*DAMPING

The keyword options in this section in alphabetical order are:

*DAMPING_FREQUENCY_RANGE

*DAMPING_GLOBAL

*DAMPING_PART_MASS

*DAMPING_PART_STIFFNESS

*DAMPING_PART_STRUCTURAL

*DAMPING_RELATIVE

*DAMPING_STRUCTURAL

*DAMPING_FREQUENCY_RANGE_{OPTION1}_{OPTION2}

Purpose: Provide approximately constant damping (that is, frequency-independent) over a range of frequencies. It applies to explicit analysis and to time-integrated implicit dynamic analysis (IMASS = 1 on *CONTROL_IMPLICIT_DYNAMICS) but not to any of the implicit analysis types that use modal superposition or those that work in the frequency domain.

Available settings of *OPTION1* are:

<BLANK>	Applies damping to global motion of nodes
DEFORM	Applies damping to element stresses/forces (see Remarks 2 and 4)

OPTION2 is available only when *OPTION1* is DEFORM. Available settings for *OPTION2* are:

<BLANK>	Applies to solid, beam, shell, thick shell and discrete elements
DMIG	Applies damping to superelements (see *ELEMENT_DIRECT_MATRIX_INPUT)

Card 1	1	2	3	4	5	6	7	8
Variable	CDAMP	FLOW	FHIGH	PSID		PIDREL	IFLG	ICARD2
Type	F	F	F	I		I	I	I
Default	0.0	none	none	0		0	0	0

Include this card only if ICARD2 = 1 and *OPTION1* is DEFORM.

Card 2	1	2	3	4	5	6	7	8
Variable	CDAMPV	IPWP						
Type	F	I						
Default	CDAMP	1						

VARIABLE	DESCRIPTION
CDAMP	Damping in fraction of critical. Accurate application of this damping depends on the time step being small compared to the period of interest.
FLOW	Lowest frequency in the range of interest (cycles per unit time, such as Hz if the time unit is seconds). Must be greater than zero.
FHIGH	Highest frequency in the range of interest (cycles per unit time, such as Hz if time unit is seconds). Must be greater than FLOW.
PSID	Meaning depends on *OPTION1* and *OPTION2*. If *OPTION1* or *OPTION2* is blank, PSID is a part set ID (see *SET_PART). The requested damping is applied only to the parts in the set. If PSID = 0, the damping is applied to all parts except those referred to by other *DAMPING_FREQUENCY_RANGE cards. If *OPTION1* is DEFORM and *OPTION2* is DMIG, PSID is the ID of a superelement (see EID on *ELEMENT_DIRECT_MATRIX_INPUT). If PSID = 0, the damping is applied to all superelements.
PIDREL	Optional part ID of a rigid body. Damping is then applied to the motion relative to the rigid body motion. This input does not apply to the DEFORM keyword option. See Remark 6.
IFLG	Method used for internal calculation of damping constants: EQ.0: Iterative (more accurate). See Remark 5. EQ.1: Approximate (same as R9 and previous versions)
CDAMPV	Damping in fraction of critical applied to pressure/volume response of solid elements. See Remark 7.
IPWP	Flag to determine whether the damping is applied to excess pore pressure in parts referenced by *BOUNDARY_PORE_FLUID (see Remark 8): EQ.0: Same as EQ.1 EQ.1: Excess pore pressure is subjected to damping ratio CDAMPV EQ.2: Damping is not applied to pore pressure, only to the effective stress.

Remarks:

1. **General.** This feature is for explicit analysis and implicit time-stepping dynamic analysis (IMASS = 1 on *CONTROL_IMPLICIT_DYNAMICS). It provides an approximately constant (i.e., frequency-independent) damping ratio over a range of frequencies given by $F_{\mathrm{low}} < F < F_{\mathrm{high}}$. It is intended for small damping ratios (< 0.05) and frequency ranges such that $F_{\mathrm{high}}/F_{\mathrm{low}}$ is in the range of 10 to 300. In contrast, other types of damping are not frequency-independent: mass-weighted damping (see *DAMPING_GLOBAL and *DAMPING_PART_MASS) gives a damping ratio that is inversely proportional to frequency, while stiffness-proportional damping (see *DAMPING_PART_STIFFNESS) gives a damping ratio that is proportional to frequency.

