*LOAD

The keyword *LOAD provides a way of defining applied forces. The keyword control cards in this section are defined in alphabetical order:

*LOAD_ACOUSTIC_SOURCE

*LOAD_ALE_CONVECTION

LOAD_BEAM_*OPTION

*LOAD_BLAST

*LOAD_BLAST_CLEARING

*LOAD_BLAST_ENHANCED

*LOAD_BLAST_SEGMENT

*LOAD_BLAST_SEGMENT_SET

LOAD_BODY_*OPTION

LOAD_BODY_GENERALIZED_*OPTION

*LOAD_BODY_POROUS

*LOAD_BRODE

*LOAD_DENSITY_DEPTH

LOAD_EDGE_UVW_*{OPTION}

*LOAD_ERODING_PART_SET

*LOAD_EXPANSION_PRESSURE

*LOAD_EXTERNAL_VARIABLE

LOAD_FACE_UVW_*{OPTION}

LOAD_FACE_XYZ_*{OPTION}

*LOAD_GRAVITY_PART

*LOAD_HEAT_CONTROLLER

*LOAD_HEAT_EXOTHERMIC_REACTION

LOAD_HEAT_GENERATION_*OPTION

*LOAD_MASK

*LOAD_MOTION_NODE

*LOAD_MOVING_PRESSURE

LOAD_NODE_*OPTION

*LOAD_NURBS_SHELL

LOAD_POINT_UVW_*{OPTION}

*LOAD_PYRO_ACTUATOR

*LOAD_PZE

*LOAD_REMOVE_PART

*LOAD_RIGID_BODY

*LOAD_SEGMENT

*LOAD_SEGMENT_ALE_INI

*LOAD_SEGMENT_CONTACT_MASK

*LOAD_SEGMENT_FILE

*LOAD_SEGMENT_FSILINK

*LOAD_SEGMENT_NONUNIFORM

*LOAD_SEGMENT_SET

*LOAD_SEGMENT_SET_ANGLE

*LOAD_SEGMENT_SET_NONUNIFORM

LOAD_SEISMIC_SSI_*OPTION1_{OPTION2}

LOAD_SEISMIC_SSI_AUX_*{OPTION}

LOAD_SHELL_*OPTION1_{OPTION2}

*LOAD_SPCFORC

*LOAD_SSA

*LOAD_STEADY_STATE_ROLLING

*LOAD_STIFFEN_PART

*LOAD_SUPERPLASTIC_FORMING

LOAD_SURFACE_STRESS_*{OPTION}

*LOAD_THERMAL_BINOUT

*LOAD_THERMAL_CONSTANT

*LOAD_THERMAL_CONSTANT_ELEMENT

*LOAD_THERMAL_CONSTANT_NODE

*LOAD_THERMAL_D3PLOT

*LOAD_THERMAL_LOAD_CURVE

*LOAD_THERMAL_RSW

*LOAD_THERMAL_TOPAZ

*LOAD_THERMAL_VARIABLE

*LOAD_THERMAL_VARIABLE_BEAM

LOAD_THERMAL_VARIABLE_ELEMENT_*OPTION

*LOAD_THERMAL_VARIABLE_NODE

*LOAD_THERMAL_VARIABLE_SHELL

*LOAD_VOLUME_LOSS

*LOAD_ACOUSTIC_SOURCE

Purpose: Specify acoustic loading sources for *CONTROL_IMPLICIT_SSD_DIRECT and *CONTROL_ACOUSTIC_SPECTRAL analyses.

Card 1	1	2	3	4	5	6	7	8
Variable	NID/SSID	SRCTYP	LCID	DATA1	DATA2	DATA3	DATA4	DATA5
Type	I	I	I	F	F	F	F	F
Default	none	↓	0	1.0	0.0	0.0	0.0	0.0

VARIABLE	DESCRIPTION
NID	Node ID of the acoustic point source for SRCTYP = 1 and 5
SSID	Segment set ID of structural faces on the external fluid-structure boundary exposed to the acoustic wave source for SRCTYP = 11 and 12
SRCTYP	Acoustic source type: EQ.1: Harmonic nodal point source. DATA1, DATA2, and LCID define the harmonic nodal source strength $\dot{Q}$, the phase angle of the nodal source strength and frequency variation for a point source at node NID. EQ.5: Transient nodal point source. DATA1 and LCID define the transient nodal source strength ($\dot{Q}$) and temporal variation for a point source at node NID. EQ.11: Harmonic plane wave: DATA1 and LCID define the magnitude and frequency variation for a harmonic plane wave with direction cosines given in DATA2, DATA3, and DATA4. SSID is the segment set ID of the external structural (coupled) surface. EQ.12: Harmonic spherical wave. DATA1, DATA5, and LCID define the magnitude, reference radius and frequency variation for a harmonic spherical wave centered at coordinates x_0, y_0, and z_0 specified with DATA2, DATA3, and DATA4. SSID is the segment set ID of the external structural (coupled) surface.

VARIABLE	DESCRIPTION
LCID	Load curve ID of curve specifying the variation of the load with frequency or time. If LCID is undefined, then the loading is constant.
DATA1	SRCTYP.EQ.1: Magnitude of the harmonic nodal source strength, $\dot{Q}$ SRCTYP.EQ.5: Magnitude of the transient nodal source strength, $\dot{Q}$ SRCTYP.EQ.11: Pressure of the harmonic plane wave, P_0 SRCTYP.EQ.12: Pressure of the harmonic spherical wave, P_0, at r_0
DATA2	SRCTYP.EQ.1: Phase angle of the nodal source strength in radians SRCTYP.EQ.11: Direction cosine, α SRCTYP.EQ.12: x coordinate of center of spherical wave, x_0
DATA3	SRCTYP.EQ.11: Direction cosine, β SRCTYP.EQ.12: y coordinate of center of spherical wave, y_0
DATA4	SRCTYP.EQ.11: Direction cosine, γ SRCTYP.EQ.12: z coordinate of center of spherical wave, z_0
DATA5	For SRCTYP = 12, reference radius, r_0, where the pressure equals p_0

Remarks:

1. **Source strength.** $\dot{Q}$ has dimensions of area times acceleration. In steady state analysis, it is related to Q_0 through

$$\dot{Q} = \omega Q_0 e^{i\left(\omega t+\frac{\pi}{2}\right)}$$

2. **External, incident wave solutions.** With SRCTYP = 11 or 12, the SSD solution in the acoustic domain is for the scattered pressure.

3. **Incident pressure and particle velocity.** For direct, steady state vibration acoustic scattering invoked with *CONTROL_IMPLICIT_SSD_DIRECT, the incident pressure and particle velocity applied depend on the source type.

a) For plane waves (SRCTYP = 11), they are given by:

$$P_{\mathrm{inc}} = P_0 e^{-ik(\alpha x+\beta y+\gamma z)}$$
$$U_{\mathrm{inc}} = \frac{P_0}{\rho_0 c_0} e^{-ik(\alpha x+\beta y+\gamma z)}$$

b) For spherical waves (SRCTYP = 12), they are given by:

$$P_{\mathrm{inc}} = \frac{P_0 r_0}{r} e^{-ik(r-r_0)}$$
$$U_{\mathrm{inc}} = \frac{P_0}{\rho_0 c_0}\left(\frac{r_0}{r}\right)\left(\frac{kr-i}{kr}\right) e^{-ik(r-r_0)}$$

LOAD_ALE_CONVECTION_*{OPTION}

Purpose: Define the convection thermal energy transfer from a hot ALE fluid to the surrounding Lagrangian structure (Remark 1). It is associated with a corresponding coupling card defining the interaction between the ALE fluid and the Lagrangian structure. It is only used when thermal energy transfer from the ALE fluid to the surrounding Lagrangian structure is significant. This is designed specifically for airbag deployment applications where the heat transfer from the inflator gas to the inflator compartment can significantly affect the inflation potential of the inflator.

Available options include:

<BLANK>

ID

To define an ID number for each convection heat transfer computation in an optional card preceding all other cards for this command. This ID number can be used to output the part temperature and temperature change as functions of time in the *DATABASE_FSI card. To do this, set CONVID in *DATABASE_FSI equal to this ID.

ID Card. Additional card for ID keyword option.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	TITLE						
Type	I	A70						
Default	none	none						

Convection Card. Include as many cards as necessary. This input terminates at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	LAGPID	LAGT	LAGCP	H	LAGMAS			
Type	I	F	F	F	F			
Default	none	none	none	none	none			

VARIABLE	DESCRIPTION
ID	ID number for each convection heat transfer computation
TITLE	A description of this convection heat transfer
LAGPID	Lagrangian structure PID from a corresponding coupling card which receives the thermal energy in the convection heat transfer
LAGT	Initial temperature of this Lagrangian structure part
LAGCP	Constant-pressure heat capacity of this Lagrangian structure part. It has a per-mass unit (for example, J/[kg*K]).
H	Convection heat transfer coefficient on this Lagrangian structure part surface. It is the amount of energy (J) transferred per unit area, per time, and per temperature difference. For example, its units may be J/[m^2*s*K].
LAGMAS	The mass of the Lagrangian structure part receiving the thermal energy. This is in absolute mass unit (for example, kg).

Remarks:

1. **Applications.** The only application of this card so far has been for the transfer of thermal energy from the ALE hot inflator gas to the surrounding Lagrangian structure (inflator canister and airbag-containing compartment) in an airbag deployment model.

2. **Model.** The heat transferred is taken out of the inflator gas thermal energy thus reducing its inflating potential. This is not a precise heat transfer modeling attempt. It is simply one mechanism for taking out excessive energy from the inflating potential of the hot inflator gas.

   The heat transfer formulation may roughly be represented as the following equation. Some representative units are shown just for clarity.

$$[\dot{Q}] = [\mathrm{H} \times A \times \Delta T] = \left(\frac{[\mathrm{E}]}{[L]^2[\mathrm{t}][\mathrm{T}]}\right) \times [\mathrm{L}]^2 \times [\mathrm{T}] = [\mathrm{Power}]$$

$$[\dot{Q}] = \left[\dot{M}C_p\left(T_{\mathrm{Lag\ New}} - T_{\mathrm{Lag\ Orig}}\right)\right] = \left(\frac{[\mathrm{M}]}{[t]}\right) \times \left(\frac{[\mathrm{E}]}{[\mathrm{M}][\mathrm{T}]}\right) \times [\mathrm{T}] = \frac{[\mathrm{E}]}{[\mathrm{t}]}$$

LOAD_BEAM_*OPTION

Available options include:

ELEMENT

SET

Purpose: Apply the distributed traction load along any local axis of a beam or a set of beams. The local axes are defined in Figure 33-1; see also *ELEMENT_BEAM.

Beam Cards. Include as many as necessary. This input stops at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	EID/ESID	DAL	LCID	SF				
Type	I	I	I	F				
Default	none	none	none	1.				

VARIABLE	DESCRIPTION
EID/ESID	Beam ID (EID) or beam set ID (ESID), see *ELEMENT_BEAM or *SET_BEAM.

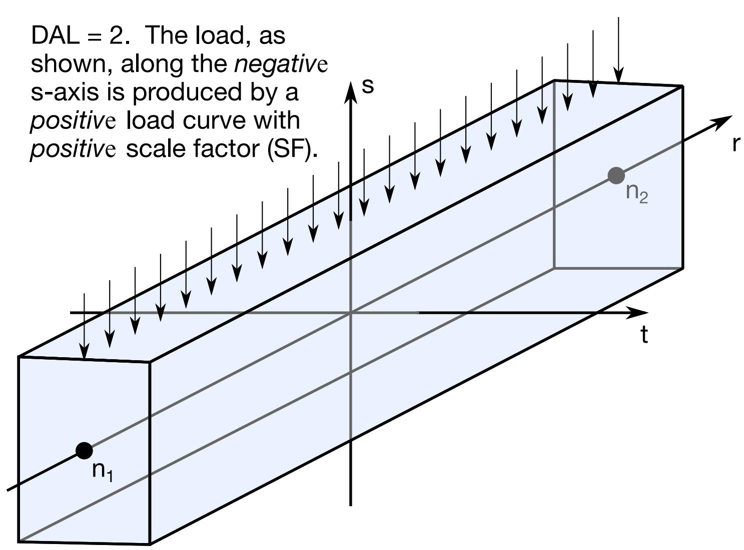

Figure 33-1. Applied traction loads are given in force per unit length. The *s* and *t*-directions are defined on the *ELEMENT_BEAM keyword.

VARIABLE	DESCRIPTION
DAL	Direction of applied load: EQ.1: parallel to r-axis of beam, EQ.2: parallel to s-axis of beam, EQ.3: parallel to t-axis of beam, EQ.4: parallel to global X-axis, EQ.5: parallel to global Y-axis, EQ.6: parallel to global Z-axis.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). See Remark 1.
SF	Load curve scale factor. This is for a simple modification of the function values of the load curve.

Remark:

1. **LCID Function Arguments.** The function defined by LCID has 7 arguments: time, the 3 current coordinates, and the 3 reference coordinates. For example, the function (see *DEFINE_FUNCTION),

   f(t,x,y,z,x0,y0,z0)= -10.*sqrt ((x-x0)*(x-x0)+(y-y0)*(y-y0)+(z-z0)*(z-z0)),

   applies a force proportional to the distance from the initial coordinates.

*LOAD_BLAST

Purpose: Define an air blast function for the application of pressure loads from the detonation of conventional explosives. The implementation is based on a report by Randers-Pehrson and Bannister [1997] where it is mentioned that this model is adequate for use in engineering studies of vehicle responses due to the blast from land mines. This option determines the pressure values when used in conjunction with the keywords: *LOAD_SEGMENT, *LOAD_SEGMENT_SET, or *LOAD_SHELL.

Card 1	1	2	3	4	5	6	7	8
Variable	WGT	XBO	YBO	ZBO	TBO	IUNIT	ISURF	
Type	F	F	F	F	F	I	I	
Default	none	0.0	0.0	0.0	0.0	2	2	

Card 2	1	2	3	4	5	6	7	8
Variable	CFM	CFL	CFT	CFP	DEATH			
Type	F	F	F	F	F			
Default	0.0	0.0	0.0	0.0	0.0			

VARIABLE	DESCRIPTION
WGT	Equivalent mass of TNT.
XBO	x-coordinate of point of explosion.
YBO	y-coordinate of point of explosion.
ZBO	z-coordinate of point of explosion.
TBO	Time-zero of explosion.
IUNIT	Unit conversion flag. EQ.1: feet, pound-mass, seconds, psi EQ.2: meters, kilograms, seconds, pascals (default)

VARIABLE	DESCRIPTION
	EQ.3: inch, dozens of slugs, seconds, psi EQ.4: centimeters, grams, microseconds, megabars EQ.5: user conversions will be supplied (see Card 2)
ISURF	Type of burst. See Remark 2. EQ.1: surface burst. The blast is located on or very near the ground, which is modeled as a surface. See Remark 5. EQ.2: air burst. The blast is spherical (default).
CFM	Conversion factor: pounds per LS-DYNA mass unit.
CFL	Conversion factor: feet per LS-DYNA length units.
CFT	Conversion factor: milliseconds per LS-DYNA time unit.
CFP	Conversion factor: psi per LS-DYNA pressure unit
DEATH	Death time. Blast pressures are deactivated at this time.

Remarks:

1. **Load Curves.** A minimum of two load curves, even if unreferenced, must be present in the model. Even though this keyword does not use load curves, unless there are at least two *DEFINE_CURVE cards LS-DYNA will error terminate with *LOAD_BLAST. Note that one of the enhancements of *LOAD_BLAST_ENHANCED is that it does not require two (place holding) load curves.

2. **Orientation.** The target's segments must be consistently oriented so that the normal vector of the portion of the target having a direct line of sight to the blast points roughly towards the blast. For example, segments defining a structure being blasted from the outside should have outwardly oriented normal vectors, whereas a cavity containing a blast should have inwardly facing normal vectors.

3. **Equivalent Mass of TNT.** Several methods can be used to approximate the equivalent mass of TNT for a given explosive. The simplest involves scaling the mass by the ratio of the Chapman-Jouguet detonation velocities given the by:

$$M_{\mathrm{TNT}} = M_{\mathrm{e}} \frac{v_{\mathrm{e}}^2}{v_{\mathrm{TNT}}^2}$$

where M_{TNT} is the equivalent TNT mass and v_{TNT} is the Chapman-Jouguet (CJ) detonation velocity of TNT. M_{e} and v_{e} are, respectively, the mass and CJ velocity of the explosive under consideration. LS-DYNA takes the density of "Standard" TNT to be 1.57 $\frac{\text{g}}{\text{cm}^3}$ and v_{TNT} to be 0.693 $\frac{\text{cm}}{\mu\text{s}}$.

4. **Limits of Model's Validity.** Define a scaled distance, Z, as follows:

$$Z = \frac{R}{M_e^{1/3}}$$

where R is the distance from the charge center to the target and M_e is the equivalent TNT mass (see Remark 3). The scaled distance determines the range of validity for these models. The spherical airburst model is valid for Z ranging from 0.37 ft/lbm$^{1/3}$ (0.147 m/kg$^{1/3}$) out to 100 ft/lb-m$^{1/3}$ (40 m/kg$^{1/3}$). The hemispherical surface burst is valid for Z ranging from 0.45 ft/lbm$^{1/3}$ (0.178 m/kg$^{1/3}$) out to 100 ft/lbm$^{1/3}$ (40 m/kg$^{1/3}$).

5. **Surface Burst Model.** The surface blast model is ideal for when a charge is located on or very near the ground. In this case the initial blast wave is immediately reflected and reinforced by the nearly rigid ground (the model accounts for yielding) to produce a hemispherical reflected wave from the point of the burst. This reflected wave merges with the initial incident wave producing overpressures which are greater than those produced by the initial wave alone. Target points equidistant from the burst point are loaded identically with the surface burst option.

6. **Single Charge Limitation.** This feature cannot model multiple blasts in one simulation. Use *LOAD_BLAST_ENHANCED for multiple charges.

7. **2D Analysis.** This feature cannot be used for 2D analysis. Instead, use *LOAD_-BLAST_ENHANCED.

*LOAD_BLAST_CLEARING

Purpose: Define a surface to be cleared by a rarefaction wave that arises from the diffraction of a blast wave around the free edges of a target face. This feature works only with *LOAD_BLAST_ENHANCED. The implementation is based on a report by Hudson [1955].

