*CONTROL_SPH

Purpose: Provide controls relating to SPH (Smooth Particle Hydrodynamics).

Card 1	1	2	3	4	5	6	7	8
Variable	NCBS	BOXID	DT	IDIM	MEMORY	FORM	START	MAXV
Type	I	I	F	I	I	I	F	F
Default	1	0	10^{20}	none	150	0	0.0	10^{15}

Remaining cards are optional.†

Card 2	1	2	3	4	5	6	7	8
Variable	CONT	DERIV	INI	ISHOW	IEROD	ICONT	IAVIS	ISYMP
Type	I	I	I	I	I	I	I	I
Default	0	0	0	0	0	0	0	100

Card 3	1	2	3	4	5	6	7	8
Variable	ITHK	ISTAB	QL					
Type	I	I	F					
Default	0	0	0.01					

VARIABLE	DESCRIPTION
NCBS	Number of time steps between particle sorting.
BOXID	SPH approximations are computed inside a specified BOX. When a particle has gone outside the BOX, it is deactivated. This will save computational time by eliminating particles that no longer interact with the structure.

VARIABLE	DESCRIPTION
DT	Death time. Determines when the SPH calculations are stopped.
IDIM	Space dimension for SPH particles: EQ.3: for 3D problems EQ.2: for 2D plane strain problems EQ.-2: for 2D axisymmetric problems (see Remark 2)
MEMORY	Defines the initial number of neighbors per particle (see Remark 1 below).
FORM	Particle approximation theory (Remark 2): EQ.0: default formulation EQ.1: renormalization approximation EQ.2: symmetric formulation EQ.3: symmetric renormalized approximation EQ.4: tensor formulation EQ.5: fluid particle approximation EQ.6: fluid particle with renormalization approximation EQ.7: total Lagrangian formulation EQ.8: total Lagrangian formulation with renormalization EQ.9: adaptive SPH formulation (ASPH) with anisotropic smoothing tensor (Remark 2g) EQ.10: renormalization approximation for adaptive SPH formulation (ASPH) with anisotropic smoothing tensor EQ.12: moving least-squares based formulation (Remark 2e) EQ.15: enhanced fluid formulation EQ.16: enhanced fluid formulation with renormalization
START	Start time for particle approximation. Particle approximations will be computed when time of the analysis has reached the value defined in START.
MAXV	Maximum value for velocity for the SPH particles. Particles with a velocity greater than MAXV are deactivated. A negative MAXV will turn off the velocity checking.

VARIABLE	DESCRIPTION
CONT	Flag for inter-part particle interaction by "particle approximation": EQ.0: Particle approximation is used for computing inter-part particle interaction for all SPH parts (default). EQ.1: Particle approximation is not used for inter-part particle interaction, except as specified by the INTERACTION option of *SECTION_SPH. As an alternative to particle approximation, inter-part particle interaction can be accomplished using *DEFINE_SPH_TO_SPH_COUPLING.
DERIV	Time integration type for the smoothing length: EQ.0: $\frac{d}{dt}[h(t)] = \frac{1}{d}h(t)\nabla \cdot \mathbf{v}$, (default), EQ.1: $\frac{d}{dt}[h(t)] = \frac{1}{d}h(t)(\nabla \cdot \mathbf{v})^{1/3}$
INI	Computation of the smoothing length during the initialization: EQ.0: Bucket sort based algorithm (default, very fast). EQ.1: Global computation on all the particles of the model. EQ.2: Based on the mass of the SPH particle.
ISHOW	Display option for deactivated SPH particles: EQ.0: No distinction in active SPH particles and deactivated SPH particles when viewing in LS-PrePost. EQ.1: Deactivated SPH particles are displayed only as points and active SPH particles are displayed as spheres when Setting → SPH → Style is set to "smooth" in LS-PrePost.
IEROD	Deactivation control for SPH particles: EQ.0: Particles remain active. See Remark 3. EQ.1: SPH particles are partially deactivated and stress states are set to 0 when erosion criteria are satisfied. See Remark 3. EQ.2: SPH particles are totally deactivated and stress states are set to 0 when erosion criteria are satisfied. See Remark 3. EQ.3: SPH particles are partially deactivated and stress states are set to 0 when erosion criteria are satisfied. If an EOS is defined, the volumetric response is unaffected. See

VARIABLE	DESCRIPTION
	Remark 3.
ICONT	Controls contact behavior for deactivated SPH particles: EQ.0: Any contact defined for SPH remains active for deactivated particles. EQ.1: Contact is inactive for deactivated particles.
IAVIS	Defines artificial viscosity formulation for SPH elements (Remark 4): EQ.0: Monaghan type artificial viscosity formulation is used. EQ.1: Standard type artificial viscosity formulation from solid element is used (this option is not supported in SPH 2D and 2D axisymmetric elements).
ISYMP	Defines the percentage of original SPH particles used for memory allocation of SPH symmetric planes ghost nodes generation process (default is 100%). Recommended for large SPH particles models (value range 10~20) to control the memory allocation for SPH ghost particles with *BOUNDARY_SPH_SYMMETRY_-PLANE keyword.
ITHK	Contact thickness option: EQ.0: The contact thickness is set to zero (default). EQ.1: The contact thickness is automatically calculated based on the volume of each SPH particle. This contact thickness calculation is ignored if a non-zero contact thickness for slave surface (SST) is provided by the contact card.
ISTAB	Stabilization type, only used when IFORM = 12: EQ.0: Incremental stabilization (default). Adequate for most materials. EQ.1: Total stabilization. Only recommended for hyperelastic materials.
QL	Quasi-Linear coefficient, only used when IFORM = 12. See Remark 5.