   At frequencies outside of the range $F_{\mathrm{low}} < F < F_{\mathrm{high}}$, some damping is applied, but the damping ratio becomes progressively lower as the frequency reduces below F_{low} or increases above F_{high}.

2. **Choice of OPTION1.** When *OPTION1* is blank, this card applies damping based on the velocities of the nodes of the parts in PSID relative to the global coordinate system. Thus, rigid body motion attracts damping forces. When *OPTION1* is DEFORM, damping is applied based on the rate of change of element stresses or forces. Therefore, rigid body motion is not damped when using the DEFORM keyword option. Thus, *we recommend DEFORM over the standard option.* The dependence of the damping on the rate of change of stresses or forces means that the damping forces depend on the current tangent stiffness. This method is believed to be more appropriate for a nonlinear analysis, which could be overdamped if a strain-rate-proportional or viscous damping scheme were used.

3. **Dynamic stiffness.** A drawback of *DAMPING_FREQUENCY_RANGE is that it alters the dynamic stiffness of the damped parts, and hence it also alters the natural frequencies of the structure. Both settings of *OPTION1* do this but in different ways. When *OPTION1* is blank, the damping method reduces the dynamic stiffness, while for the DEFORM option, the method increases dynamic stiffness. In both cases, the change of dynamic stiffness is proportional to the damping ratio CDAMP and is greater when the ratio $F_{\mathrm{high}}/F_{\mathrm{low}}$ is greater. The degree to which the natural frequency of a particular mode increases or decreases depends on where the frequency sits within the band F_{low} to F_{high} and on *OPTION1*. When *OPTION1* is DEFORM, the maximum increase occurs for natural frequencies close to F_{high}, while the increase for natural frequencies close to F_{low} is typically less than a third of the maximum increase. When *OPTION1* is blank, the reverse situation occurs: maximum decrease of natural frequency occurs for frequencies close to F_{low}, with decreases less than one-third of the maximum occurring for frequencies close to F_{high}. The maximum increase or

reduction can be estimated from the following table, which is applicable to both settings of *OPTION1*.

Table 15-1. Approximate error in natural frequency for a given damping ratio

	% error in frequency for F_{high}/F_{low} =		
Damping Ratio	3 to 30	30 to 300	300 to 3000
0.01	3%	4.5%	6%
0.02	6%	9%	12%
0.04	12%	18%	24%

Modifying the elastic stiffnesses to compensate can workaround the above issue to some extent. For example, for 1% damping across a frequency range of 30 to 600 Hz (F_{high}/F_{low} = 20), the maximum error is 3% while the average error across the frequency range is about 2%. For the DEFORM option, it would therefore be appropriate to reduce the elastic stiffness by $(1.02)^2$, that is, by 4%.

4. **Further information about the DEFORM option.** The DEFORM keyword option works with the following element formulations:

   - Solids – types -1, -2, 1, 2, 3, 4, 9, 10, 13, 15, 16, 17, 99
   - Beams – types 1, 2, 3, 4, 5, 9, 13 (note: not type 6)
   - Shells – types 1-5, 7-17, 20, 21, 23-27, 99
   - Thick shells – all types
   - Discrete elements (see *ELEMENT_DISCRETE)
   - Superelements (see *ELEMENT_DIRECT_MATRIX_INPUT) if *OPTION2* is DMIG

   Table 15-2 lists how the DEFORM option differs from the standard option.

Table 15-2. Comparison of standard damping to deformation damping.