Card 1	1	2	3	4	5	6	7	8
Variable	BID							
Type	I							
Default	none							

Card 2	1	2	3	4	5	6	7	8
Variable	N1	N2	N3	N4				
Type	I	I	I	I				
Default	none	none	none	none				

VARIABLE	DESCRIPTION
BID	Blast source ID (see *LOAD_BLAST_ENHANCED)
N1 - N4	Node IDs of the corners of the surface

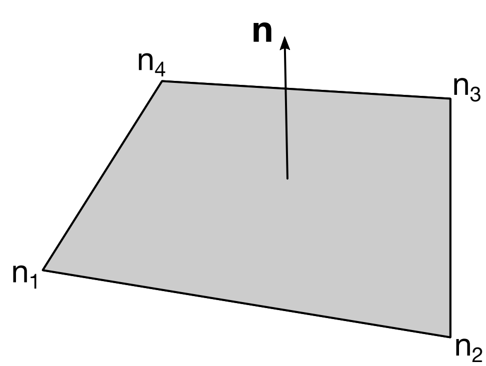

Figure 33-2. Nodal numbering for a cleared surface. Normal vector, **n**, roughly points toward the blast origin.

Remarks:

1. **Orientation.** The normal vector for the clear surface must roughly point toward the blast origin. The node numbering and normal convention are specified in Figure 33-2.

*LOAD_BLAST_ENHANCED

Purpose: Define an air blast function for the application of pressure loads due the detonation of a conventional explosive. While similar to *LOAD_BLAST, this feature includes enhancements for treating ground-reflected waves, moving warheads and multiple blast sources. The loads are applied to facets defined with the keyword *LOAD_BLAST_SEGMENT. A database containing blast pressure history is also available (see *DATABASE_BINARY_BLSTFOR).

Card Summary:

Card Sets. Include as many sets of the following cards as necessary. This input terminates at the next keyword ("*") card.

Card 1. This card is required.

BID	M	XBO	YBO	ZBO	TBO	UNIT	BLAST

Card 2. This card is required.

CFM	CFL	CFT	CFP	NIDBO	DEATH	NEGPHS	

Card 3a. This card is included if BLAST = 3.

VEL	TEMP	RATIO	VID				

Card 3b. This card is included if BLAST = 4.

GNID	GVID				FLOOR		

Data Card Definitions:

Card 1	1	2	3	4	5	6	7	8
Variable	BID	M	XBO	YBO	ZBO	TBO	UNIT	BLAST
Type	I	F	F	F	F	F	I	I
Default	none	0.0	0.0	0.0	0.0	0.0	2	2

VARIABLE	DESCRIPTION
BID	Blast ID. A unique number must be defined for each blast source (charge). Multiple charges may be defined, however, interaction of the waves in air is not considered. LT.-2: Blast ID that can be referenced by LCID in *LOAD_-ERODING_PART_SET, allowing the pressure from the blast to be used by *LOAD_ERODING_PART_SET.
M	Equivalent mass of TNT (see Remark 1).
XBO	x-coordinate of charge center.
YBO	y-coordinate of charge center.
ZBO	z-coordinate of charge center.
TBO	Time of detonation. See Remark 3.
UNIT	Unit conversion flag. See Remark 4. EQ.1: pound-mass, foot, second, psi EQ.2: kilogram, meter, second, Pascal (default) EQ.3: dozen slugs (i.e., lbf-s2/in), inch, second, psi EQ.4: centimeters, grams, microseconds, Megabars EQ.5: user conversions will be supplied (see Card 2) EQ.6: kilogram, millimeter, millisecond, GPa EQ.7: metric ton, millimeter, second, MPa EQ.8: gram, millimeter, millisecond, MPa
BLAST	Type of blast source (see Remark 5). EQ.1: Hemispherical surface burst – charge is located on or very near the ground surface (see Remark 7) EQ.2: Spherical air burst (default) – no amplification of the initial shock wave due to interaction with the ground surface EQ.3: Air burst – moving non-spherical warhead EQ.4: Air burst with ground reflection – initial shock wave impinges on the ground surface and is reinforced by the reflected wave to produce a Mach front. See Remark 8.

Card 2	1	2	3	4	5	6	7	8
Variable	CFM	CFL	CFT	CFP	NIDBO	DEATH	NEGPHS	
Type	F	F	F	F	I	F	I	
Default	0.0	0.0	0.0	0.0	none	10^{20}	0	

VARIABLE	DESCRIPTION
CFM	Conversion factor - pounds per LS-DYNA mass unit.
CFL	Conversion factor - feet per LS-DYNA length units.
CFT	Conversion factor - milliseconds per LS-DYNA time unit.
CFP	Conversion factor - psi per LS-DYNA pressure unit.
NIDBO	Optional node ID representing the charge center. If nonzero, XBO, YBO, and ZBO are ignored.
DEATH	Death time. Blast pressures are deactivated at this time.
NEGPHS	Treatment of negative phase pressure and positive phase duration (see Remark 9): EQ.0: Negative phase dictated by the Friedlander equation EQ.1: Negative phase pressure ignored EQ.10: Positive phase duration in closer agreement with Con-Wep results (not recommended). EQ.11: Positive phase duration in closer agreement with Con-Wep results and negative phase pressure ignored (recommended for comparisons with ConWep).

Moving Non-Spherical Warhead Card. Additional Card for BLAST = 3.

Card 3a	1	2	3	4	5	6	7	8
Variable	VEL	TEMP	RATIO	VID				
Type	F	F	F	F				
Default	0.0	70.0	1.0	none				

VARIABLE	DESCRIPTION
VEL	Speed of warhead
TEMP	Ambient air temperature, Fahrenheit
RATIO	Aspect ratio of the non- spheroidal blast front. This is the longitudinal axis radius divided by the lateral axis radius. Shaped charge and EFP warheads typically have significant lateral blast resembling an oblate spheroid with RATIO < 1. Cylindrically cased explosives produce more blast in the longitudinal direction, so RATIO > 1, rendering a prolate spheroid blast front, is more appropriate.
VID	Vector ID representing the longitudinal axis of the warhead (see *DEFINE_VECTOR). This vector is parallel to the velocity vector when a non-zero velocity VEL is defined.

Spherical Air Burst with Ground Reflection Card. Additional card for BLAST = 4.

Card 3b	1	2	3	4	5	6	7	8
Variable	GNID	GVID				FLOOR		
Type	I	I				I		
Default	none	none				0		

VARIABLE	DESCRIPTION
GNID	ID of node residing on the ground surface

VARIABLE	DESCRIPTION
GVID	ID of vector representing the vertically upward direction, that is, normal to the ground surface (see *DEFINE_VECTOR).
FLOOR	Treatment subterranean segments. EQ.0: Subterranean segments are not affected by the blast. EQ.1: Blast pressure is applied to segments residing below the ground plane. The pressure is computed for the ground plane location regardless of the segment's depth below the plane.

Remarks:

1. **Equivalent Mass of TNT.** Several methods can be used to approximate the equivalent mass of TNT for a given explosive. The simplest involves scaling the mass by the ratio of the Chapman-Jouguet detonation velocities given by:

$$M_{\mathrm{TNT}} = M_e \frac{v_e^2}{v_{\mathrm{TNT}}^2}$$

where M_{TNT} is the equivalent TNT mass and v_{TNT} is the Chapman-Jouguet (CJ) detonation velocity of TNT. M_e and v_e are, respectively, the mass and CJ velocity of the explosive under consideration. LS-DYNA takes the density of "Standard" TNT to be $1.57\ \mathrm{g/cm^3}$ and v_{TNT} to be $0.693\ \mathrm{cm}/\mu\mathrm{s}$.

2. **Orientation.** The target's segments must be consistently oriented so that the normal vector of the portion of the target having a direct line of sight to the blast points roughly towards the blast, unless pressure is to be applied to the leeward side of a structure. For example, segments defining a structure being blasted from the outside should have outwardly oriented normal vectors, whereas a cavity containing a blast should have inwardly facing normal vectors. The angle of incidence is zero when the segment normal points directly at the charge. Only incident pressure is applied to a segment when the angle of incidence is greater than 90 degrees.

3. **Detonation Time.** The blast time offset TBO can be used to adjust the detonation time of the charge relative to the start time of the LS-DYNA simulation. The detonation time is delayed when TBO is positive. More commonly, TBO is set negative so that the detonation occurs before time-zero of the LS-DYNA calculation. Time is, therefore, not wasted while "waiting" for the blast wave to reach the structure. The following message, written to the messag and d3hsp files as well as the screen, is useful for setting TBO:

```
Blast wave reaches structure at 2.7832E-01 milliseconds
```

For example, one might run LS-DYNA for one integration cycle and record the arrival time listed in the message above. Then TBO is set to a negative number slightly smaller in magnitude than the reported arrival time, for example TBO = -0.275 milliseconds. For this case, the blast wave would reach the structure shortly after the start of the simulation.

4. **Units.** Computation of blast pressure relies on an underlying method which uses base units of lbm-foot-millisecond-psi; note that this internal unit system is inconsistent. Calculations require that the system of units in which the LS-DYNA model is constructed must be converted to this internal set of units. Predefined and user-defined unit conversion factors are available (see the parameter UNIT) and these unit conversion factors are echoed back in the d3hsp file. Below is an example of user-defined (UNIT = 5) conversion factors for the gm-mm-millisecond-MPa unit system.

$$1 = \left[\frac{\text{CFM} \times \text{lb}}{\text{LS-DYNA mass unit}}\right] = \left[\underbrace{2.2 \times 10^{-3}}_{=\text{CFM}} \frac{\text{lbm}}{\text{gm}}\right]$$

$$1 = \left[\frac{\text{CFL} \times \text{ft}}{\text{LS-DYNA length unit}}\right] = \left[3.28 \times 10^{-3} \frac{\text{ft}}{\text{mm}}\right]$$

$$1 = \left[\frac{\text{CFT} \times \text{ms}}{\text{LS-DYNA time unit}}\right] = \left[1.0 \frac{\text{ms}}{\text{ms}}\right]$$

$$1 = \left[\frac{\text{CFP} \times \text{psi}}{\text{LS-DYNA pressure unit}}\right] = \left[145.0 \frac{\text{psi}}{\text{MPa}}\right]$$

5. **Limits of Model's Validity.** Define a scaled distance, Z, as follows:

$$Z = \frac{R}{M_{\text{TNT}}^{1/3}} \;,$$

where R is the distance from the charge center to the target and M_{TNT} is the equivalent TNT mass (see Remark 1). The scaled distance determines the range of validity for these models. The spherical airburst model is valid for Z ranging from 0.37 ft/lbm$^{1/3}$ (0.147 m/kg$^{1/3}$) out to 100 ft/lbm$^{1/3}$ (40 m/kg$^{1/3}$). The hemispherical surface burst is valid for Z ranging from 0.45 ft/lbm$^{1/3}$ (0.178 m/kg$^{1/3}$) out to 100 ft/lbm$^{1/3}$ (40 m/kg$^{1/3}$).

For the spherical air burst with ground reflection (BLAST = 4), the same scaled distance can be used to determine validity, except R is now the height of the charge center above the ground. This model is valid for Z ranging from 1.0 ft/lbm$^{1/3}$ (0.397 m/kg$^{1/3}$) out to 7.0 ft/lbm$^{1/3}$ (2.78 m/kg$^{1/3}$)

6. **Axisymmetric Analyses.** Blast loads can be used in 2D axisymmetric analyses. Repeat the second node for the third and fourth nodes of the segment definition in *LOAD_BLAST_SEGMENT and *LOAD_BLAST_SEGMENT_SET.

7. **Surface Burst Model.** The surface blast model is ideal for when a charge is located on or very near the ground. In this case the initial blast wave is

immediately reflected and reinforced by the nearly rigid ground (the model accounts for yielding) to produce a hemispherical reflected wave from the point of the burst. This reflected wave merges with the initial incident wave producing overpressures which are greater than those produced by the initial wave alone. Target points equidistant from the burst point are loaded identically with the surface burst option.

8. **BLSTFOR Components.** The BLSTFOR file (see *DATABASE_BINARY_BLSTFOR) contains blast pressures, blast wind velocity, air density, and wave index. The “wave index”, relevant only for BLAST = 4, denotes the nature of the blast pressure applied to the segment, such that,

   EQ.-1: below the ground plane

   EQ.0: no blast pressure

   EQ.1: primary incident wave

   EQ.2: detached ground-reflected wave

   EQ.3: Mach stem region

9. **ConWep.** ConWep is neither embedded in nor coupled with LS-DYNA. The *LOAD_BLAST_ENHANCED feature is based on the work of Randers-Pehrson and Bannister. NEGPHS = 11 gives positive phase duration in close agreement with ConWep, and it zeroes out the negative phase pressure, as in ConWep. NEGPHS = 10 should not be used for analysis because it presents a significant negative phase pressure; it is included only to illustrate this unwanted effect. *LOAD_BLAST_ENHANCED combines incident and reflected pressure according to the work of Randers-Pehrson and Bannister while ConWep computes reflected pressure in a different manner.

10. **Internally Used Values for Ambient Air Pressure and Density.** The following values for ambient air pressure and density are used internally:

$$p = 101.325\ \text{kPa}$$
$$\rho = 1.225\ \text{kg/m}^3$$

These values come into play only when the blast load is coupled to ALE air (see ALEPID in LOAD_BLAST_SEGMENT). Accordingly, the initial density of the air should be set (in *MAT) as well as pressure (through *EOS). Those values should reflect the unit system selected with UNIT in *LOAD_BLAST_ENHANCED.

*LOAD_BLAST_SEGMENT

Purpose: Apply blast pressure loading over a triangular or quadrilateral segment for 3D geometry or line segment for 2D geometry (see *LOAD_BLAST_ENHANCED).

Segment Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	BID	N1	N2	N3	N4	ALEPID	SFNRB	SCALEP
Type	I	I	I	I	I	I	F	F
Default	none	none	none	none	none	none	0.	1.

VARIABLE	DESCRIPTION
BID	Blast source ID (see *LOAD_BLAST_ENHANCED).
N1	Node ID.
N2	Node ID.
N3	Node ID. For line segments on two-dimensional geometries set N3 = N2.
N4	Node ID. For line segments on two-dimensional geometries set N4 = N3 = N2 or for triangular segments in three diemensions set N4 = N3.
ALEPID	Part ID of ALE ambient part underlying this segment to be loaded by this blast (see *PART and *SECTION_SOLID, AET = 5). This applies only when the blast load is coupled to an ALE air domain.
SFNRB	Scale factor for the ambient element non-reflecting boundary condition. Shocks waves reflected back to the ambient elements can be attenuated with this feature. A value of 1.0 works well for most situations. The feature is disabled when a value of zero is specified
SCALEP	Pressure scale factor.

*LOAD_BLAST_SEGMENT_SET

Purpose: Apply blast pressure loading over each segment in a segment set (see *LOAD_-BLAST_ENHANCED).

Segment Set Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	BID	SSID	ALEPID	SFNRB	SCALEP			
Type	I	I	I	F	F			
Default	none	none	↓	0.	1.			

VARIABLE	DESCRIPTION
BID	Blast source ID (see *LOAD_BLAST_ENHANCED).
SSID	Segment set ID (see *SET_SEGMENT).
ALEPID	Part ID of ALE ambient part underlying this segment to be loaded by this blast (see *PART and *SECTION_SOLID, AET = 5). This applies *only* when the blast load is coupled to an ALE air domain.
SFNRB	Scale factor for the ambient element non-reflecting boundary condition. Shocks waves reflected back to the ambient elements can be attenuated with this feature. A value of 1.0 works well for most situations.
SCALEP	Pressure scale factor.

Remarks:

1. **Triangular Segments.** Triangular segments are defined by setting N4 = N3.

2. **Line Segments.** Line segments for two-dimensional geometries are defined by setting N4 = N3 = N2.

LOAD_BODY_*OPTION

Available options include for base accelerations:

X

Y

Z

for angular velocities:

RX

RY

RZ

for loading in any direction, specified by vector components (see About Keyword Option VECTOR):

VECTOR

and to specify a part set:

PARTS

Purpose: Define body force loads due to a prescribed base acceleration or angular velocity using global axes directions. This option applies nodal forces only: it cannot be used to prescribe translational or rotational motion. By default, these body forces do not take into account non-physical mass added via mass scaling, see DT2MS on *CONTROL_-TIMESTEP. However, if in addition EMSCL > 0 on *CONTROL_TIMESTEP, then EMSCL ×100% of the added mass contributes to the gravity load.

> **NOTE:** This data applies to all nodes in the complete problem unless a part subset is specified via the *LOAD_-BODY_PARTS keyword.

If a part subset with *LOAD_BODY_PARTS, then all nodal points belonging to the subset will have body forces applied.

> **NOTE:** Only one *LOAD_BODY_PARTS card is permitted per deck. To specify, for instance, one body load on one part and another body load on another part use *LOAD_BODY_GENERALIZED instead.

Card Summary:

Card 1a.1. This card is included if and only if the keyword option is X, Y, Z, RX, RY, RZ, or VECTOR.

LCID	SF	LCIDDR	XC	YC	ZC	CID	

Card 1a.2. This card is included if and only if the VECTOR keyword option is used.

V1	V2	V3					

Card 1b. This card is included if and only if the PARTS keyword option is used.

PSID							

Data Cards:

For options X, Y, Z, RX, RY, RZ and VECTOR.

Card 1a.1	1	2	3	4	5	6	7	8
Variable	LCID	SF	LCIDDR	XC	YC	ZC	CID	
Type	I	F	I	F	F	F	I	
Default	none	1.	↓	0.	0.	0.	global	

VARIABLE	DESCRIPTION
LCID	Load curve ID specifying loading, see *DEFINE_CURVE. See Remark 1.
SF	Load curve scale factor. Applies to both LCID and LCIDDR.
LCIDDR	Load curve ID for dynamic relaxation phase (optional). This is needed when dynamic relaxation is defined and a different load curve to LCID is required during the dynamic relaxation phase. Note if LCID is undefined, then no body load will be applied during dynamic relaxation regardless of the value LCIDDR. See *CONTROL_DYNAMIC_RELAXATION. See Remark 1.
XC	x-center of rotation, define for angular velocities.
YC	y-center of rotation, define for angular velocities.

VARIABLE	DESCRIPTION
ZC	*z*-center of rotation, define for angular velocities.
CID	Coordinate system ID to define acceleration in local coordinate system. The accelerations (LCID) are with respect to CID. EQ.0: Global

For option VECTOR.

Card 1a.2	1	2	3	4	5	6	7	8
Variable	V1	V2	V3					
Type	F	F	F					
Default	0.0	0.0	0.0					

VARIABLE	DESCRIPTION
V1, V2, V3	Components of vector **V**

For option PARTS.

Card 1b	1	2	3	4	5	6	7	8
Variable	PSID							
Type	I							
Default	none							

VARIABLE	DESCRIPTION
PSID	Part set ID

Remarks:

1. **Base Accelerations.** Translational base accelerations allow body force loads to be imposed on a structure. Conceptually, base acceleration may be thought of as accelerating the coordinate system in the direction specified, and, thus, the

inertial loads acting on the model are of opposite sign. For example, if a cylinder were fixed to the *yz*-plane and extended in the positive *x*-direction, then a positive *x*-direction base acceleration would tend to shorten the cylinder, i.e., create forces acting in the negative *x*-direction.