Remark:

1. **Memory.** MEMORY is used to determine the initial memory allocation for the SPH arrays. Its value can be positive or negative. If MEMORY is positive, memory allocation is dynamic such that the number of neighboring particles is initially equal to MEMORY but that number is subsequently allowed to exceed MEMORY as the solution progresses. If MEMORY is negative, memory allocation is static and |MEMORY| is the maximum allowed number of neighboring particles for each particle throughout the entire solution. Using this static memory option can avoid memory allocation problems.

2. **Form.** The user has to be careful to pick the right FORM which depends upon the application. Below are some guidelines for selecting the FORM value:

   a) For most solid structure applications, FORM = 1 is recommended for more accurate results around the boundary area.

   b) For fluid or fluid-like material applications, FORM = 15 or 16 is recommended. FORM = 16 usually has better accuracy but requires more CPU time. Also note that formulations 15 and 16 include a smoothing of the pressure field and are, therefore, not recommended for materials with failure or problems with important strain localization.

   c) All SPH formulations with Eulerian kernel, that is, FORM with values 0 to 6, 15 and 16, can be used for large or extremely large deformation applications but will have tensile instability issues. FORM = 2 or 3 is not recommended for any case.

   d) All SPH formulations with Lagrangian kernel (FORM = 7 or 8) can be used to avoid tensile instability issue but they cannot endure very large deformations.

   e) For improved accuracy and tensile stability, a formulation based on moving least-squares (FORM = 12) is available. This formulation can be used for extremely large deformation applications but entails a significant computational cost. FORM = 12 is available for MPP simulations only. It is strongly recommended to keep a constant smoothing length for this formulation by setting HMIN = 1.0 and HMAX = 1.0 in *SECTION_SPH.

   f) Only formulations 0, 1, 15 and 16 are implemented for 2D axisymmetric problems (IDIM = -2).

   g) Formulations 9 and 10 are adaptive smoothed particle hydrodynamics formulations with an anisotropic kernel (Eulerian kernel) whose axes evolve automatically to follow the mean particles spacing as it varies in time, space and direction based on the strain rate tensors. These forms

must be used with the *SECTION_SPH_ELLIPSE keyword. They have better accuracy and stability than the standard SPH. These forms can be used for extremely large deformation problems and are available for 3D and SMP case only.

3. **Erosion.** The erosion criteria, which triggers particle deactivation when IEROD = 1, 2 or 3, may come from the material model, from *MAT_ADD_-EROSION, or from the ERODE field in *CONTROL_TIMESTEP.

   a) For IEROD = 0, SPH particles remain active. This option is generally not recommended when materials with erosion are used, as many material models will still reset the stress field to zero periodically. If an unaltered stress field is desired, simply remove the erosion criteria in the material model parameters.

   b) For IEROD = 1, SPH particles are partially deactivated; that is, the stress states of the deactivated SPH particles will be set to zero, but these particles still remain in the domain integration for more stable results.

   c) For IEROD = 2, SPH particles are totally deactivated, so the stress states will be set to 0 and the deactivated particles do not remain in the domain integration.

   d) For IEROD = 3, SPH particles remain active. The deviatoric stress is set to zero. If an equation of state is used, the volumetric response remains unaltered; otherwise the volumetric stress is set to zero as well.

   e) Deactivated particles can be distinguished from active particles by setting ISHOW = 1.

   f) To disable contact for deactivated particles, set ICONT = 1.

4. **Artificial Viscosity.** The artificial viscosity for standard solid elements, which is active when AVIS = 1, is given by:

$$q = \rho l\left(Q_1 l\dot{\varepsilon}_{kk}^2 - Q_2 a\dot{\varepsilon}_{kk}\right) \quad \dot{\varepsilon}_{kk} < 0$$
$$q = 0 \quad \dot{\varepsilon}_{kk} \geq 0$$

   where Q_1 and Q_2 are dimensionless input constants, which default to 1.5 and .06, respectively (see *CONTROL_BULK_VISCOSITY); l is a characteristic length given as the square root of the area in two dimensions and as the cube root of the volume in three; and a is the local sound speed. This formulation, which is consistent with solid artificial viscosity, has better energy balance for SPH elements.

   For general applications, Monaghan type artificial viscosity is recommended since this type of artificial viscosity is specifically designed for SPH particles.

The Monaghan type artificial viscosity, which is active when AVIS = 0, is defined as follows:

$$q = \begin{cases} \dfrac{-Q_2\bar{c}_{ij}\phi_{ij} + Q_1\phi_{ij}^2}{\bar{\rho}_{ij}} & v_{ij}x_{ij} < 0 \\ 0 & v_{ij}x_{ij} \geq 0 \end{cases}$$

where

$$\phi_{ij} = \frac{h_{ij}v_{ij}x_{ij}}{|x_{ij}|^2 + \varphi^2}$$
$$\bar{c}_{ij} = 0.5(c_i + c_j)$$
$$\bar{\rho}_{ij} = 0.5(\rho_i + \rho_j)$$
$$h_{ij} = 0.5(h_i + h_j)$$
$$\varphi = 0.1h_{ij}$$

and Q_1/Q_2 are input constants. When using Monaghan type artificial viscosity, it is recommended that the user set both Q_1 and Q_2 to 1.0 on either the *CONTROL_BULK_VISCOSITY or *HOURGLASS keywords; see for example G. R. Liu.

5. **Quasi-Linear Coefficient.** The moving least-squares based formulation contains a quasi-linear approximation term to combine accuracy with stability in extremely large deformations simulations. The default value QL = 0.01 gives a good compromise between accuracy and stability in most cases. For greater accuracy, its value can be reduced to QL = 0.001 in simulations with small deformations, or increased to QL = 0.1 for extreme deformations, if instabilities are present.