	Keyword Option	
Characteristic Property	<BLANK>	DEFORM
Damping on	Node velocities	Element responses
Rigid body motion	Can be damped	Never damped
Natural frequencies	Reduced (maximum percentages shown in the above table)	Increased (maximum percentages shown in the above table)
Recommended compensation	Increase elastic stiffness	Reduce elastic stiffness

	Keyword Option	
Characteristic Property	<BLANK>	DEFORM
Effect on time step	None	Small reduction applied automatically, the same percentage as in the frequency change
Element types damped	All	See list above
Damping energy output	Included in "system damping energy"	Included in Internal Energy only if RYLEN = 2 on *CONTROL_ENERGY

5. **Iterative method**. Starting with version R10, the internal calculation of the damping constants uses an iterative method by default (see input variable IFLG). This iterative method is available both with and without the DEFORM keyword option. The iterative method results in the actual damping matching the user-input damping ratio CDAMP more closely across the frequency range FLOW to FHIGH. As an example, for CDAMP = 0.01, FLOW = 1 Hz, and FHIGH = 30 Hz, the actual damping achieved by the previous approximate method varied between 0.008 and 0.012 (different values at different frequencies), meaning there were errors of up to 20% of the target CDAMP. The iterative algorithm reduces the errors to 1% of the target CDAMP.

6. **PIDREL**. This is applicable only when *OPTION1* is blank. It is intended to reduce the extent to which rigid body motion is damped (but note that damping of rigid body motion can be avoided completely by using the DEFORM option). PIDREL is the ID of a part with *MAT_RIGID as the material. The part could represent, for example, the foundation or base of a structure. In this case, instead of resisting the global motion of the structure, the damping forces resist motion relative to the base and are reacted onto the rigid part PIDREL. "Relative motion" here means the difference between the velocity of the node being damped and the velocity of a point rigidly connected to PIDREL at the same coordinates as the node being damped.

7. **CDAMPV.** CDAMPV applies only with the DEFORM option and only affects solid elements; see *ELEMENT_SOLID. By default, the same damping ratio CDAMP is applied to all stress components of solid elements. If CDAMPV is nonzero, it affects the volumetric response of solid elements, while CDAMP applies only to the deviatoric response.

8. **Damping of parts with pore pressure.** This remark and the input parameter IPWP are relevant only to models containing *CONTROL_PORE_FLUID. IPWP has no effect unless the damping card references a part containing pore pressure (meaning a part that *BOUNDARY_PORE_FLUID references). The remarks

section of *CONTROL_PORE_FLUID explains the terminology used in this remark. In LS-DYNA versions through R14, *DAMPING_FREQUENCY_RANGE_DEFORM was ineffective when applied to solid elements in models containing pore pressure. Starting from R15, the default is for the damping ratio CDAMP to be applied to both the excess pore pressure and the effective stress. A nonzero CDAMPV affects the excess pore pressure and the effective pressure, while CDAMP applies to the deviatoric response. IPWP set to 2 switches off damping of the pore pressure, leaving only the effective stress subjected to damping.

*DAMPING_GLOBAL

Purpose: Define mass weighted nodal damping that applies globally to the nodes of deformable bodies and to the mass center of the rigid bodies. For specification of mass damping by part ID or part set ID, use *DAMPING_PART_MASS.

Card 1	1	2	3	4	5	6	7	8
Variable	LCID	VALDMP	STX	STY	STZ	SRX	SRY	SRZ
Type	I	F	F	F	F	F	F	F
Default	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Remarks	1		2	2	2	2	2	2

VARIABLE	DESCRIPTION
LCID	Load curve ID (see *DEFINE_CURVE) which specifies the system damping constant vs. time: EQ.0: a constant damping factor as defined by VALDMP is used, GT.0: system damping is given by load curve LCID (which must be an integer). The damping force applied to each node is $f = -d(t)mv$, where $d(t)$ is defined by load curve LCID.
VALDMP	System damping constant, D_s (this option is bypassed if the load curve number defined above is non zero).
STX	Scale factor on global x translational damping forces.
STY	Scale factor on global y translational damping forces.
STZ	Scale factor on global z translational damping forces.
SRX	Scale factor on global x rotational damping moments.
SRY	Scale factor on global y rotational damping moments.
SRZ	Scale factor on global z rotational damping moments.

Remarks:

1. **Restart.** This keyword is also used for the restart, see *RESTART.