Base accelerations are frequently used to impose gravitational loads during dynamic relaxation to initialize the stresses and displacements. During the analysis, in this latter case, the body forces loads are held constant to simulate gravitational loads. When imposing loads during dynamic relaxation, the load curve should slowly ramp up to avoid the excitation of a high frequency response.

2. **Angular Velocity.** Body force loads due to the angular velocity about an axis are calculated with respect to the deformed configuration and act radially outward from the axis of rotation. Torsional effects which arise from changes in angular velocity are neglected with this option. The angular velocity is assumed to have the units of radians per unit time.

3. **Body Force Density.** The body force density is given at a point **P** of the body by:

$$\mathbf{b} = \rho[\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r})] \ ,$$

where ρ is the mass density, $\boldsymbol{\omega}$ is the angular velocity vector, and $\mathbf{r}$ is a position vector from the origin to point **P**. Although the angular velocity may vary with time, the effects of angular acceleration are not included.

4. **Transient Deformation.** Angular velocities are useful for studying transient deformation of spinning three-dimensional objects. Typical applications have included stress initialization during dynamic relaxation where the initial rotational velocities are assigned at the completion of the initialization, and this option ceases to be active.

Example:

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$  *LOAD_BODY_Z
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$  Add gravity such that it acts in the negative Z-direction.
$  Use units of mm/ms2.  Since gravity is constant, the load
$  curve is set as a constant equal to 1.  If the simulation
$  is to exceed 1000 ms, then the load curve needs to be
$  extended.
$
$$$  Note: Positive body load acts in the negative direction.
$
*LOAD_BODY_Z
$
$...>....1....>....2....>....3....>....4....>....5....>....6....>....7....>....8
```

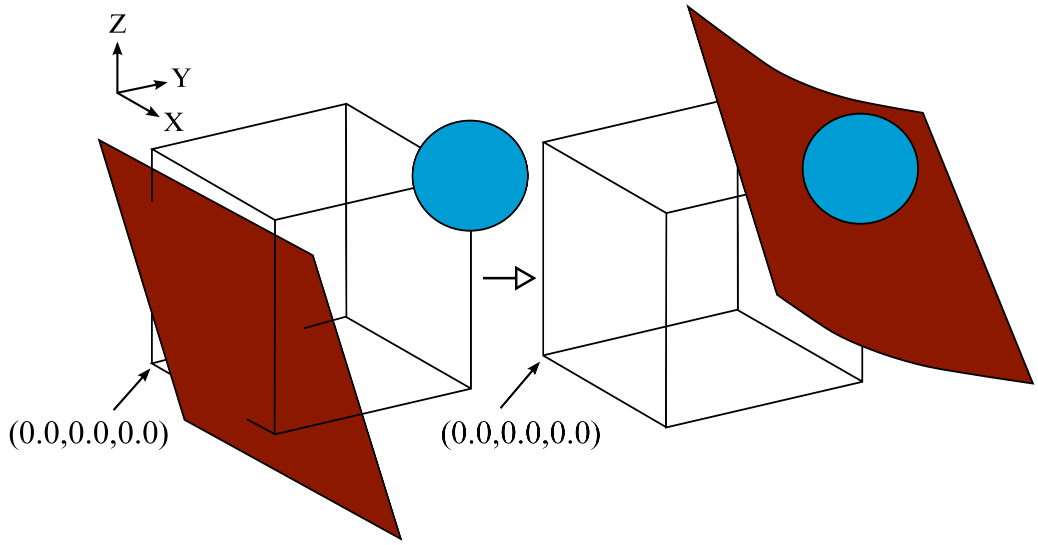

Figure 33-3. A validation example for option **VECTOR**.

```
$      lcid         sf    lciddr         xc         yc         zc
          5    0.00981
$
$
*DEFINE_CURVE
$      lcid       sidr      scla       sclo       offa       offo
          5
$
$            abscissa              ordinate
                 0.00                 1.000
              1000.00                 1.000
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

About Keyword Option VECTOR:

The vector **V** defines the direction of the body force. Body forces act in the negative direction of the vector **V**.

In the example shown in Figure 33-3, a rectangular sheet metal blank is loaded with gravity which causes it to be deformed by a fixed rigid ball. Given the global coordinate system shown, if the part set ID of the blank is 1, the keywords responsible for specifying the body force (in units of mm, second, tonne and Newton) in positive direction of $(1.0, 1.0, 1.0)$ will be as follows,

```
*LOAD_BODY_PARTS
1
*LOAD_BODY_VECTOR
101, 9810.0
-1.0, -1.0, -1.0
*DEFINE_CURVE
101
0.0, 1.0
10.0, 1.0
```

It is note that straight lines represent a cube with each edge length of 500.0 mm.

Revision Information:

The VECTOR keyword option is available in LS-DYNA R5 Revision 59290 and later releases.

LOAD_BODY_GENERALIZED_*OPTION

Available options include:

SET_NODE

SET_PART

Purpose: Define body force loads due to a prescribed base acceleration or a prescribed angular motion over a subset of the complete problem. The subset is defined by using nodes or parts. Warning: Nodes, which belong to rigid bodies, should not be specified. Rigid bodies must be included within the part sets definitions.

The body forces defined using this command do not take into account non-physical mass added via mass scaling; see *CONTROL_TIMESTEP.

Card Sets. Include as many sets of Cards 1 and 2 as necessary. This input terminates at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	N1/SID	N2	LCID	DRLCID	XC	YC	ZC	
Type	I	I	I	I	F	F	F	
Default	none	none	none	0	0.	0.	0.	

Card 2	1	2	3	4	5	6	7	8
Variable	AX	AY	AZ	OMX	OMY	OMZ	CID	ANGTYP
Type	F	F	F	F	F	F	I	A
Default	0.	0.	0.	0.	0.	0.	global	CENT
Remarks	1, 2	1, 2	1, 2	3, 4, 5	3, 4, 5	3, 4, 5		3

VARIABLE	DESCRIPTION
N1/SID	Beginning node ID for body force load or the node or part set ID.

VARIABLE	DESCRIPTION
N2	Ending node ID for body force load. Set to zero if a set ID is defined.
LCID	Load curve ID; see *DEFINE_CURVE.
DRLCID	Load curve ID for dynamic relaxation phase. Only necessary if dynamic relaxation is defined. See *CONTROL_DYNAMIC_RELAXATION.
XC	x-center of rotation. Define only for angular motion.
YC	y-center of rotation. Define only for angular motion.
ZC	z-center of rotation. Define only for angular motion.
AX	Scale factor for acceleration in x-direction
AY	Scale factor for acceleration in y-direction
AZ	Scale factor for acceleration in z-direction
OMX	Scale factor for x-angular velocity or acceleration
OMY	Scale factor for y-angular velocity or acceleration
OMZ	Scale factor for z-angular velocity or acceleration
CID	Coordinate system ID to define acceleration in the local coordinate system. The coordinate (XC, YC, ZC) is defined with respect to the local coordinate system if CID is nonzero. The accelerations, LCID and their scale factors are with respect to CID. EQ.0: global
ANGTYP	Type of body loads due to angular motion: EQ.CENT: body load from centrifugal acceleration, $\rho[\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r})]$. EQ.CORI: body load from Coriolis-type acceleration, $2\rho(\boldsymbol{\omega} \times \mathbf{v})$. EQ.ROTA: body load from rotational acceleration, $\rho(\boldsymbol{\alpha} \times \mathbf{r})$,

VARIABLE	DESCRIPTION
	where $\boldsymbol{\omega}$ is the angular velocity, $\boldsymbol{\alpha}$ is the angular acceleration, $\mathbf{r}$ is the position vector relative to center of rotation and $\mathbf{v}$ is the velocity vector

Remarks:

1. **Base Accelerations.** Translational base accelerations allow body forces loads to be imposed on a structure. Conceptually, base acceleration may be thought of as accelerating the coordinate system in the direction specified, and, thus, the inertial loads acting on the model are of opposite sign. For example, if a cylinder were fixed to the yz-plane and extended in the positive x-direction, then a positive x-direction base acceleration would tend to shorten the cylinder, that is, create forces acting in the negative x-direction.

2. **Gravitational Loads.** Base accelerations are frequently used to impose gravitational loads during dynamic relaxation to initialize the stresses and displacements. During the analysis, in this latter case, the body forces loads are held constant to simulate gravitational loads. When imposing loads during dynamic relaxation, the load curve should slowly ramp up to avoid the excitation of a high frequency response.

3. **Angular Motion.** Body force loads due to the angular motion about an axis are calculated with respect to the deformed configuration. When ANGYP = CENT or CORI, torsional effects which arise from changes in angular velocity are neglected. Such torsional effects can be taken into account by setting ANGTYP = ROTA. The angular velocity is assumed to have the units of radians per unit time, accordingly angular acceleration has the units of radians/time^2.

4. **Body Force Density.** With ANGTYP = CENT, the body force density at a point $\mathbf{P}$ of the body (similar to *LOAD_BODY) is given by:

   $$\mathbf{b} = \rho[\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r})] \ ,$$

   where ρ is the mass density, $\boldsymbol{\omega}$ is the angular velocity vector, and $\mathbf{r}$ is a position vector from the origin to point $\mathbf{P}$.

   One of the enhancements in *LOAD_BODY_GENERALIZED, compared to *LOAD_BODY, is that it provides additional options ANGTYP = CORI and ANGTYP = ROTA to include Coriolis and Euler forces, respectively.

5. **Transient Deformation.** Angular velocities are useful for studying transient deformation of spinning three-dimensional objects. Typical applications have included stress initialization during dynamic relaxation where the initial

rotational velocities are assigned at the completion of the initialization, and this option ceases to be active.

*LOAD_BODY_POROUS

Purpose: Define the effects of porosity on the flow with body-force-like loads applied to the ALE element nodes. Ergun porous flow assumptions are used. This only applies to non-deformable (constant-porosity), fully saturated porous media. This model only works with a non-zero and constant viscosity fluid defined using either *MAT_NULL or *MAT_ALE_VISCOUS card.

Card Sets. Include as many sets of Cards 1 and 2 as necessary. This input terminates at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	SID	SIDTYP	AX	AY	AZ	BX	BY	BZ
Type	I	I	F	F	F	F	F	F
Default	none	0	0.0	0.0	0.0	0.0	0.0	0.0

Card 2	1	2	3	4	5	6	7	8
Variable	AOPT							
Type	I							
Default	0							

VARIABLE	DESCRIPTION
SID	Set ID of the ALE fluid part subjected to porous flow condition.
SIDTYP	Set ID type of the SID above: EQ.0: Part set ID (default) EQ.1: Part ID EQ.2: Element set ID (*SET_BEAM for 1D ALE, *SET_SHELL for 2D ALE, and *SET_SOLID for 3D ALE)
AX, AY, AZ	Viscous coefficients for viscous terms in global x, y, and z directions (see Remark 1). If $A_x \neq 0.0$ and $A_y = A_z = 0.0$, then an isotropic

VARIABLE	DESCRIPTION
	viscous permeability condition is assumed for the porous medium.
BX, BY, BZ	Inertial coefficients for inertia terms in global x, y, and z directions (see Remarks 1 and 2). If $B_x \neq 0.0$, and $B_y = B_z = 0.0$, then an isotropic inertial permeability condition is assumed for the porous medium.
AOPT	Material axis option: EQ.0: Inactive EQ.1: The forces are applied in a local system attached to the ALE solid (see CTYPE = 12 and DIREC = 1 in *CONSTRAINED_LAGRANGE_IN_SOLID).

Remarks:

1. **Ergun porous flow model.** Consider the basic general Ergun equation for porous flow in one direction:

$$\frac{\Delta P}{\Delta L} = \frac{\mu}{k_1} V_s + \frac{\rho}{k_2} V_s^{\,2} \quad ,$$

where

$$\begin{aligned}
\rho &= \text{Fluid Density} \\
\mu &= \text{Fluid dynamic vicosity} \\
V_s = \frac{4Q}{\pi D^2} &= \text{Superficial fluid velocity} \\
Q &= \text{Overall volume flow rate } \left(\frac{\mathrm{m}^3}{\mathrm{s}}\right) \\
D &= \text{Porous channel characteristic width (perpendicular to } \Delta \mathrm{L}) \\
k_1 = \frac{\varepsilon^3 d_p^{\,2}}{150(1-\varepsilon)^2} &= \text{Permeability parameter} \\
k_2 = \frac{\varepsilon^3 d_p}{1.75(1-\varepsilon)} &= \text{Passability parameter} \\
\varepsilon &= \text{Porosity} = \frac{\text{total pore volume}}{\text{total media volume}} \\
d_p &= \text{Effective particle diameter}
\end{aligned}$$

The above equation can be generalized into 3 dimensional flows where each component may be written as

$$-\frac{dP}{dx_i} = A_i \mu V_i + B_i \rho |V_i| V_i$$

where $i = 1,2,3$ refers to the global coordinate directions (no summation intended for repeated indices), μ is the constant dynamic viscosity, ρ is the fluid density, V_i is the fluid velocity components, A_i is analogous to k_1 above, and B_i is analogous to k_2 above. A matrix version can be defined by ALE elements with *DEFINE_POROUS_ALE.

2. **Inertia coefficients.** If $B_i = 0$, the equation is reduced to simple Darcy Law for porous flow (may be good for sand-like flow). For coarse grain (rocks) media, the inertia term will be important, so you need to input these coefficients.

*LOAD_BRODE

Purpose: Define Brode function for application of pressure loads due to explosion; see Brode [1970]. See also *LOAD_SEGMENT, *LOAD_SEGMENT_SET, or *LOAD_SHELL.

Card 1	1	2	3	4	5	6	7	8
Variable	YLD	BHT	XBO	YBO	ZBO	TBO	TALC	SFLC
Type	F	F	F	F	F	F	I	I
Default	0.0	0.0	0.0	0.0	0.0	0.0	0	0

Card 2	1	2	3	4	5	6	7	8
Variable	CFL	CFT	CFP					
Type	F	F	F					
Default	0.0	0.0	0.0					

VARIABLE	DESCRIPTION
YLD	Yield, W, (Kt, equivalent tons of TNT). This parameter is constant yield unless SFLC is defined. In that case it becomes a parameter for calculating the variable yield where it will be referenced as YLD. See Remark 1.
BHT	Height of burst.
XBO	x-coordinates of Brode origin.
YBO	y-coordinates of Brode origin.
ZBO	z-coordinates of Brode origin.
TBO	Time offset of Brode origin.
TALC	Load curve number giving time of arrival as a function of range relative to Brode origin (space, time). See *DEFINE_CURVE and Remark 1.

VARIABLE	DESCRIPTION
SFLC	Load curve number giving yield scaling, W_s, as a function of scaled time. Scaled time is time relative to the Brode origin, t_B, divided by $\mathrm{YLD}^{1/3}$, that is, $t_B/\mathrm{YLD}^{1/3}$. See *DEFINE_CURVE and Remark 1.
CFL	Conversion factor - kft to LS-DYNA length units.
CFT	Conversion factor - milliseconds to LS-DYNA time units.
CFP	Conversion factor - psi to LS-DYNA pressure units.

Remarks:

1. **Yield Parameter.** If the curves, TALC and SFLC, are defined, a variable yield as opposed to a constant yield is assumed. *Both* load curves must be specified for the variable yield option. If this option is used, the shock time of arrival is found from the time of arrival curve. The yield used in the Brode formulas is computed by taking the yield scaling value, W_s, at the current scaled time ($t_B/\mathrm{YLD}^{1/3}$) and multiplying W_s by the constant yield input in field YLD, that is,

$$W\Big|_{t_B} = W_s\Big|_{t_B/\mathrm{YLD}^{1/3}} \times \mathrm{YLD} \ .$$

*LOAD_DENSITY_DEPTH

Purpose: Define density versus depth for gravity loading. This option has been occasionally used for analyzing underground and submerged structures where the gravitational preload is important. The purpose of this option is to initialize the hydrostatic pressure field at the integration points in the element. See also GRAV in *PART.

This card should be only defined once in the input deck.

Card 1	1	2	3	4	5	6	7	8
Variable	PSID	GC	DIR	LCID				
Type	I	F	I	I				
Default	0	0.0	1	none				
Remarks	1,2			3				

VARIABLE	DESCRIPTION
PSID	Part set ID, see *SET_PART. If a PSID of zero is defined, all parts are initialized.
GC	Gravitational acceleration value
DIR	Direction of loading: EQ.1: Global x EQ.2: Global y EQ.3: Global z
LCID	Load curve ID defining density as a function of depth; see *DEFINE_CURVE.

Remarks:

1. **Hydrostatic pressure.** Density as a function of depth curves are used to initialize hydrostatic pressure due to gravity acting on an overburden material. The hydrostatic pressure acting at a material point at depth, d, is given by:

$$p = -\int_{d}^{d_{\text{surface}}} \rho(\mathrm{z}) g dz \ ,$$

where p is pressure, d_{surface}, is the depth of the surface of the material to be initialized (usually zero), $\rho(\mathrm{z})$ is the mass density at depth z, and g is the acceleration of gravity. This integral is evaluated for each integration point. Depth may be measured along any of the global coordinate axes, and the sign convention of the global coordinate system should be respected. The sign convention of gravity also follows that of the global coordinate system. For example, if the positive z-axis points "up", then gravitational acceleration should be input as a negative number.

2. **Limitations.** For this option there is a limit of 12 parts that can be defined by PSID, unless all parts are initialized.

3. **Depth LCID.** Depth is the ordinate of the curve and is input as a descending x, y, or z coordinate value. Density is the abscissa of the curve and must vary (increase) with depth, that is, an infinite slope is not allowed.

*LOAD_EDGE_UVW_{OPTION}

Available options include:

<BLANK>

SET

Purpose: Apply a uniformly distributed load on a parametric edge or a set of parametric edges.

Edge/Edge Set Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	EUID	DOF	LCID	SF				
Type	I	I	I	F				
Default	none	none	none	1.				

VARIABLE	DESCRIPTION
EUID	Parametric edge ID or parametric edge set ID when using the SET keyword option
DOF	Applicable load direction: EQ.1: x-direction of load action EQ.2: y-direction of load action EQ.3: z-direction of load action EQ.5: Moment about the x-axis EQ.6: Moment about the y-axis axis EQ.7: Moment about the z-axis axis
LCID	Load curve ID (see *DEFINE_CURVE) giving the load as a function of time
SF	Load curve scale factor

*LOAD_ERODING_PART_SET

Purpose: Apply a pressure load to the exposed surface composed of solid elements that may erode.

