrated feedback and understand the computational code's current state.

All models and test cases mentioned are available without restriction within the Ansys Channel Partner Network and can be made available upon customer request.

## 6 Literature

- [1] Ansys, "LS-DYNA® KEYWORD USER'S MANUAL," LS-DYNA R14, 2023