2. **Defaults for Scale Factors.** If STX = STY = STZ = SRX = SRY = SRZ = 0.0 in the input above, all six values are defaulted to unity.

3. **Damping Exceptions.** Mass damping will not be applied to deformable nodes with prescribed motion or to nodes tied with CONSTRAINED_NODE_SET.

4. **Formulation.** With mass proportional system damping the acceleration is computed as:

$$\mathbf{a}^n = \mathbf{M}^{-1}\left(\mathbf{P}^n - \mathbf{F}^n - \mathbf{F}^n_{\mathrm{damp}}\right)$$

where, $\mathbf{M}$ is the diagonal mass matrix, $\mathbf{P^n}$ is the external load vector, $\mathbf{F}^n$ is the internal load vector, and $\mathbf{F}^n_{\mathrm{damp}}$ is the force vector due to system damping. This latter vector is defined as:

$$\mathbf{F}^n_{\mathrm{damp}} = D_s m \mathbf{v}$$

The best damping constant for the system is usually some value approaching the critical damping factor for the lowest frequency mode of interest.

$$(D_s)_{\mathrm{critical}} = 2\omega_{\mathrm{min}}$$

The natural frequency ω_{min} (given in radians per unit time) is generally taken as the fundamental frequency of the structure. This frequency can be determined from an eigenvalue analysis or from an undamped transient analysis. Note that this damping applies to both translational and rotational degrees of freedom. Also note that mass proportional damping will damp rigid body motion as well as vibration.

Energy dissipated by through mass weighted damping is reported as system damping energy in the ASCII file glstat. This energy is computed whenever system damping is active.

5. **Filtering.** When global damping is used, IACCOP = 1 is automatically set in *CONTROL_OUTPUT, causing nodal accelerations to be averaged in the nodout and d3thdt files.

DAMPING_PART_MASS_*{OPTION}

OPTION specifies that a part set ID is given with the single option:

<BLANK>

SET

If not used a part ID is assumed.

Purpose: Define mass weighted damping by part ID. Parts may be either rigid or deformable. In rigid bodies the damping forces and moments act at the center of mass. This command may appear multiple times in an input deck but cannot be combined with *DAMPING_GLOBAL.

Card 1	1	2	3	4	5	6	7	8
Variable	PID/PSID	LCID	SF	FLAG				
Type	I	I	F	I				
Default	0	0	1.0	0				

Scale Factor Card. Additional Card for FLAG = 1.

Card 2	1	2	3	4	5	6	7	8
Variable	STX	STY	STZ	SRX	SRY	SRZ		
Type	F	F	F	F	F	F		
Default	0.0	0.0	0.0	0.0	0.0	0.0		

VARIABLE	DESCRIPTION
PID/PSID	Part ID, see *PART or part set ID, see *SET_PART.
LCID	Load curve ID (see *DEFINE_CURVE) which specifies the damping constant vs. time, applied to the part(s) specified in PID/PSID.
SF	Scale factor for load curve. This allows a simple modification of the load curve values.

VARIABLE	DESCRIPTION
FLAG	Set this flag to unity if the global components of the damping forces require separate scale factors.
STX	Scale factor on global x translational damping forces.
STY	Scale factor on global y translational damping forces.
STZ	Scale factor on global z translational damping forces.
SRX	Scale factor on global x rotational damping moments.
SRY	Scale factor on global y rotational damping moments.
SRZ	Scale factor on global z rotational damping moments.

Remarks:

Mass weighted damping damps all motions including rigid body motions. For high frequency oscillatory motion stiffness weighted damping may be preferred. With mass proportional system damping the acceleration is computed as:

$$\boldsymbol{\alpha}^n = \mathbf{M}^{-1}(\mathbf{P}^n - \mathbf{F}^n - \mathbf{F}^n_{\text{damp}})$$

where, $\mathbf{M}$ is the diagonal mass matrix, $\mathbf{P}^n$ is the external load vector, $\mathbf{F}^n$ is the internal load vector, and $\mathbf{F}^n_{\text{damp}}$ is the force vector due to system damping. This latter vector is defined as:

$$\mathbf{F}^n_{\text{damp}} = D_s m \boldsymbol{v}$$

The critical damping constant for the lowest frequency mode of interest is

$$D_s = 2\omega_{\text{min}}$$

where ω_{min} is that lowest frequency in units of radians per unit time. The damping constant specified as the ordinate of curve LCID is typically less than the critical damping constant. The damping is applied to both translational and rotational degrees of freedom. The component scale factors can be used to limit which global components see damping forces.