Card Sets. Include as many sets of Cards 1 and 2 as necessary. This input terminates at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	ID	LCID	SF	AT	PSID	BOXID	MEM	ALPHA
Type	I	I	F	F	I	I	I	F
Default	none	none	1.0	0.0	none	0	50	80

Card 2	1	2	3	4	5	6	7	8
Variable	IFLAG	X	Y	Z	BETA			
Type	I	F	F	F	F			
Default	0	0.0	0.0	0.0	90			

VARIABLE	DESCRIPTION
ID	ID number.
LCID	Load curve ID defining pressure as a function of time; see *DEFINE_CURVE. LT.0: Pressure determined from certain *LOAD keywords. See Remark 1.
SF	Scale factor.
AT	Arrival time.
PSID	Part set ID; see *SET_PART.

VARIABLE	DESCRIPTION
BOXID	Box ID; see *DEFINE_BOX. Any segment that would otherwise be loaded but whose centroid falls outside of this box is not loaded.
MEM	Extra memory, in percent, to be allocated above the initial memory for storing the new load segments exposed by the erosion.
ALPHA	The maximum angle (in degrees) permitted between the normal of a segment at its centroid and the average normal at its nodes. This angle is used to eliminate interior segments.
IFLAG	Flag for choosing a subset of the exposed surface that is oriented towards a blast or other loading source. The vector from the center of the element to the source location must be within an angle of BETA of the surface normal. If IFLAG > 0, then the subset is chosen, otherwise if IFLAG = 0, the entire surface is loaded.
X, Y, Z	Optional source location.
BETA	Maximum permitted angle (in degrees) between the surface normal and the vector to the source. The exposed segment is not loaded if the calculated angle is greater than BETA.

Remarks:

1. **Special Values Input for LCID.** If LCID is input as:

   a) -1, then the Brode function is used to determine the pressure for the segments; see *LOAD_BRODE.

   b) -2, then an empirical air blast function is used to determine the pressure for the segments; see *LOAD_BLAST.

   c) An integer < -2, then LCID references BID from *LOAD_BLAST_ENHANCED and the air blast function specified with the referenced *LOAD_BLAST_ENHANCED instantiation is used to determine the pressure for the segments.

2. **Load Curve Multipliers.** The load curve multipliers may be used to increase or decrease the pressure. The time value is not scaled.

3. **Activation Time.** The activation time, AT, is the time during the solution that the pressure begins to act. Until this time, the pressure is ignored. The function value of the load curves will be evaluated at the offset time given by the difference of the solution time and AT, that is solution time − AT.

4. **Requirements.** For proper evolution of the loaded surface, it is a requirement that DTMIN in *CONTROL_TERMINATION be greater than zero and ERODE in *CONTROL_TIMESTEP be set to 1.

*LOAD_EXPANSION_PRESSURE_{OPTION}

To define an ID for the pressure loading, the following option is available:

ID

Purpose: Apply a uniform pressure to a section of a chamber that can vary in size due to a moving edge. For instance, this keyword can be used to apply pressure to a cylinder on one side of a moving piston. See Figure 33-4.

ID Card. Additional card needed for the ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	Heading						
Type	I	A70						

Card 1	1	2	3	4	5	6	7	8
Variable	SSID	LCID	SF	AT				
Type	I	I	F	F				
Default	none	none	1.0	0.0				

Card 2	1	2	3	4	5	6	7	8
Variable	NSID	XN	YN	ZN				
Type	I	F	F	F				
Default	none	none	none	none				

VARIABLE	DESCRIPTION
ID	Loading ID
Heading	Description of the loading

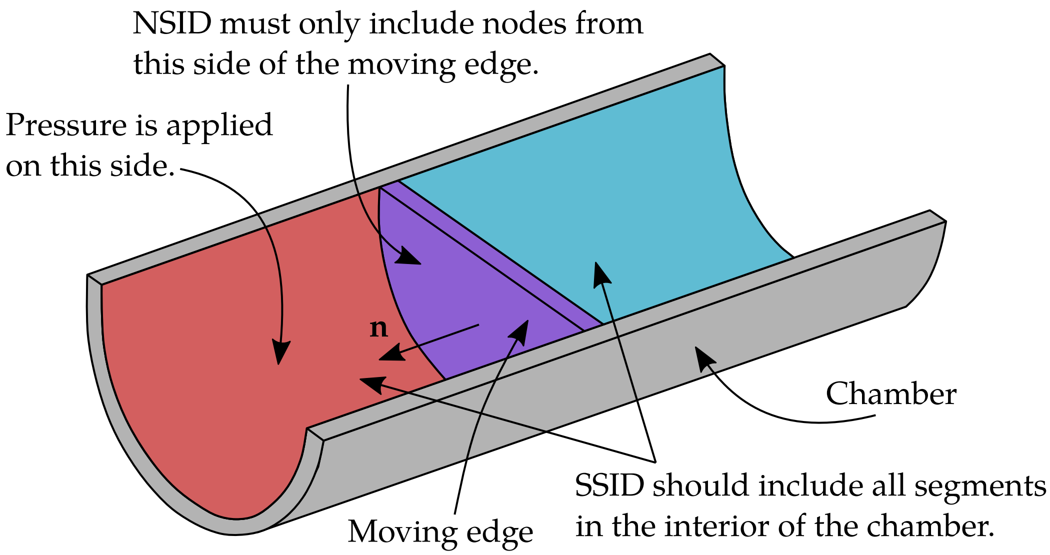

Figure 33-4. Schematic view of half a chamber (cut for clarity). Pressure is applied through this keyword to the red region but not the blue region of the chamber. The normal of the moving edge (in purple) must point toward the part of the chamber where the pressure is applied.

VARIABLE	DESCRIPTION
SSID	Segment set ID which specifies the interior of the chamber. As the edge moves, the pressure is applied or could be applied to these segments.
LCID	Load curve ID that defines the pressure as a function of time
SF	Load curve scale factor
AT	Activation time which is the time at which the pressure begins to be applied. Before this time, pressure will not be applied to the chamber. See Remark 2.
NSID	Node set ID that defines the moving edge/plane of the dynamic chamber. Note that this node set must include at least 3 nodes to define a plane. See Remark 1.
XN	X component of the initial outward normal of the moving plane/edge. See Remark 1.
YN	Y component of the initial outward normal of the moving plane/edge
ZN	Z component of the initial outward normal of the moving plane/edge

Remarks:

1. **Moving plane/edge.** NSID defines the position of the moving plane/edge. It must include enough nodes (at least 3) on the side facing where the pressure is applied to define a plane. Note that the moving plane/edge is not loaded with this keyword. It should be loaded with the same load curve, LCID, as this keyword using *LOAD_SEGMENT_SET.

   The reference normal direction of the plane/edge defined by XN, YN, and ZN should point toward the part of the chamber where the pressure is applied. At each time step, the normal direction of the edge is found by applying the right-hand rule to the node set in the order of the nodes in the set. Note that for a non-flat edge, the normal can be an average or estimate.

2. **Activation time.** The activation time, AT, is the time during the solution that the pressure begins to act. Until this time, the pressure is ignored. The function value of the load curves will be evaluated at the offset time given by the difference of the solution time and AT, that is, solution time − AT.

*LOAD_EXTERNAL_VARIABLE

Purpose: Define the nodal values of an external variable α with a user-defined ID. The value can be given as a function of time for individual nodes or node sets or read from the temperature field from a previous simulation. For nodes that are not explicitly accounted for by the keyword definition, default values can be set. If this keyword is used more than once, each external variable must have a unique ID. The external variables can be used to influence the material in certain structural and thermal materials. Additionally, a volumetric expansion can be defined based on the distribution of an external variable using *MAT_ADD_EXTVAR_EXPANSION.

Card Summary:

Card 1. This card is required.

VID	DBAS	DSCA	DLCID	NMP	NTMP		

Card 2. Include NMP instantiations of this card.

IMP	PID	PTYP					

Card 3. Include NTMP instantiations of this card.

ITMP	TPID	TPTYP					

Card 4. Include as many instantiations of this card or of this card in a set with Card 4.1 if IDTYP = 3 as desired. This input ends at the next keyword ("*") card.

ID	IDTYP	BAS	SCA	LCID			

Card 4.1. Include this card in a set of Card 4 and this card if IDTYP = 3.

FILENAME

Data Card Definitions:

Card 1	1	2	3	4	5	6	7	8
Variable	VID	DBAS	DSCA	DLCID	NMP	NTMP		
Type	I	F	F	I	I	I		
Default	1	0.0	1.0	none	0	0		

VARIABLE	DESCRIPTION
VID	Variable ID. If this keyword contains more than one *LOAD_EXTERNAL_VARIABLE instantiation, each variable must have a unique ID.
DBAS	Base value $\tilde{\alpha}_B$. It is the default used for nodes that are not specified in a node or node set card (Card 2). See Remark 4.
DSCA	Scaled value $\tilde{\alpha}_S$. It is the default used for nodes that are not specified in a node or node set card (Card 2). See Remark 4.
DLCID	Load curve ID defining a scaling $\tilde{f}(t)$ as function of time. This is the default for all nodes not specified in a node or node set card (Card 2). See Remark 4.
NMP	Number of material properties to be defined
NTMP	Number of thermal material properties to be defined

Material Properties Card. Include NMP cards.

Card 2	1	2	3	4	5	6	7	8
Variable	IMP	PID	PTYP					
Type	I	I	I					
Default	none	none	0					

VARIABLE	DESCRIPTION
IMP	Index of the material property. See Remark 5.
PID	Part or part set ID. For the parts referenced, the material property associated with material property index IMP will be modified by the state of the external variable. See Remark 5.
PTYPE	ID type of PID: EQ.1: Part ID EQ.2: Part set ID

Thermal Material Properties Card. Include NTMP cards.

Card 3	1	2	3	4	5	6	7	8
Variable	ITMP	TPID	TPTYP					
Type	I	I	I					
Default	none	none	0					

VARIABLE	DESCRIPTION
ITMP	Index of the thermal material property. See Remark 6.
TPID	Part or part set ID. For parts referenced here, the thermal material property associated with material property index ITMP will be modified by the state of the external variable. See Remark 6.
TPTYPE	ID type of TPID: EQ.1: Part ID EQ.2: Part set ID

Node/Node Set/LSDA Cards. Include as many cards or card sets of this card and Card 4.1 for the LSDA option (IDTYP = 3) in the following format as desired. This input ends at the next keyword ("*") card. See Remark 3.

Card 4	1	2	3	4	5	6	7	8
Variable	ID	IDTYP	BAS	SCA	LCID			
Type	I	I	F	F	I			
Default	none	1	0.	1.0	none			

Additional LSDA file cards for IDTYP=3. Additional input card needed in a set with Card 4 if IDTYP = 3 (LSDA option) in Card 4.

Card 4.1	1	2	3	4	5	6	7	8
Variable	FILENAME							
Type	A80							

VARIABLE	DESCRIPTION
ID	Node or node set ID. Ignored for IDTYP = 3.
IDTYP	ID type (see Remark 3): EQ.1: Node ID. See Remark 1. EQ.2: Node set ID. See Remark 1. EQ.3: LSDA option (rest of this Card 4 is ignored in this case). See Remark 2.
BAS	Base value α_B used for nodes defined by ID and IDTYP. See Remark 1. Ignored for IDTYP = 3.
SCA	Scaling parameter α_S used for nodes defined by ID and IDTYP. See Remark 1. Ignored for IDTYP = 3.
LCID	Load curve ID defining a scaling $f(t)$ as a function of time used for nodes defined by ID and IDTYP. See Remark 1. Ignored for IDTYP = 3.
FILENAME	Name of an LSDA file that contains temperature information that is interpreted as the value of the external variable. See Remark 2.

Remarks:

1. **Tabular input data for specific nodes.** For nodes referenced by their node ID (IDTYP = 1) or by a node set ID (IDTYP = 2), the value α of the external variable VID can be defined as a function of time. Using tabulated data (see *DEFINE_CURVE), α is defined as

$$\alpha = \alpha_B + \alpha_S \times f(t)$$

where $f(t)$ is the current value of the load curve LCID, α_S is the scaling parameter SCA, and α_B is the base value BAS. Note that these parameters are defined individually for each node or node set.

2. **LSDA option.** With IDTYP = 3, LS-DYNA interprets the temperature results from a previous simulation as a nodal distribution of an external variable varying in time. Here, a binary LSDA file must be specified as input, which should provide the same information as the TPRINT section in the binary database binout.

   The algorithm then loops over the nodes in the LSDA file, reads the respective temperature values, and uses that value as external variable data if a node with the same user ID is found in the current model.

3. **Combining input options.** It is possible to define the external variable for an arbitrary number of nodes, node sets, and LSDA files by repetitive input of Card 4 or Card 4 and Card 4.1. Any combination is possible. If a node is included more than once, such as in two different sets, the input order is important because data from the last entry overwrites previous data for that node.

4. **Tabular input for default values.** For nodes not included in Card 4 or the set of Cards 4 and 4.1, default values can be defined. The treatment is very similar to that of specified nodes as discussed in Remark 1. Tabular data can be used to define the default value, $\tilde{\alpha}$, of the external variable as:

$$\tilde{\alpha} = \tilde{\alpha}_B + \tilde{\alpha}_S \times \tilde{f}(t).$$

   Here, load curve DLCID defines the function $\tilde{f}(t)$, parameter DSCA the scaling factor $\tilde{\alpha}_S$, and parameter DBAS the base value $\tilde{\alpha}_B$.

5. **Defining structural material properties.** For all elements in a given part or part set, the external variable can be used to locally modify one or more material properties. The material property index IMP defines which material property the external variable field influences. The following structural material models currently support the definition of certain properties via external variables: *MAT_106, *MAT_251, and *MAT_254. Tables referencing the material indexes and the material properties can be found in the respective material sections of the Material Models manual

6. **Defining thermal material properties.** The external variable can be used to locally modify one or more thermal material properties for a part or part set. The material property index ITMP defines which material property the external variable field influences. Currently, *MAT_T08 and *MAT_T10 support external variable modifications. The meanings of the material indexes are shown in tables in the respective material sections of the Material Models manual.

7. **Example input.** In the following example, it is assumed that external variable 2 is defined for two nodes directly, for two node sets, and by two temperature result files. The external variable follows load curves 101 and 102 for nodes in node sets 11 and 12, respectively. Temperature data from files res1.binout and

res2.binout are used. Finally, for nodes 1 and 3, the same load curve 100 is used but with an offset of 2.5 for node 3. For all other nodes, load curve 105 gives the default value.

The external variable distribution influences the structural material properties with indexes 3 and 5 for part 1 and the thermal material property with index 1 for part set 11.

```
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+---
-8
*LOAD_EXTERNAL_VARIABLE
$      VID      DBAS      DSCA     DLCID       NMP      TNMP
         2       0.0       1.0       105         2         1
$      IMP       PID      PTYP
         3         1         0
$      IMP       PID      PTYP
         5         1         0
$     ITMP      TPID     TPTYP
         1        11         1
$       ID     IDTYP       BAS       SCA      LCID
        11         2       0.0       1.0       101
$       ID     IDTYP       BAS       SCA      LCID
        12         2       0.0       1.0       102
$       ID     IDTYP       BAS       SCA      LCID
                   3
$ FILENAME
res1.binout
$       ID     IDTYP       BAS       SCA      LCID
                   3
$ FILENAME
res2.binout
$       ID     IDTYP       BAS       SCA      LCID
         1         1       0.0       1.0       100
$       ID     IDTYP       BAS       SCA      LCID
         3         1       2.5       1.0       100
```

*LOAD_FACE_UVW_{OPTION}

Available options include:

SET

Purpose: Apply a uniform pressure load on a parametric face or a set of parametric faces.

Face/Face Set Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	FID	LCID	SF	AT				
Type	I	I	F	F				
Default	none	none	1.0	0.0				

VARIABLE	DESCRIPTION
FID	Parametric face ID or parametric face set ID for the SET keyword option; see *IGA_FACE_UVW and *SET_IGA_FACE_UVW (see Remark 1)
LCID	Load curve ID (see *DEFINE_CURVE). The load curve must provide pressure as a function of time.
SF	Load curve scale factor
AT	Arrival or birth time for pressure

Remarks:

1. **Parametric Control Points.** The coordinates of the control points in *IGA_2D_NURBS_UVW referenced in *IGA_FACE_UVW are defined in the parametric space of *IGA_3D_NURBS_XYZ. The parametric plane defined by this *IGA_2D_NURBS_UVW must be parallel to one of the parametric r-s, s-t, or t-r planes (u, v, or w must be constant). General cases are currently not supported.

*LOAD_FACE_XYZ_{OPTION}

Available options include:

SET

Purpose: Apply a uniform pressure load on a physical face or a set of physical faces.

Face/Face Set Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	FXYZID	LCID	SF	AT				
Type	I	I	F	F				
Default	none	none	1.0	0.0				

VARIABLE	DESCRIPTION
FXYZID	Physical face ID or physical face set ID for the SET keyword option; see *IGA_FACE_XYZ and *SET_IGA_FACE_XYZ (see Remark 2)
LCID	Load curve ID (see *DEFINE_CURVE). The load curve must provide pressure as a function of time.
SF	Load curve scale factor
AT	Arrival or birth time for pressure

Remarks:

2. **Pressure Load on Partial Areas.** When an instantiation of *IGA_SHELL references this FXYZID, the pressure load will be applied on all elements of this physical face (full area). If you want to apply a pressure load on a certain area of this physical face, you need to define another *IGA_FACE_XYZ for this area and reference this face on *LOAD_FACE_XYZ. This additional *IGA_FACE_XYZ references the same *IGA_2D_NURBS_XYZ of the physical face. It also has its own *IGA_1D_BREP that selects the partial area on the current physical face. No additional *IGA_SHELL is needed since the shell elements have been defined by the current *IGA_SHELL.

*LOAD_GRAVITY_PART_{OPTION}

Available options are:

<BLANK>

SET

Purpose: Define gravity for individual parts. This feature is intended for use with *LOAD_STIFFEN_PART to simulate staged construction. This keyword is available for solids, shells and thick shells as well as beam element types 1, 2, 3, 4, 5, 6, 9, 11, 12 and 13.