Energy dissipated by through mass weighted damping is reported as system damping energy in the ASCII file glstat. This energy is computed whenever system damping is active.

Mass damping will not be applied to deformable nodes with prescribed motion or to nodes tied with CONSTRAINED_NODE_SET.

DAMPING_PART_STIFFNESS_*{OPTION}

OPTION specifies that a part set ID is given with the single option:

<BLANK>

SET

If the SET option is not used, a part ID goes in the first field of Card 1.

Purpose: Assign stiffness damping coefficient by part ID or part set ID. This damping command does not apply to parts comprised of discrete elements (*ELEMENT_DISCRETE) or discrete beams (*ELEMENT_BEAM with ELFORM = 6).

Card 1	1	2	3	4	5	6	7	8
Variable	PID/PSID	COEF						
Type	I	F						
Default	none	0.0						

VARIABLE	DESCRIPTION
PID/PSID	Part ID (see *PART) or part set ID (see *SET_PART).
COEF	Rayleigh damping coefficient. Two methods are now available: LT.0.0: Rayleigh damping coefficient in units of time, set based on a given frequency and applied uniformly to each element in the specified part or part set. This method is typically used for implicit dynamic analysis. See remarks below. EQ.0.0: Inactive. GT.0.0: Unitless damping coefficient for stiffness weighted damping. This non-classical method is typically used for explicit analyses as it does not require assembly of a stiffness matrix. Values between 0.01 and 0.25 are recommended. Higher values are strongly discouraged, and values less than 0.01 may have little effect. The damping coefficient is uniquely calculated internally for each element of the part ID.

Remarks:

The damping matrix in classical Rayleigh damping is defined as:

$$\mathbf{C} = \alpha\mathbf{M} + \beta\mathbf{K}$$

where **C**, **M**, and **K** are the damping, mass, and stiffness matrices, respectively. The constants α and β are the mass and stiffness proportional damping constants. The mass proportional damping can be treated by system damping (see keywords *DAMPING_-GLOBAL and *DAMPING_PART_MASS). Transforming **C** with the i^{th} eigenvector $\boldsymbol{\phi}_i$ gives:

$$\boldsymbol{\phi}_i^{\mathrm{T}}\mathbf{C}\boldsymbol{\phi}_i = \boldsymbol{\phi}_i^{\mathrm{T}}(\alpha\mathbf{M} + \beta\mathbf{K})\boldsymbol{\phi}_i = \alpha + \beta\omega_i^2 = 2\omega_i\xi_i\delta_{ij}$$

where ω_i is the i^{th} frequency (radians/unit time) and ξ_i is the corresponding modal damping parameter.

Generally, the stiffness proportional damping is effective for high frequencies and is orthogonal to rigid body motion. Mass proportional damping is more effective for low frequencies and damps rigid body motion. *If a large value of the stiffness-based damping coefficient is used, it may be necessary to lower the time step size significantly.* This must be done manually by reducing the time step scale factor on the *CONTROL_TIMESTEP control card.

The critical stiffness damping coefficient for mode i is equal to 2 divided by ω_i. For example, 10% of critical damping in the i^{th} mode corresponds to

$$\beta = \frac{0.20}{\omega_i}$$

If COEF < 0.0 is input, COEF is -β. For implicit dynamic analysis, classical Rayleigh stiffness damping is performed. For an explicit analysis, a negative COEF is generally impractical because solution stability requires that β be significantly smaller than the explicit time step.

If COEF > 0.0 is input, COEF represents, in only a very approximate sense, a fraction of critical damping in the high-frequency domain. This approach is *not* classical Rayleigh damping and is only recommended for explicit analysis.