Part Cards. Include this card as many times as necessary. This input ends at the next keyword (“*”) card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID	DOF	LC	ACCEL	LCDR	STGA	STGR	
Type	I	I	I	F	I	I	I	
Default	none	none	1.0	0	none	0	0	

VARIABLE	DESCRIPTION
PID/PSID	Part ID (or Part Set ID for the SET option) for application of gravity load
DOF	Direction: enter 1, 2 or 3 for x, y or z
LC	Load curve defining factor as a function of time (or zero if STGA, STGR are defined). See Remark 1.
ACCEL	Acceleration (will be multiplied by factor from curve)
LCDR	Load curve defining as a function of time during dynamic relaxation
STGA	Construction stage at which part is added (optional)
STGR	Construction stage at which part is removed (optional)

Remarks:

1. **Defining Gravity Load.** There are 3 options for defining how the gravity load on a part varies with time.

   a) Curve LC gives factor as a function of time. This overrides the other methods if LC is non-zero. A constant factor of 1.0 is assumed if LC is not specified.

   b) STGA, STGR refer to stages at which part is added and removed – the stages are defined in *DEFINE_CONSTRUCTION_STAGES. If STGA is zero, the gravity load starts at time zero. If not, it ramps up from the small factor FACT (on *CONTROL_STAGED_CONSTRUCTION) up to full value over the ramp time ATR at the start of stage STGA (see *DEFINE_CONSTRUCTION_STAGES). If STGR is zero, the gravity load continues until the end of the analysis. If not, it ramps down from full value to FACT over the ramp time ATR at the start of stage STGR.

   c) *DEFINE_STAGED_CONSTRUCTION_PART can be used instead of *LOAD_GRAVITY_PART to define this loading. During initialization, a *LOAD_GRAVITY_PART card will be created and the effect is the same as using the STGA, STGR method described above; ACCEL is then taken from *CONTROL_STAGED_CONSTRUCTION.

2. **Mass Loading.** This feature calculates the loading from the mass of the elements of the referenced parts only (density × volume). This mass does not include any attached lumped mass elements. Only solid, beam, shell and thick shell elements can be loaded.

*LOAD_HEAT_CONTROLLER

Purpose: Used to define a thermostat control function. The thermostat controls the heat generation within a material by monitoring a remote nodal temperature. Control can be specified as on-off, proportional, integral, or proportional with integral.

Sensor Node Cards. Include up to 20 cards. This input ends at the next keyword (“*”) card.

Card 1	1	2	3	4	5	6	7	8
Variable	NODE	PID	LOAD	TSET	TYPE	GP	GI	
Type	I	I	F	F	I	F	F	
Default	none	none	none	none	none	none	none	

VARIABLE	DESCRIPTION
NODE	Sensor is located at this node number.
PID	Part ID assigned to the elements modeling the heater or cooler being controlled.
LOAD	Heater output q_0. [typical units: W/m^3]
TSET	Controller set point temperature at the location identified by NODE.
TYPE	Type of control function. EQ.1: on-off EQ.2: proportional + integral
GP	Proportional gain.
GI	Integral gain.

Remarks:

The thermostat control function is

$$\dot{q}''' = \dot{q}_0''' \left[G_P (T_{\mathrm{set}} - T_{\mathrm{node}}) + G_I \int_{t=0}^{t} (T_{\mathrm{set}} - T_{\mathrm{node}})\, dt \right]$$

*LOAD_HEAT_EXOTHERMIC_REACTION

Purpose: Define solid element sets with heat generation coming from battery abuse thermal models. This keyword is intended for thermal runaway studies.

Card Summary:

Card 1. This card is required.

HSID	STYPE	ESID	BT	DT	TMIN	TMAX	TOFF

Card 2a. This card is included if STYPE = 0 or 1.

CSEI0	ASEI	EASEI	MSEI	HSEI	WC		RU

Card 2b. This card is included if STYPE = 2.

ALPHA0	ASEI	EASEI	MSEI	HSEI	WC	P	RU

Card 3a. This card is included if STYPE = 0 or 1.

CNE0	ANE	EANE	MNE	HNE	WCNE	TSEI0	TSEIR

Card 3b. This card is included if STYPE = 2.

N							

Card 4. This card is included if STYPE = 0 or 1.

ALPHA0	APE	EAPE	MPEP1	HPE	WPE	MPEP2	

Card 5. This card is included if STYPE = 0 or 1.

CE0	AE	EAE	ME	HE	WE		

Data Card Definitions:

Card 1	1	2	3	4	5	6	7	8
Variable	HSID	STYPE	NSID	BT	DT	TMIN	TMAX	TOFF
Type	I	I	I	F	F	F	F	F
Default	none	none	none.	0.	10^{16}	0.	10^{16}	0.

VARIABLE	DESCRIPTION
HSID	Heat source ID
STYPE	Heat source model type: EQ.0.or.1: Heat source defined by NREL's 4-Equation model. See Remark 1. EQ.2: Heat source defined by 1-Equation model. See Remark 2.
ESID	Solid Element set ID
BT/DT	Birth and death times for application of heat source term
TMIN/TMAX	Minimum and maximum temperature before heat source activation is triggered
TOFF	Option offset for temperature used in heat source calculation

Solid Electrolyte Interface (SEI) decomposition reaction. This card is included if STYPE = 0 or 1. See Remark 1.

Card 2a	1	2	3	4	5	6	7	8
Variable	CSEI0	ASEI	EASEI	MSEI	HSEI	WC		RU
Type	F	F	F	F	F	F		F
Default	0.	0.	0.	0.	0.	0.		8.314

VARIABLE	DESCRIPTION
CSEI0	Initial concentration of Solid Electrolyte Interphase (SEI)
ASEI	SEI decomposition frequency factor, A_{sei}
EASEI	SEI decomposition activation energy, $E_{a,\mathrm{sei}}$
MSEI	Reaction order for c_{sei}, m_{sei}
HSEI	SEI decomposition heat release, H_{sei}
WC	Specific carbon content in jellyroll, W_c

VARIABLE	DESCRIPTION
RU	Reaction constant. R_u

1-Equation Model Card. This card is included if STYPE = 2. See Remark 2.

Card 2b	1	2	3	4	5	6	7	8
Variable	ALPHA0	ASEI	EASEI	MSEI	HSEI	WC	P	RU
Type	F	F	F	F	F	F	F	F
Default	0.	0.	0.	0.	0.	0.	0.	8.314

VARIABLE	DESCRIPTION
ALPHA0	Initial concentration of α
ASEI	SEI decomposition frequency factor, A_{sei}
EASEI	SEI decomposition activation energy, $E_{a,\mathrm{sei}}$
MSEI	Reaction order for c_{sei}, m_{sei}
HSEI	SEI decomposition heat release, H_{sei}
WC	Specific carbon content in jellyroll, W_c
P	Reaction order of $\log(1-\alpha)$
RU	Reaction constant, R_u

Negative solvent reaction. This card is included if STYPE = 0 or 1. See Remark 1.

Card 3a	1	2	3	4	5	6	7	8
Variable	CNE0/N	ANE	EANE	MNE	HNE	WCNE	TSEI0	TSEIR
Type	F	F	F	F	F	F	F	F
Default	0.	0.	0.	0.	0.	0.	0.	0.

VARIABLE	DESCRIPTION
CNE0	Initial concentration value of NE
ANE	Negative solvent frequency factor, A_{ne}
EANE	Negative solvent activation energy, $E_{a,ne}$
MNE	Reaction order forc_{neg}, $m_{ne,n}$
HNE	Negative solvent heat release, H_{ne}
WCNE	Specific carbon content in jellyroll, W_{cne}
TSEI0	Initial value of t_{sei}
TSEIR	Reference t_{sei} value, $t_{sei,ref}$

Second 1-Equation Model Card. This card is included if STYPE = 2. See Remark 2.

Card 3b	1	2	3	4	5	6	7	8
Variable	N							
Type	F							
Default	0.							

VARIABLE	DESCRIPTION
N	$(1-\alpha)$ reaction order, n

Positive Solvent Reaction Card. This card is included if STYPE = 0 or 1. See Remark 1.

Card 4	1	2	3	4	5	6	7	8
Variable	ALPHA0	APE	EAPE	MPEP1	HPE	WPE	MPEP2	
Type	F	F	F	F	F	F	F	
Default	0.	0.	0.	0.	0.	0.	0.	

VARIABLE	DESCRIPTION
ALPHA0	Initial value of α
APE	Positive solvent frequency factor, A_{pe}
EAPE	Positive solvent activation energy, $E_{a,\mathrm{pe}}$
MPEP1	Reaction order for α, $m_{\mathrm{pe,p1}}$
HPE	Positive solvent heat release, H_{pe}
WPE	Specific positive active content, W_p
MPEP2	Reaction order for $(1-\alpha)$, $m_{\mathrm{pe,p2}}$

Electrolyte Decomposition Reaction Card. This card is included if STYPE = 0 or 1. See Remark 1.

Card 5	1	2	3	4	5	6	7	8
Variable	CE0	AE	EAE	ME	HE	WE		
Type	F	F	F	F	F	F		
Default	0.	0.	0.	0.	0.	0.		

VARIABLE	DESCRIPTION
CE0	Initial concentration value of CE (c_e)
AE	Electrolyte decomposition frequency factor, A_e
EAE	Electrolyte activation energy, $E_{a,e}$
ME	Reaction order for CE, m_e
HE	Electrolyte decomposition heat release, H_e
WE	Specific electrolyte content, W_e

Remarks:

1. **NREL's 4-equation model.** When this model is selected, the total heat generation can be modelled as four exothermic reactions:

$$S_{\text{abuse\_chem}} = S_{\text{sei}} + S_{\text{ne}} + S_{\text{pe}} + S_{\text{ele}}$$

These reactions are the solid electrolyte interface (SEI) decomposition reaction, the negative solvent reaction, the positive solvent reaction, and the electrolyte decomposition reaction. The models for these reactions are described below. See Hatchard et al 2001 and Kim et al 2007 for details about this model. The equations here are taken from Kim et al 2007.

a) SEI decomposition reaction:

$$\begin{aligned} R_{\text{sei}}(T, c_{\text{sei}}) &= A_{\text{sei}} \times \exp\left(-\frac{E_{a,\text{sei}}}{R_u T}\right) \times c_{\text{sei}}^{m_{\text{sei}}} \\ S_{\text{sei}} &= H_{\text{sei}} \times W_c \times R_{\text{sei}} \\ \frac{dc_{\text{sei}}}{dt} &= -R_{\text{sei}} \end{aligned}$$

Here A_{sei}, $E_{a,\text{sei}}$, m_{sei}, H_{sei}, and W_c are model constants input on Card 2.

b) Negative solvent reaction:

$$\begin{aligned} R_{\text{ne}}(T, c_{\text{neg}}, t_{\text{sei}}) &= A_{\text{ne}} \times \exp\left(-\frac{t_{\text{sei}}}{t_{\text{sei,ref}}}\right) \times c_{\text{neg}}^{m_{\text{ne},n}} \times \exp\left(-\frac{E_{a,\text{ne}}}{R_u T}\right) \\ S_{\text{ne}} &= H_{\text{ne}} \times W_{\text{cne}} \times R_{\text{ne}} \\ \frac{dc_{\text{neg}}}{dt} &= -R_{\text{ne}} \\ \frac{dt_{\text{sei}}}{dt} &= R_{\text{ne}} \end{aligned}$$

Here A_{ne}, $m_{\text{ne,n}}$, $E_{a,\text{ne}}$, H_{ne}, W_{cne}, and $t_{\text{sei,ref}}$ are model constants input on Cards 2 and 3.

c) Positive solvent reaction:

$$\begin{aligned} R_{\text{pe}}(t, \alpha) &= A_{\text{pe}} \times \alpha^{m_{\text{pe,p1}}} \times (1-\alpha)^{m_{\text{pe,p2}}} \times \exp\left(-\frac{E_{a,\text{pe}}}{R_u T}\right) \\ S_{\text{pe}} &= H_{\text{pe}} \times W_p \times R_{\text{pe}} \\ \frac{d\alpha}{dt} &= R_{\text{pe}} \end{aligned}$$

Here A_{pe}, $m_{\text{pe,p1}}$, $m_{\text{pe,p2}}$, $E_{a,\text{pe}}$, H_{pe}, and W_p are model constants

d) Electrolyte decomposition reaction:

$$
\begin{aligned}
R_e(T, c_e) &= A_e \times \exp\left(-\frac{E_{a,e}}{R_u T}\right) \times c_e^{m_e} \\
S_{\text{ele}} &= H_e \times W_e \times R_e \\
\frac{dc_e}{dt} &= -R_e
\end{aligned}
$$

Here A_e, $E_{a,e}$, m_e, H_e, and W_e are model constants

2. **1-equation reaction model.** Total heat generation due to thermal abuse can be modeled as one exothermic reaction (MacNeil and Dahn 2001):

$$
\begin{aligned}
R(T, \alpha) &= A_{\text{sei}} \times \alpha^{m_{\text{sei}}} \times (1 - \alpha)^n \times (-\ln(1 - \alpha))^p \times \exp\left(-\frac{E_{a,\text{sei}}}{R_u T}\right) \\
S &= H_{\text{sei}} \times W_c \times R \\
\frac{d\alpha}{dt} &= R
\end{aligned}
$$

Here A_{sei}, m_{sei}, n, p, $E_{a,\text{sei}}$, R_u, H_{sei}, and W_c are input parameters.

LOAD_HEAT_GENERATION_*OPTION

Available options include:

SOLID

SET_SOLID

SHELL

SET_SHELL

Purpose: Define elements or element sets with heat generation.

Generation Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	SID	LCID	MULT	WBLCID	CBLCID	TBLCID		
Type	I	I	F	I	I	I		
Default	none	none	0.	0	0	0		

VARIABLE	DESCRIPTION
SID	Element ID or element set ID, see *ELEMENT_SOLID, *SET_SOLID, *ELEMENT_SHELL, and *SET_SHELL, respectively.
LCID	Volumetric heat generation rate, $\dot{q}'''$, specification. SI units are W/m^3. This parameter can reference a load curve ID (see *DEFINE_CURVE) or a function ID (see *DEFINE_FUNCTION and Remark 1). When the reference is to a curve, LCID has the following interpretation: GT.0: $\dot{q}'''$ is defined by a curve consisting of (time, $\dot{q}'''$) data pairs. EQ.0: $\dot{q}'''$ is a constant defined by the value MULT. LT.0: $\dot{q}'''$ is defined by a curve consisting of (temperature, $\dot{q}'''$) data pairs. Enter |-LCID| on the DEFINE_CURVE keyword.
MULT	Volumetric heat generation, $\dot{q}'''$, curve multiplier.

VARIABLE	DESCRIPTION
WBLCID	Load curve ID defining the blood perfusion rate [e.g., kg/m^3 sec] as a function of time.
CBLCID	Load curve ID defining the blood specific heat [e.g., J/kg C] as a function of the blood temperature.
TBLCID	Load curve ID defining the blood temperature [e.g., C] as a function of time.

Remarks:

1. **Volumetric Heat Generation Rate Function.** If LCID references a *DEFINE_-FUNCTION, the volumetric heat generation rate can be a function of element centroid coordinates, element centroid velocity components, the element integration point temperature, and solution time, that is, "f(x, y, z, vx, vy, vz, temp, time)."

2. **Blood Heat Transfer to Tissue Rate.** Rate of heat transfer from blood to tissue is $W_b C_b (T_b - T)$ [units: J/m^3 sec].

*LOAD_MASK

Purpose: Apply a distributed pressure load over a three-dimensional shell part. The pressure is applied to a subset of elements that are within a fixed global box and lie either outside or inside of a closed curve in space which is projected onto the surface.

Card Sets. Include as many sets of Cards 1 and 2 as necessary. This input terminates at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID	LCID	VID1	OFF	BOXID	LCIDM	VID2	INOUT
Type	I	I	I	F	I	I	I	I
Default	none	none	0	0.	↓	0	none	0

Card 2	1	2	3	4	5	6	7	8
Variable	ICYCLE							
Type	I							
Default	200							

VARIABLE	DESCRIPTION
PID	Part ID (PID). This part must consist of three-dimensional shell elements. To use this option with solid elements the surface of the solid elements must be covered with null shells. See *MAT_NULL.
LCID	Curve ID defining the pressure time history, see *DEFINE_-CURVE.
VID1	Vector ID normal to the surface on which the applied pressure acts. Positive pressure acts in a direction that is in the opposite direction. This vector may be used if the surface on which the pressure acts is relatively flat. EQ.0: the pressure load depends on the orientation of the shell elements as shown in Figure 33-12.

VARIABLE	DESCRIPTION
OFF	Pressure loads will be discontinued if $\lvert \mathrm{VID1} \cdot \mathbf{n}_{\mathrm{shell}} \rvert < \mathrm{OFF}$, where $\mathbf{n}_{\mathrm{shell}}$ is the normal vector to the shell element.
BOXID	Only elements inside the box with part ID, PID, are considered. If no ID is given, all elements of PID, are included. When the active list of elements is updated, elements outside the box will no longer have pressure applied, that is, the current configuration is always used.
LCIDM	Curve ID defining the mask. This curve defines (x, y) pairs of points in a local coordinate system defined by the vector ID, VID2. Generally, the curve should form a closed loop, that is, the first point is identical to the last point, and the curve should be flagged as a DATTYP = 1 curve in the *DEFINE_CURVE section. If no curve ID is given, all elements of PID are included with the exception of those deleted by the box. The mask works like the trimming option; see DEFINE_CURVE_TRIM and Figure 17-25.
VID2	Vector ID used to project the masking curve onto the surface of part ID, PID. The origin of this vector determines the origin of the local system that the coordinates of the PID are transformed into prior to determining the pressure distribution in the local system. This vector must be defined if LCIDM is nonzero. See Figure 17-25.
INOUT	Flag for applying pressure to elements inside or outside of projected curve: EQ.0: elements whose center falls inside the projected curve are considered. EQ.1: elements whose center falls outside the projected curve are considered.
ICYCLE	Number of time steps between updating the list of active elements. The list update can be quite expensive and should be done at a reasonable interval. The default is not appropriate for all problems.

*LOAD_MOTION_NODE

Purpose: Apply a concentrated nodal force or moment to a node based on the motion of another node.

Node Cards. Include as many cards as desired. This input ends at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	NODE1	DOF1	LCID	SF	CID1	NODE2	DOF2	CID2
Type	I	I	I	F	I	I	I	I
Default	none	none	none	1.	global	none	none	global

VARIABLE	DESCRIPTION
NODE1	Node ID for the concentrated force.
DOF1	Applicable degrees-of-freedom: EQ.1: x-direction of load action, EQ.2: y-direction of load action, EQ.3: z-direction of load action, EQ.4: Moment about the x-axis, EQ.5: Moment about the y-axis, EQ.6: Moment about the z-axis.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). The applied force is a function of the applicable degree-of-freedom of NODE2.
SF	Load curve scale factor.
CID1	Coordinate system ID (optional). See Remark 1.
NODE2	Node ID for calculating the force.
DOF2	Applicable degrees-of-freedom: EQ.1: x-coordinate EQ.2: y-coordinate,

VARIABLE	DESCRIPTION
	EQ.3: z-coordinate, EQ.4: x-translational displacement, EQ.5: y-translational displacement, EQ.6: z-translational displacement, EQ.7: Rotational displacement about the x-axis, EQ.8: Rotational displacement about the y-axis, EQ.9: Rotational displacement about the z-axis. EQ.10: x-translational velocity, EQ.11: y-translational velocity, EQ.12: z-translational velocity, EQ.13: Rotational velocity about the x-axis, EQ.14: Rotational velocity about the y-axis, EQ.15: Rotational velocity about the z-axis.
CID2	Coordinate system ID (optional); see Remark 1.