The energy dissipated by Rayleigh damping is computed only if the RYLEN on *CONTROL_ENERGY is set to 2. This energy is accumulated as an element's internal energy and is included in the energy balance. In the glstat file this energy will be lumped in with the internal energy.

NOTE: Type 2 beam elements are a special case in which COEF is internally scaled by 0.1. Thus, there is a factor of 10 less damping than stated above. This scaling applies to both negative and positive values of COEF.

DAMPING_PART_STRUCTURAL_*{OPTION}

Available options include:

<BLANK>

SET

Purpose: Assign a structural damping coefficient by part ID or part set ID for frequency domain analysis.

Card 1	1	2	3	4	5	6	7	8
Variable	PID/PSID	G						
Type	I	F						
Default	0	0.0						

VARIABLE	DESCRIPTION
PID/PSID	Part ID (see *PART) with no keyword option or part set ID (see *SET_PART) with the SET keyword option
G	Constant structural damping coefficient

Remarks:

1. **Damping force.** The structural damping force F_j (for part or par set j) is calculated as follows:

$$F_j = iG_jK_ju_j$$

where i is the imaginary unit, G_j is structural damping coefficient for part or part set j, K_j is stiffness matrix for part or part set j, and u_j is nodal displacements for part or part set j. The damping force F_j and the nodal displacements u_j are both complex variables.

*DAMPING_RELATIVE

Purpose: Apply damping relative to the motion of a rigid body. For example, it could damp the deformation of a rotating tire relative to the wheel without damping the rotating motion.

Card 1	1	2	3	4	5	6	7	8
Variable	CDAMP	FREQ	PIDRB	PSID	DV2	LCID		
Type	F	F	F	I	F	I		
Default	0	0	0	0	0.0	0		

VARIABLE	DESCRIPTION
CDAMP	Fraction of critical damping.
FREQ	Frequency at which CDAMP is to apply (cycles per unit time; for example, Hz if time unit is seconds).
PIDRB	Part ID of rigid body; see *PART. Motion relative to this rigid body will be damped.
PSID	Part set ID. The requested damping is applied only to the parts in the set.
DV2	Optional constant for velocity-squared term. See Remark 3.
LCID	ID of curve that defines fraction of critical damping as a function of time. CDAMP will be ignored if LCID is non-zero.

Remarks:

1. **Model Description.** This feature provides damping of vibrations for objects that are moving through space. The vibrations are damped, but not the rigid body motion. This is achieved by calculating the velocity of each node relative to that of a rigid body, and applying a damping force proportional to that velocity. The forces are reacted onto the rigid body such that overall momentum is conserved. It is intended that the rigid body is embedded within the moving object.

2. **Damping.** Vibrations at frequencies below FREQ are damped by more than CDAMP, while those at frequencies above FREQ are damped by less than CDAMP. It is recommended that FREQ be set to the frequency of the lowest mode of vibration.

3. **Damping Force.** The damping force of each node is calculated as follows:

$$F = -(Dmv) - \left(\mathrm{DV2} \times mv^2\right),$$

where $D = 4\pi \times \mathrm{CDAMP} \times \mathrm{FREQ}$, m is the mass of the node, and v is the velocity of the node relative to the velocity of a point on the rigid body at the same coordinates as the node.

*DAMPING_STRUCTURAL

Purpose: Define structural damping coefficients to be used in frequency domain analysis.

Card 1	1	2	3	4	5	6	7	8
Variable	G	LCID	LCTYP					
Type	F	I	I					
Default	0.0	0	0					

VARIABLE	DESCRIPTION
G	Constant structural damping coefficient.
LCID	Curve ID to define frequency dependent structural damping coefficients.
LCTYP	Type of load curve defining structural damping coefficients: EQ.0: abscissa value defines frequency. EQ.1: abscissa value defines mode number.

Remarks:

1. **Damping Force.** The structural damping force F is calculated as follows:

$$F = iGKu$$

where i is imaginary unit, G is structural damping coefficient, K is global stiffness matrix, and u is nodal displacements. The damping force F and the nodal displacements u are both complex variables.