Remarks:

1. **Coordinate system.** The global coordinate system is the default. The local coordinate system IDs are defined in the *DEFINE_COORDINATE_SYSTEM section.

*LOAD_MOVING_PRESSURE

Purpose: Apply moving pressure loads to a surface. The pressure loads approximate a jet of high velocity fluid impinging on the surface. Multiple surfaces may be defined each acted on by a set of nozzles.

Card 1	1	2	3	4	5	6	7	8
Variable	LOADID							
Type	I							
Default	none							

Nozzle Cards. Define the following cards for each nozzle. Include as many cards as desired. This input ends at the first card with the second field (NODE2) ≤ 3.

Card 2	1	2	3	4	5	6	7	8
Variable	NODE1	NODE2	LCID	CUTOFF	LCIDT	LCIDD	IDIR	LSFLG
Type	I	I	I	F	I	I	I	I
Default	none	none	none	none	0	0	0	0

The following card defines the surface where the nozzles act.

Card 3	1	2	3	4	5	6	7	8
Variable	ID	IDTYPE	NIP					
Type	I	I	I					
Default	none	none	3x3					

VARIABLE	DESCRIPTION
LOADID	Loading ID
NODE1	Node located at the origin of the nozzle

VARIABLE	DESCRIPTION
NODE2	Node located at the head of the nozzle
LCID	Load curve or function ID (see *DEFINE_FUNCTION) defining pressure as a function of radial distance from the center of the jet
CUTOFF	Outer radius of jet. The pressure acting outside this radius is set to zero.
LCIDT	Load curve or function ID (see *DEFINE_FUNCTION), which scales the pressure as a function of time. If a load curve isn't specified, the scale factor defaults to 1.0.
LCIDD	Load curve or function ID (see *DEFINE_FUNCTION), which scales the pressure as a function of distance from the nozzle. If a load curve isn't specified, the scale factor defaults to 1.0.
IDIR	Direction of the pressure applied to the segments (see Remark 1): EQ.0: The normal direction of the segments EQ.1: The direction from the nozzle (NODE1) to the segments EQ.2: The direction from NODE1 to NODE2 EQ.3: Pressure is in the direction from NODE1 to NODE2 but only the normal component is applied on the segments.
LSFLG	Line-of-sight flag: EQ.0: See Remark 2. EQ.1: Pressure is applied on the first-hit segments from the nozzle.
ID	Segment set ID, shell element set ID, shell part set ID, or shell part ID. See IDTYPE below.
IDTYPE	Value that determines the meaning of variable ID. If segments to be loaded are located on solid elements or on thick shell elements, IDTYPE must be set to 0. EQ.0: ID is a segment set ID. EQ.1: ID is a shell set ID. EQ.2: ID is a shell part set ID. EQ.3: ID is a shell part ID.

VARIABLE	DESCRIPTION
NIP	Number of integration points in segment used to compute pressure loads

Remarks:

1. **Pressure direction.** Pressure directions for different cases of IDIR are illustrated in Figure 33-5. The magnitude of the pressure, p, is determined by the curves given in LCID, LCIDT, and LCIDD.

2. **Line of sight.** When LSFLG = 0, this feature is turned off, and the originally implemented algorithm of *LOAD_MOVING_PRESSURE is performed. With this algorithm, pressure is applied differently depending on if MPP or SMP is used. In SMP, it works well for non-disjoint and single-layer surfaces. Examples of applying pressure in SMP are demonstrated in Figure 33-6. For continuous surfaces, the pressure is applied to all segments inside the cylinder defined by the CUTOFF radius. However, with disjoint surfaces, the pressure is only applied to the surface which is cut by the line through NODE1 and NODE2. For the cases with multiple layers, the algorithm does not work consistently and may apply the pressure to the bottom layer as illustrated in Figure 33-6. In MPP, pressure will be applied to all segments inside the cylinder (see Figure 33-7). Note that, in the multiple-layer case, the pressure is applied on all layers.

   When LSFLG = 1, the line-of-sight feature is turned on and the pressure is applied to the first-hit segments (from the nozzle). LS-DYNA will check all the potential segments inside the cylinder to find these segments. Note that this cylinder is defined by the CUTOFF radius, so specifying this radius by a value larger than the effective radius defined by the curve in LCID will unnecessarily increase the computational time. For example, if the curve in LCID is in the range of 0 to 100 with non-zero values only from 0 to 5, the CUTOFF radius should be 5. With this feature, the pressure is applied in the same way in both SMP and MPP (see Figure 33-8).

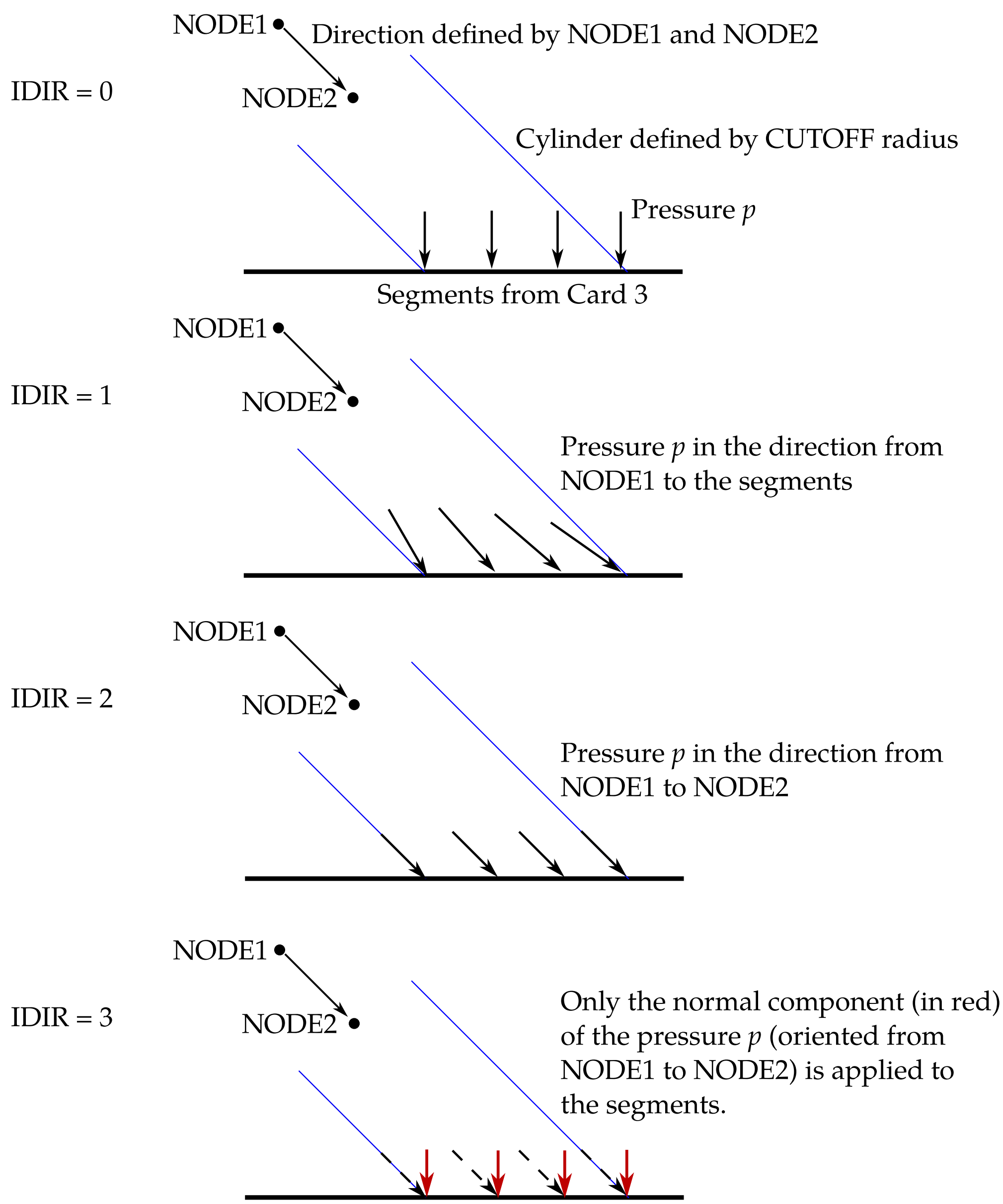

Figure 33-5. Pressure directions for different values of IDIR.

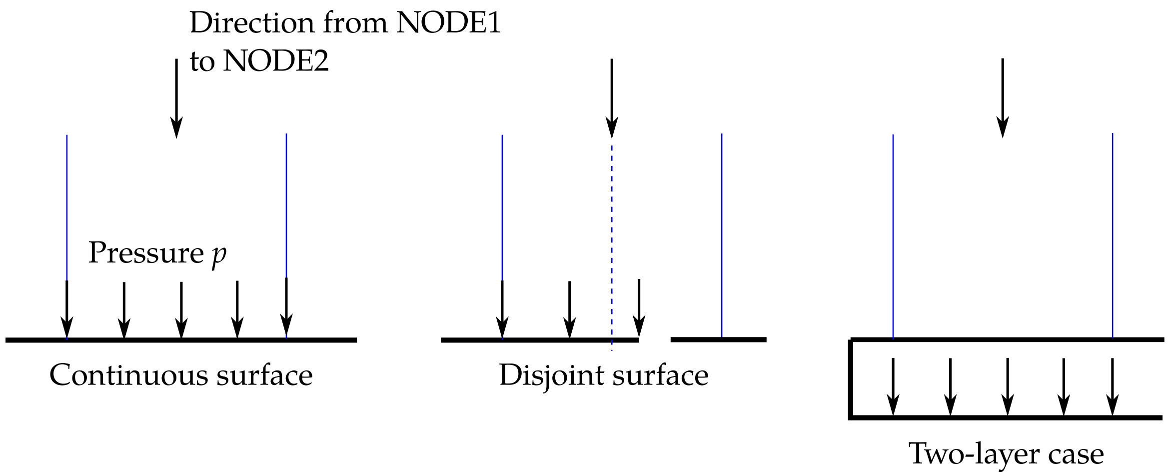

Figure 33-6. Applying pressure in SMP when LSFLG = 0

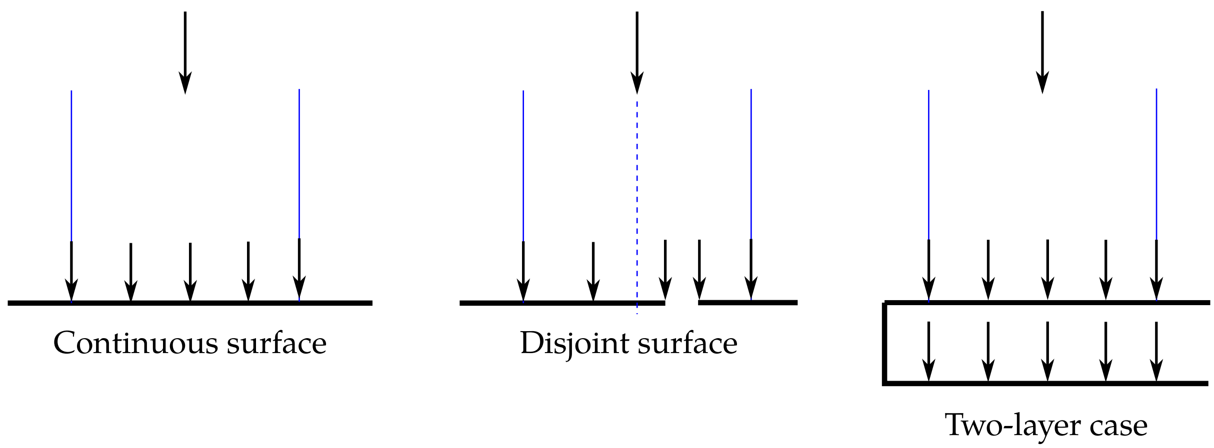

Figure 33-7. Applying pressure in MPP when LSFLG = 0

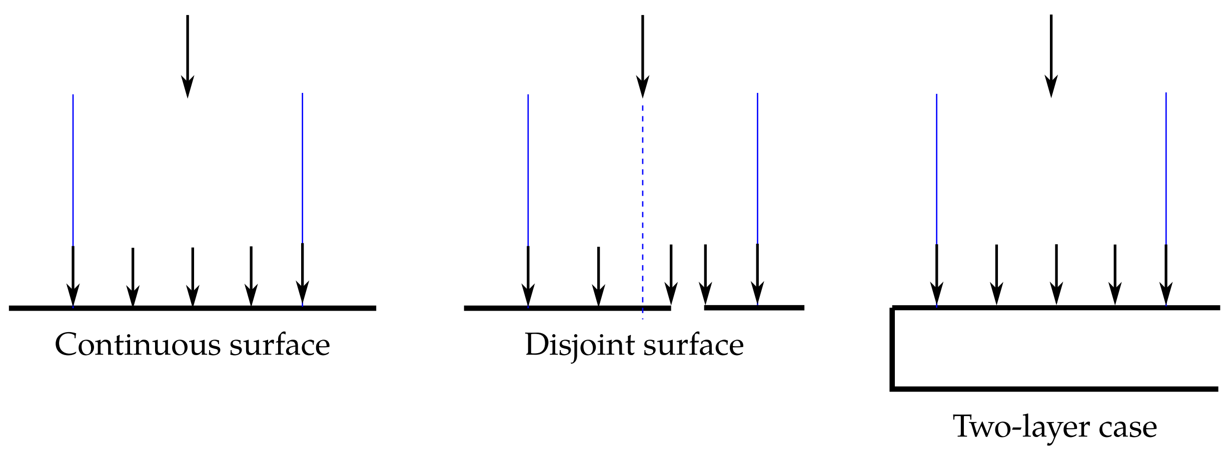

Figure 33-8. Applying pressure in SMP/MPP when LSFLG = 1

LOAD_NODE_*OPTION

Available options include:

POINT

SET

SET_ONCE

For SET_ONCE, the load function (LCID) is only evaluated once. The value is stored and applied to the rest of run.

Purpose: Apply a concentrated nodal force to a node or each node in a set of nodes.

Node/Node Set Cards. Include as many of this card for the SET and POINT keyword options or sets of this card with the next card for the SET_ONCE keyword option. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	NID/NSID	DOF	LCID	SF	CID	M1	M2	M3
Type	I	I	I	F	I	I	I	I
Default	none	none	none	1.	global	↓	↓	↓

VARIABLE	DESCRIPTION
NID/NSID	Node ID (POINT keyword option) or nodal set ID (SET or SET_-ONCE keyword option); see *SET_NODE.
DOF	Applicable degrees-of-freedom: EQ.1: x-direction of load action, EQ.2: y-direction of load action, EQ.3: z-direction of load action, EQ.4: Follower force (see Remark 2), EQ.5: Moment about the x-axis (see Remark 4), EQ.6: Moment about the y-axis axis (see Remark 4), EQ.7: Moment about the z-axis axis (see Remark 4), EQ.8: Follower moment (see Remarks 2 and 4).

VARIABLE	DESCRIPTION
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION and Remark 5 below). For SET_ONCE, LCID must refer to a function ID. In this case, the function is only evaluated once. The value is stored and applied for the rest of the run.
SF	Load curve scale factor. For SET_ONCE, this field is ignored.
CID	Coordinate system ID (optional); see Remark 1.
M1	Node 1 ID. Only necessary if DOF = 4 or 8; see Remark 2 below.
M2	Node 2 ID. Only necessary if DOF = 4 or 8; see Remark 2 below.
M3	Node 3 ID. Only necessary if DOF = 4 or 8; see Remark 2 below.

SET_ONCE Scale Factor Card. Include this card in a set with the previous card for the SET_ONCE keyword option. Include as many sets as necessary. This input ends at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	LCIDSF							
Type	I							
Default	none							

VARIABLE	DESCRIPTION
LCIDSF	Load curve ID giving a scale factor as a function of time which scales the stored value.

Remarks:

1. **Coordinate Systems.** The global coordinate system is the default. If CID is nonzero, the local coordinate is defined using *DEFINE_COORDINATE_*OPTION*, and furthermore, if *DEFINE_COORDINATE_NODES is used with FLAG=1 to define the local coordinate system, the local coordinate system and thus the direction of the applied load is updated with time; otherwise the

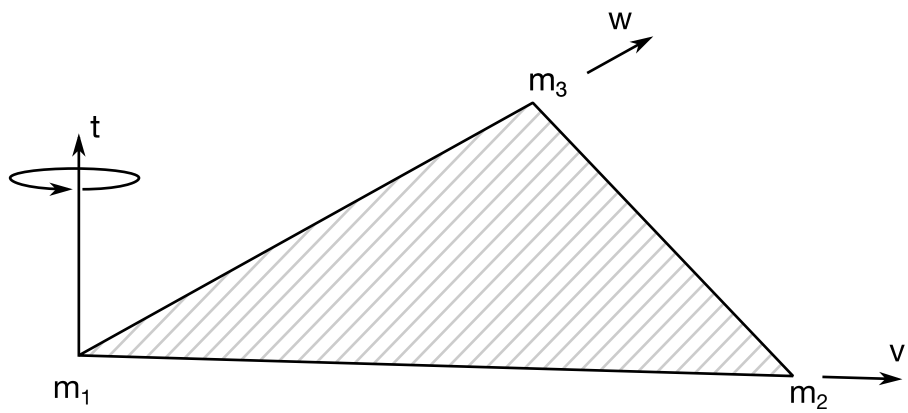

Figure 33-9. Nodes M1, M2, and M3 define a plane. A positive follower force acts in the positive t-direction of that plane, that is, along the normal vector of the plane. A positive follower moment puts a counterclockwise torque about the normal vector. The normal vector is found by the cross product $\mathbf{t} = \mathbf{v} \times \mathbf{w}$ where $\mathbf{v}$ and $\mathbf{w}$ are vectors as shown.

direction of the load is static. An alternative way to update the direction of the load is to use the follower forces option (see next remark).

2. **Follower Forces.** The current position of nodes M1, M2, and M3 are used to control the direction of a follower force. A positive follower force acts normal to the plane defined by these nodes, and a positive follower moment puts a counterclockwise torque about the t-axis. These actions are depicted in Figure 33-9. An alternative way to define the force direction is by setting M3 to any non-positive value, in which case the follower force is in the M1 to M2 direction.

3. **Axisymmetric Elements with Area and Volume Weighting.** For shell formulations 14 and 15, the axisymmetric solid elements with area and volume weighting, respectively, the specified nodal load is per unit length (type14) and per radian (type 15).

4. **Moments.** Moments can only be applied to nodes that have rotational degrees of freedom. Element type and formulation determine the degrees of freedom for a node. For example, the nodes of solid formulation 1 have only 3 translational degrees of freedom and no rotational degrees of freedom.

5. ***DEFINE_FUNCTION for LCID.** The function defined by LCID has 8 arguments: time (float), the 3 current coordinates (float), the 3 reference coordinates (float) and the number of nodes in the node set (int). A function that applies a force proportional to the distance from the initial coordinates would be:

```
f(t,x,y,z,x0,y0,z0,nnodes)= -10.*sqrt ( (x-x0)*(x-x0)+(y-y0)*(y-y0)+(z-z0)*(z-z0) )
```

Example:

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$   *LOAD_NODE_SET
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$  A cantilever beam (made from shells) is loaded on the two end nodes
$  (nodes 21 & 22).  The load is applied in the y-direction (dof=2).
$  Load curve number 1 defines the load, but is scaled by sf=0.5 in the
$  *LOAD_NODE_SET definition.
$
*LOAD_NODE_SET
$
$...>....1....>....2....>....3....>....4....>....5....>....6....>....7....>....8
$     nsid       dof      lcid        sf       cid        m1        m2        m3
        14         2         1       0.5
$
$
*SET_NODE_LIST
$      sid
        14
$
$     nid1      nid2      nid3      nid4      nid5      nid6      nid7      nid8
        21        22
$
$
*DEFINE_CURVE
$     lcid      sidr      scla      sclo      offa      offo
         1
$
$           abscissa            ordinate
                 0.0                 0.0
                10.0               100.0
                20.0                 0.0
$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

*LOAD_NURBS_SHELL_{OPTION}

The following option is available to define an ID for the load applied to a NURBS shell patch:

ID

If the ID is defined, an additional card is required.

Purpose: Apply a load over a NURBS shell patch.

Card Summary:

Card ID. This card is included if and only if the ID option is used.

ID	HEADING

Card 1. This card is required.

PTID	LCID	SF	AT	DT	LTYPE	REGDEF	

Card 1.1. This card is included if and only if LTYPE = "TRACT".

CID	V1	V2	V3				

Card 2a. This card included if and only if LTYPE = "PRESS" or "TRACT" and REGDEF = "RS". Define as many cards as needed.

RMIN	SMIN	RMAX	SMAX				

Card 2b. This card is included if and only if LTYPE = "PRESS" or "TRACT" and REGDEF = "NBEW". Define as many cards as needed.

NE1	NE2	NE3	NE4	NE5	NE6	NE7	NE8

Card 2c. This card is included if and only if LTYPE = "PRESS" or "TRACT" and REGDEF = "NBEP". Define as many cards as needed.

NT1	NT2	NT3	NT4	NTE			

Card 2d. This card is included if and only if LTYPE = "CRV," "CRVS," "CRVT," or "CRVN" and REGDEF = "RS". Define as many cards as needed.

R1	S1	R2	S2				

Card 2e. This card is included if and only if LTYPE = "CRV," "CRVS," "CRVT," or "CRVN" and REGDEF = "NBEP". Define as many cards as needed.

NC1	NC2	NCE					

Data Cards:

ID Card. Additional card for ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

VARIABLE	DESCRIPTION
ID	Loading ID
HEADING	A description of the loading.

Card 1	1	2	3	4	5	6	7	8
Variable	PTID	LCID	SF	AT	DT	LTYPE	REGDEF	
Type	I	I	F	F	F	A10	A10	
Default	none	none	1.	0.	10^{16}	PRESS	RS	

VARIABLE	DESCRIPTION
SSID	NURBS shell patch ID; see *ELEMENT_SHELL_NURBS_PATCH.
LCID	Load curve ID
SF	Load curve scale factor
AT	Arrival/birth time for load.
DT	Death time for load.

VARIABLE	DESCRIPTION
LTYPE	Load type. Default = “PRESS”. EQ.CRV: Loading is applied on a curve on a NURBS patch, along (V1,V2,V3) of CID coordinate system. The loading dimension is force per unit length along the curve. EQ.CRVS: Loading, force per unit length, is applied on a curve on the surface of a NURBS patch, along the local shear direction, CS direction, in Figure 33-10. EQ.CRVT: Loading, force per unit length, is applied on a curve on the surface of a NURBS patch, along the local transverse direction, CT direction, in Figure 33-10. EQ.CRVN: Loading, force per unit length, is applied on a curve on the surface of a NURBS patch, along the local normal direction, CN direction, in Figure 33-10. EQ.PRESS: Surface traction is applied on a region on a NURBS patch, along the opposite direction to the NURBS patch surface normal. The loading unit is force per unit area of the region. EQ.TRACT: Surface traction, force per unit area, is applied on a region on a NURBS patch, along (V1,V2,V3) of the coordinate system CID.
REGDEF	The method of defining the region of a NURBS shell patch on which the loading is applied. Default = “RS”. When LTYPE = “PRESS” or “TRACT”: EQ.RS: The extreme values of the univariate knot vector in local *r* and *s*-directions are used to define the traction application region; see RK*i* and SK*i* of *ELEMENT_SHELL_NURBS_PATCH. When not defined, the whole NURBS shell patch is subject to the traction. EQ.NBEW: The traction loading is applied to the whole NURBS-element which is identified by an interior node on the surface of the NURBS-element, such as NE1 through NE4 in Figure 33-10. EQ.NBEP: The traction loading is applied to part of a NURBS-element which is identified by four nodes on the surface of the NURBS-element, such as NT1 through NT4 in Figure 33-10. When LTYPE = “CRV,” “CRVS,” “CRVT,” or “CRVN”:

VARIABLE	DESCRIPTION
	EQ.RS: The values of (RK, SK) of the starting point and the ending point of a curve. NC1 and NC2 in Figure 33-10, on the surface of the NURBs shell patch are used to define the curve loading application region.
	EQ.NBEP: The curve loading is applied to a curve on a NURBS-element which is identified by two nodes on the surface of the NURBS-element, NC1 and NC2 in Figure 33-10.

"TRACT" Coordinate Card. Include this card if LTYPE = "TRACT." This card defines the traction load's coordinate system and loading direction.

Card 1.1	1	2	3	4	5	6	7	8
Variable	CID	V1	V2	V3				
Type	I	F	F	F				
Default	0	none	none	none				

VARIABLE	DESCRIPTION
CID	Coordinate system ID, only applicable when LTYPE = "TRACT".
V1, V2, V3	Vector direction cosines defining the direction of the traction loading.

Region definition card for surface traction loading using when LTYPE = "PRESS" or "TRACT" and REGDEF = "RS". Define as many cards as needed.

Card 2a	1	2	3	4	5	6	7	8
Variable	RMIN	SMIN	RMAX	SMAX				
Type	F	F	F	F				
Default	none	none	none	none				

VARIABLE	DESCRIPTION
RMIN, SMIN, RMAX, SMAX	The minimum and maximum values of the univariate knot vector in local *r* and *s*-directions of the area on which the pressure loading is applied. See *ELEMENT_SHELL_NURBS_PATCH for details.

Region definition card when LTYPE = "PRESS" or LTYPE = "TRACT" and REGDEF = "NBEW". Define as many cards as needed.

Card 2b	1	2	3	4	5	6	7	8
Variable	NE1	NE2	NE3	NE4	NE5	NE6	NE7	NE8
Type	I	I	I	I	I	I	I	I
Default	none	none	none	none	none	none	none	none

VARIABLE	DESCRIPTION
NE*i*	An interior node on the surface of the NURBS element on which the traction loading is applied.

Region definition card when LTYPE = "PRESS" or LTYPE = "TRACT" and REGDEF = "NBEP". Define as many cards as needed.

Card 2c	1	2	3	4	5	6	7	8
Variable	NT1	NT2	NT3	NT4	NTE			
Type	I	I	I	I	I			
Default	none	none	none	none	see below			

VARIABLE	DESCRIPTION
NT*i*	Nodes defining an area on the surface of a NURBS element where loading is applied. Using nodes shared with other NURBS elements, such as node NB in Figure 33-10, as NT*i* is not recommended.
NTE	Optional node used to identify the NURBS element on which the load application area defined by the NT*i*'s is located. NTE is *only*

VARIABLE	DESCRIPTION
	needed when *all* NT*i*'s are shared with other NURBS elements. If not defined, node NT1 has to be owned exclusively by the NURBS element containing the load application region.

Region definition card for curve loading when LTYPE = "CRV", "CRVS", "CRVT", or "CRVN" and REGDEF = "RS". Define as many cards as needed.

Card 2d	1	2	3	4	5	6	7	8
Variable	R1	S1	R2	S2				
Type	F	F	F	F				
Default	none	none	none	none				

VARIABLE	DESCRIPTION
R1, S1, R2, S2	The univariate knot vector in local *r* and *s*-directions of the starting and ending points of the curve on which the curve loading is applied. An example would be the knot vector for nodes NC1 and NC2 as shown in Figure 33-10.

Region definition card for curve loading when LTYPE = "CRV", "CRVS", "CRVT", or "CRVN" and REGDEF = "NBEP". Define as many cards as needed.

Card 2e	1	2	3	4	5	6	7	8
Variable	NC1	NC2	NCE					
Type	I	I	I					
Default	none	none	see below					

VARIABLE	DESCRIPTION
NC*i*	Nodes defining a curve on the surface of a NURBS element where loading is applied. Using nodes shared with other NURBS elements, such as node NB in Figure 33-10, as NC*i* is not recommended.

VARIABLE	DESCRIPTION
NCE	Optional node used to identify the NURBS element on which the load application curve defined by the NT*i*s is located. NCE is *only* needed when *both* NC*i*s are shared with other NURBS elements. If not defined, node NC1 has to be owned exclusively by the NURBS element containing the load application curve.

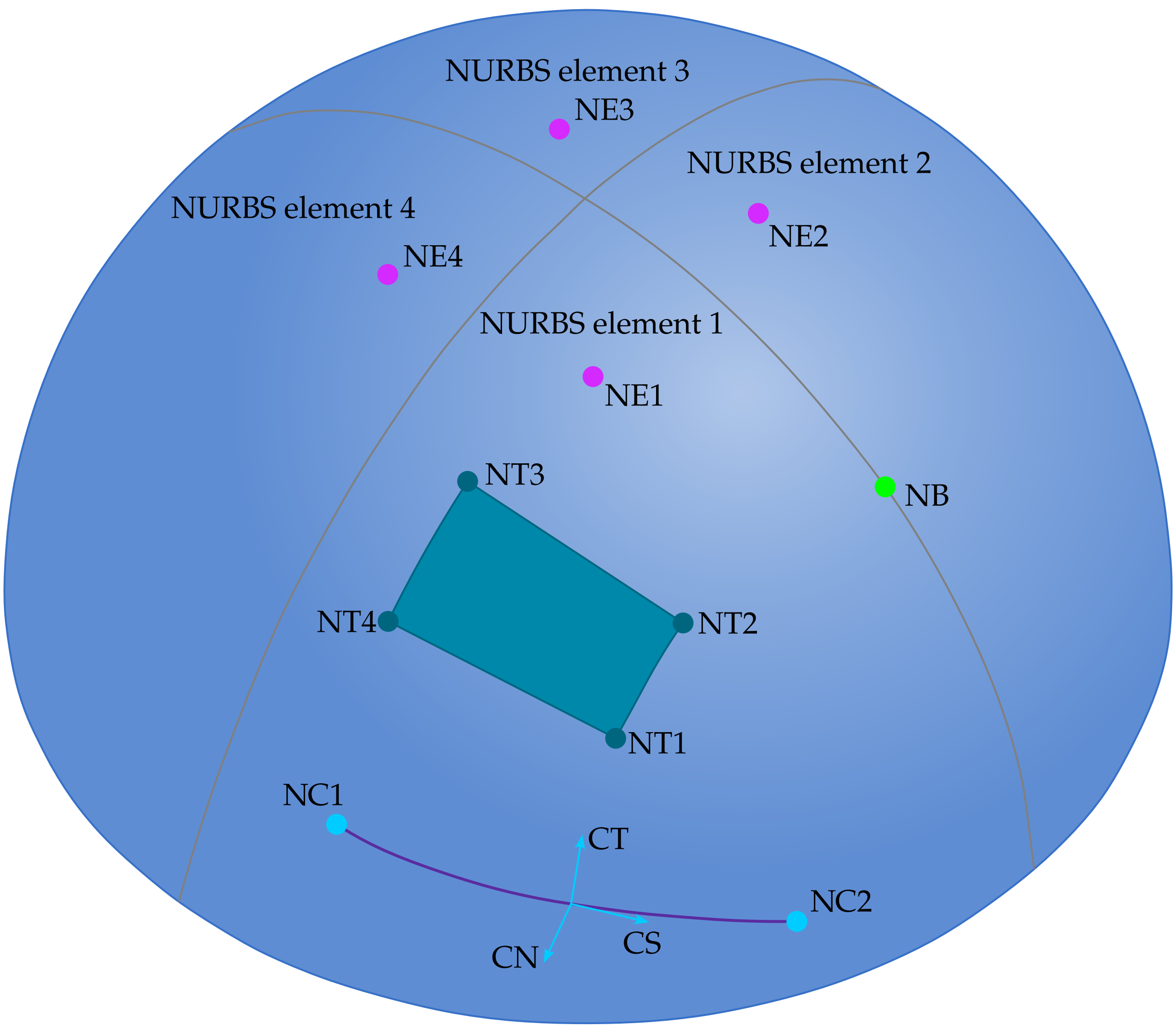

Figure 33-10. NURBS shell patch with four NURBS shell elements.

*LOAD_POINT_UVW_{OPTION}

Available options include:

SET

Purpose: Apply a concentrated force to a parametric point or each parametric point in a set of parametric points.

Point/Point Set Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID	DOF	LCID	SF				
Type	I	I	I	F				
Default	none	none	none	1.				

VARIABLE	DESCRIPTION
PID	Parametric point ID or parametric point set ID for the SET keyword option; see *IGA_POINT_UVW and *SET_IGA_POINT_UVW
DOF	Applicable degrees-of-freedom: EQ.1: x-direction of load action, EQ.2: y-direction of load action, EQ.3: z-direction of load action, EQ.5: Moment about the x-axis, EQ.6: Moment about the y-axis axis, EQ.7: Moment about the z-axis axis.
LCID	Load curve ID (see *DEFINE_CURVE)
SF	Load curve scale factor

*LOAD_PYRO_ACTUATOR

Purpose: Calculate forces from a pyrotechnic actuator between nodes/segments. The main application in mind is active hood lifters for pedestrian protection. The keyword models the expansion/contraction of the gas chamber in a piston actuator using a mass flow curve, the chamber cross section area, and cylinder length determined by the nodes/segments. It uses the same gas law as *AIRBAG_SIMPLE_AIRBAG_MODEL but does not require modeling the chamber/piston. You can access chamber solution data by including *DATABASE_PYRO in the input deck.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	ID1	ID2	CSA	VOL	PRS	DENS	ATIME
Type	I	I	I	F	F	F	F	F

Card 2	1	2	3	4	5	6	7	8
Variable	MCID	CV	CP	TEMP				
Type	F	F	F					

VARIABLE	DESCRIPTION
ID	Unique ID for actuator
ID1	Node or segment set where forces act on one side of the chamber (see Remarks): GT.0: Node ID LT.0: |ID1| is a segment set ID.
ID2	Node or segment set where forces act on the other side of the chamber (see Remarks): GT.0: Node ID LT.0: |ID2| is a segment set ID.
CSA	Chamber cross section area
VOL	GT.0: Initial chamber volume

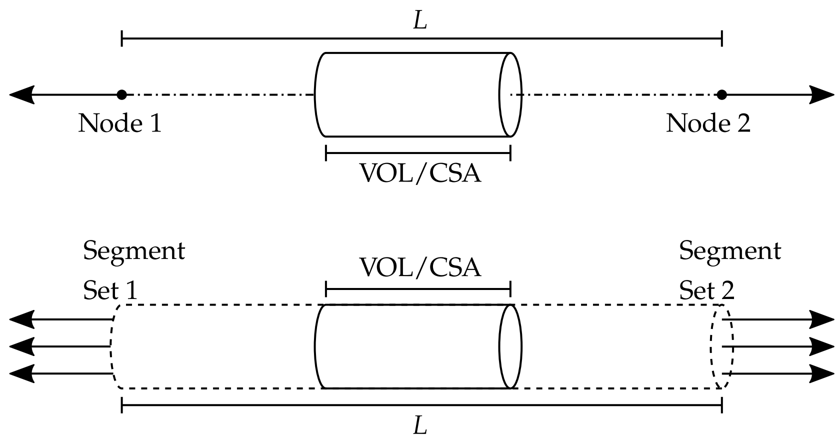

Figure 33-11. Model of a chamber between nodes or segments. For VOL > 0.0, the initial chamber length is VOL/CSA which may be shorter or longer than the node/set distance L.

VARIABLE	DESCRIPTION
	EQ.0: Initial chamber volume given by distance between ID1 and ID2. See Remarks and Figure 33-11.
PRS	Ambient pressure
DENS	Ambient gas density
ATIME	Activation time
MCID	Mass flow curve ID (mass flow as function of time)
CV	Specific heat capacity at constant pressure
CP	Specific heat capacity at constant volume
TEMP	Gas generator temperature

Remarks:

This feature calculates axial forces resulting from pressure in a (cylindric) chamber of varying length. ID1 and ID2 can be segment sets or single nodes upon which the forces act. Before the activation time, ATIME,

$$p(t) = \mathrm{PRS} \ .$$

Starting at the activation time, LS-DYNA solves the following pressure ODE:

$$\dot{p}(t) = \frac{\gamma}{V(t)}\left(R \times \mathrm{TEMP} \times \mathrm{MCID}(t) - p(t)\dot{V}(t)\right) \ .$$

where

$$R = \mathrm{CP} - \mathrm{CV}, \qquad \gamma = \frac{\mathrm{CP}}{\mathrm{CV}} \ .$$

The chamber volume is given by

$$V(t) = \begin{cases} \big(L(t) - L(\mathrm{ATIME})\big) \times \mathrm{CSA} + \mathrm{VOL}, & \mathrm{VOL} > 0, \\ L(t) \times \mathrm{CSA}, & \mathrm{VOL} = 0, \end{cases}$$

where the length, $L(t)$, is the current distance between the nodes/sets ID1 and ID2. Note that for VOL > 0.0, the actual chamber length may be shorter or longer than the distance between ID1 and ID2. For VOL $= 0$, ID1 and ID2 mark the endpoints of the chamber. If ID1 and ID2 are nodes, the initial length must be greater than 0 to calculate the direction of the forces on the nodes. We assume the segment sets are planar, parallel, and form the two ends of a chamber. The forces are applied in the direction of the segment normal vectors.

*LOAD_PZE

Purpose: Apply a concentrated or distributed electric charge over a set of segments or nodes with piezoelectric properties.

Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	SETID	LCID	SF	SETYP				
Type	I	I	F	A				
Default	none	0	none	NSET				

VARIABLE	DESCRIPTION
SETID	Set ID; see *SET_SEGMENT or *SET_NODE.
LCID	Load curve gives concentrated charge (in electric charge units) or distributed electric charge (in unit of electric charge per unit area) vs. time.
SF	Scale factor on curve or constant electric charge if LCID = 0.
SETYP	Type of SETID EQ.NSET: SETID is a node set. EQ.SEGSET: SETID is a segment set.

LOAD_REMOVE_PART_*{OPTION}

Available options include:

<BLANK>

SET

Purpose: Delete the elements of a part in a staged construction simulation. Shock effects are prevented by gradually reducing the stresses prior to deletion. This feature is available for solid, shell, thick shell and beam elements.

Part Cards. Include as many cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID/PSID	TIME0	TIME1	STGR				
Type	I	F	F	I				
Default	none	0.	0.	0				

VARIABLE	DESCRIPTION
PID	Part ID (or Part Set ID for the SET keyword option) for deletion
TIME0	Time at which stress reduction starts
TIME1	Time at which stresses become zero and elements are deleted
STGR	Construction stage at which the part is removed (optional)

Remarks:

There are 3 methods to define the part removal time:

1. TIME0 and TIME1 override all the other methods if non-zero.

2. STGR refers to the stage at which the part is removed; the stages are defined in *DEFINE_CONSTRUCTION_STAGES. This method is equivalent to setting TIME0 and TIME1 equal to the start and end of the ramp time at the beginning of stage STGR.

3. *DEFINE_STAGED_CONSTRUCTION_PART can be used instead of *LOAD_-REMOVE_PART to achieve the same effect.

*LOAD_RIGID_BODY

Purpose: Apply a concentrated nodal force to a rigid body. The force is applied at the center of mass or a moment is applied around a global axis. As an option, local axes can be defined for force or moment directions.

Rigid Body Cards. Include as many Rigid Body Cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID	DOF	LCID	SF	CID	M1	M2	M3
Type	I	I	I	F	I	I	I	I
Default	none	none	none	1.	global	0	0	0

VARIABLE	DESCRIPTION
PID	Part ID of the rigid body; see *PART_*OPTION*.
DOF	Applicable degrees-of-freedom: EQ.1: x-direction of load action, EQ.2: y-direction of load action, EQ.3: z-direction of load action, EQ.4: follower force; see Remark 2, EQ.5: moment about the x-axis, EQ.6: moment about the y-axis, EQ.7: moment about the z-axis. EQ.8: follower moment; see Remark 2.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION and Remark 3). GT.0: force as a function of time. LT.0: force as a function of the absolute value of the rigid body displacement. This option only applies to load curves.
SF	Load curve scale factor

VARIABLE	DESCRIPTION
CID	Coordinate system ID. See Remark 1.
M1	Node 1 ID. Only necessary if DOF = 4 or 8; see Remark 2.
M2	Node 2 ID. Only necessary if DOF = 4 or 8; see Remark 2.
M3	Node 3 ID. Only necessary if DOF = 4 or 8; see Remark 2.

Remarks:

1. **Coordinate System.** The global coordinate system is the default. The local coordinate system ID's are defined in the *DEFINE_COORDINATE_SYSTEM section. This local axis is fixed in inertial space, i.e., it does not move with the rigid body.

2. **Follower Force and Moments.** Nodes M_1, M_2, and M_3 must be defined for a follower force or moment. The follower force acts normal to the plane defined by these nodes as depicted in Figure 33-9. The positive t-direction is found by the cross product $\mathbf{t} = \mathbf{v} \times \mathbf{w}$ where $\mathbf{v}$ and $\mathbf{w}$ are vectors as shown. The follower force is applied at the center of mass. A positive follower moment puts a counterclockwise torque about the t-axis. An alternative way to define the force direction is by setting M_3 to any non-positive value, in which case the follower force is in the M_1 to M_2 direction.

3. **Force Function.** When LCID defines a function, the function has seven arguments: time, the 3 current coordinates for the center of mass, and the 3 reference coordinates. A function that applies a force proportional to the distance from the initial coordinates would be

f(t,x,y,z,x0,y0,z0)= -10.*sqrt ((x-x0)*(x-x0)+(y-y0)*(y-y0)+(z-z0)*(z-z0)).

Example:

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$   *LOAD_RIGID_BODY
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$  From a sheet metal forming example.  A blank is hit by a punch, a binder is
$  used to hold the blank on its sides.  The rigid holder (part 27) is held
$  against the blank using a load applied to the cg of the holder.
$
$  The direction of the load is in the y-direction (dof=2) but is scaled
$  by sf = -1 so that the load is in the correct direction.  The load
$  is defined by load curve 12.
$
```

```
*LOAD_RIGID_BODY
$
$...>....1....>....2....>....3....>....4....>....5....>....6....>....7....>....8
$      pid       dof      lcid        sf       cid        m1        m2        m3
        27         2        12      -1.0
$
$
*DEFINE_CURVE
$     lcid      sidr      scla      sclo      offa      offo
        12
$
$           abscissa            ordinate
           0.000E+00           8.000E-05
           1.000E+04           8.000E-05
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

*LOAD_SEGMENT_{OPTION}

To define an ID for the segment loading, the following option is available:

ID

If the ID is defined, an additional card is required.

Purpose: Apply the distributed pressure load over one triangular or quadrilateral segment defined by four, six, or eight nodes, or in the case of two-dimensional geometries, over one two-noded line segment. The pressure and node numbering convention are specified in Figure 33-12. To apply a uniform pressure, see Remark 5.

ID Card. Additional card for the ID keyword option.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Card 2	1	2	3	4	5	6	7	8
Variable	LCID	SF	AT	N1	N2	N3	N4	N5
Type	I	F	F	I	I	I	I	I
Default	none	1.	0.	none	none	none	none	none

Additional card for when N5 $\neq$ 0.

Card 3	1	2	3	4	5	6	7	8
Variable	N6	N7	N8					
Type	I	I	I					
Default	none	none	none					

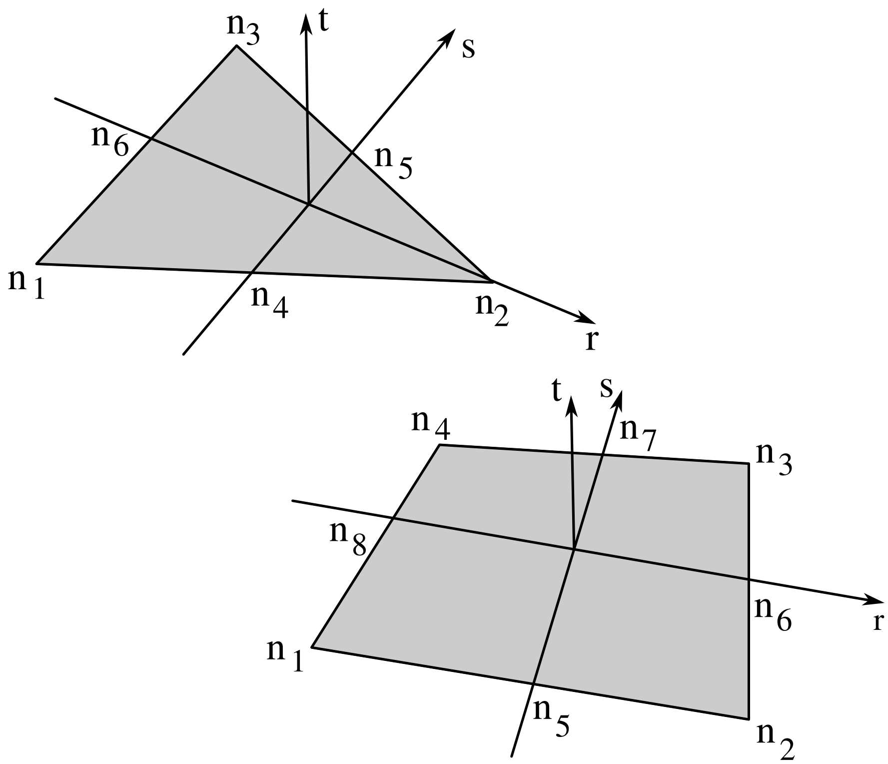

Figure 33-12. Nodal numbering for pressure segments in three-dimensional geometries. Positive pressure acts in the negative **t**-direction.

VARIABLE	DESCRIPTION
ID	Loading ID
HEADING	A description of the loading.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). For a load curve ID, the load curve gives the pressure as a function of time. For a function ID, the function for pressure has 10 arguments: time, the 3 current coordinates, the 3 reference coordinates, and the 3 velocities; that is, f(t,x,y,z,x0,y0,z0,vx,vy,vz). See Remark 1.
SF	Load curve scale factor. See Remark 2.
AT	Arrival time for pressure or birth time of pressure. See Remark 3.
N1	Node ID
N2	Node ID
N3	Node ID. See Remark 4.

VARIABLE	DESCRIPTION
N4	Node ID. See Remark 4.
N5	Mid-side node ID, if applicable. See Figure 33-12.
N6	Mid-side node ID, if applicable. See Figure 33-12.
N7	Mid-side node ID, if applicable. See Figure 33-12.
N8	Mid-side node ID, if applicable. See Figure 33-12.

Remarks:

1. **Empirical functions for pressure.** If LCID is input as -1, then the Brode function is used to determine the pressure for the segments; see *LOAD_BRODE. If LCID is input as -2, then an empirical airblast function is used to determine the pressure for the segments; see *LOAD_BLAST.

2. **Load curve multipliers.** The load curve multipliers may be used to increase or decrease the pressure. The time value is not scaled.

3. **Activation time.** The activation time, AT, is the time during the solution that the pressure begins to act. Until this time, the pressure is ignored. The function value of the load curves will be evaluated at the offset time given by the difference of the solution time and AT, that is, solution time − AT.

4. **Triangular segments and two-dimensional geometries.** Triangular segments without mid-side nodes are defined by setting N4 = N3. Segments for two-dimensional geometries are defined by two nodes, N1 and N2. Leave N3 and N4 as zero or set both equal to N2. A positive pressure acts on the segment in the $\hat{\mathbf{z}} \times (\mathrm{N1} - \mathrm{N2})$ direction where $\hat{\mathbf{z}}$ is the unit vector in the z-direction and (N1 − N2) is the vector from N1 to N2.

5. **Uniform pressure.** To apply a uniform pressure to type 17 tetrahedral elements, 4 triangular segments should be defined for each loaded face of an element. Three of the segments should each have one corner node and the two adjacent mid-side nodes. The 4$^{\text{th}}$ segment should be made from the 3 mid-side nodes.

   To apply a uniform pressure to type 16 tetrahedral elements or type 24 triangular shell elements, one 6-node segment may be defined for each loaded face. However, this segment loading feature will accept and properly treat "any" other segment definition. In other words, if the preprocessor happens to create *one* 3-node segment corresponding to local node numbering convention {1,2,3,3} in Figure 33-12, or permutations thereof, then this will internally be detected as a 6-node segment, and the nodal forces will be consistently distributed over the 6 involved nodes. Likewise, if four 3-noded segments corresponding to local node numbering conventions {1,4,6,6}, {2,5,4,4}, {3,6,5,5} and {4,5,6,6}, or permutations thereof, are created, then these will be detected to belong to the same 6-noded segment and again result in the correct nodal forces. The difference between the two latter approaches is that using four "sub-segments" will provide four different normal directions **t** instead of just one, and for curved faces this will provide a more accurate representation of the pressure load.

To apply a uniform pressure to type 23 hexahedral elements or type 23 quadrilateral shell elements, one 8-node segment may be defined for each loaded face. However, this segment loading feature will accept and properly treat a segment excluding the 4 mid-side nodes. In other words, if the preprocessor happens to create just one 4-noded segment corresponding to local node numbering convention {1,2,3,4} in Figure 33-12, or permutations thereof, then this will internally be detected as an 8-node segment, and the nodal forces will be consistently distributed over the 8 involved nodes.

To apply a uniform pressure to type 24 hexahedral elements, either one 4-node segment corresponding to the numbering convention {1,2,3,4} in Figure 33-12, or permutations thereof, may be defined for each loaded face. But this segment loading feature will also accept and properly treat *four* 4 node segments corresponding to {1,5,9,8}, {2,6,9,5}, {3,7,9,6} and {4,8,9,7}, where local node number 9 is located in the center of the face. The difference between these two approaches is that using four "sub-segments" will provide four different normal directions **t** instead of just one, and for curved faces this will provide a more accurate representation of the pressure load.

6. **Example.** The partial input deck below applies pressure to a solid block, using this keyword. The function defined by LCID has 10 arguments: time, the 3 current coordinates, the 3 reference coordinates, and the 3 velocities. A function that applies a pressure proportional to the distance from the initial coordinates with damping in the x-direction would be, for example,

f(t,x,y,z,x0,y0,z0,vx,vy,vz)= 10.*sqrt ((x-x0)*(x-x0)+(y-y0)*(y-y0)+(z-z0)*(z-z0))+2.*vx

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$   *LOAD_SEGMENT
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$  A block of solid elements is pressed down onto a plane as it moves along
$  that plane.  This pressure is defined using the *LOAD_SEGMENT keyword.
$
$  The pressure is applied to the top of the block.  This top is defined
$  by the faces on top of the appropriate solid elements.  The faces are
$  defined with segments.  For example, nodes 97, 106, 107 & 98 define
$  a top face on one of the solids (and thus, one of the faces to apply the
```

```
$  pressure too).  This "face" is referred to as a single segment.
$
$  The load is defined with load curve number 1.  The curve starts at zero,
$  ramps to 100 in 0.01 time units and then remains constant.  However,
$  the curve is then scaled by sclo = 2.5.  Thus, raising the load to 250.
$  Note that the load is NOT scaled in the *LOAD_SEGMENT keyword, but
$  could be using the sf variable.
$
*LOAD_SEGMENT
$
$...>....1....>....2....>....3....>....4....>....5....>....6....>....7....>....8
$     lcid        sf        at        n1        n2        n3        n4
         1      1.00       0.0        97       106       107        98
         1      1.00       0.0       106       115       116       107
         1      1.00       0.0        98       107       108        99
         1      1.00       0.0       107       116       117       108
$
$
*DEFINE_CURVE
$
$     lcid      sidr      scla      sclo      offa      offo
         1         0       0.0       2.5
$
$           abscissa            ordinate
               0.000                 0.0
               0.010               100.0
               0.020               100.0
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

*LOAD_SEGMENT_ALE_INI

Purpose: Apply the initial pressures of boundary ALE elements to their faces that lack neighbors. This keyword has no data cards.

*LOAD_SEGMENT_CONTACT_MASK

Purpose: Mask the pressure from a *LOAD_SEGMENT_SET when the pressure segments are in contact with another material. For non-Mortar contact, this keyword is currently only supported in the MPP version, while Mortar contact is supported in all versions. Note that the Heading Card is required.

Heading Card.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Load Set Card.

Card 2	1	2	3	4	5	6	7	8
Variable	LSID	P1	P2	CID1	CID2	CID3	CID4	CID5
Type	I	F	F	I	I	I	I	I

Optional Cards. Include as many cards as desired. This data ends at the next keyword ("*") card.

Card 3	1	2	3	4	5	6	7	8
Variable	CID6	CID7	CID8	CID9	CID10	CID11N	CID12	CID13
Type	I	I	I	I	I	I	I	I

VARIABLE	DESCRIPTION
LSID	Load set ID to mask, which must match a *LOAD_SEGMENT_SET. See Remark 2.
P1	Lower pressure limit. When the surface pressure due to contact is below P1, no masking is done and the full load defined in *LOAD_-SEGMENT_SET is applied. For pressures between P1 and P2 see Remark 1.

VARIABLE	DESCRIPTION
P2	Upper pressure limit. When the surface pressure due to contact is above P2, no load is applied due to the *LOAD_SEGMENT_SET. For pressures between P1 and P2 see Remark 1.
CID*n*	The IDs of contacts that can mask the pressure loads. The specified contact definitions must all be of the same type. Furthermore, only non-automatic SURFACE_TO_SURFACE (two way) and AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK contacts are supported. For TIEBREAK contacts, pressure is masked until the tie fails. Once the tie fails, the full pressure will be applied for the remainder of the simulation. The values P1 and P2 are ignored. For other contact types, the contact forces, along with the nodal contact surface areas, are used to compute the contact pressure at each node to determine any masking effect.

Remarks:

1. **Intermediate Pressures.** If the contact pressure, p_{contact} is between P1 and P2, the pressure load is scaled by a factor of

$$f = \frac{\mathrm{P2} - p_{\mathrm{contact}}}{P2 - P1}.$$

   P1 may be set equal to P2 if desired.

2. **LSID.** The LSID values must be unique. Having two instances of this referencing the same*LOAD_SEGMENT_SET *is not supported*. However, a contact ID *may* appear in two different instances of this keyword.

3. **IDOF on *SECTION_SHELL.** When IDOF = 3 on *SECTION_SHELL, the shell thickness strain is governed by the stress from contact and pressure loads. If IDOF = 3 *and* the masking contact is of Mortar type, the masking will not apply for the thickness strain. Other contact types do not have this limitation.

*LOAD_SEGMENT_FILE

Purpose: To define *time-varying* distributed pressure loads over triangular or quadrilateral segments defined by four, six, or eight nodes using *a binary file*.

Card 1	1	2	3	4	5	6	7	8
Variable	FILENAME							
Type	A80							

Card 2 is required but may be left blank.

Card 2	1	2	3	4	5	6	7	8
Variable	LCID							
Type	I							
Default	none							

VARIABLE	DESCRIPTION
FILENAME	Filename of binary database containing segment pressures as a function of time. There are three sections in this database.
LCID	Optional load curve ID defining segment pressure scale factor as a function of time.

Remarks:

Each database is assumed to be written with a block size equal to a multiple of 512 words, with each block containing 1 or more states. If the data does not complete the last block, it is padded with zeros. The code will open and read the next family file if it detects a phony word or EOF. If the IO returns a zero length read, the code assumes end of IO and stops reading.

Linear interpolation is used if the IO can find the current time between two states. Therefore, the given database can have more states than simulation time steps.

Linear extrapolation will only be used when the IO reaches the end of the database. The last two states will be used and the warning message "MSG_SOL+1323" will be issued to the d3hsp and messag files.

Section	Words	Description
Control Section 64 words	10	Title
	1	NSEG: The absolute value, |NSEG|, specifies the number of segments contained within the file. If NSEG < 0, then the file contains mid-side nodes.
Segment Data 4 words	1	N1: Node ID.
	1	N2: Node ID.
	1	N3: Node ID. Repeat N2 for two-dimensional geometries.
	1	N4: Node ID. Repeat N2 for two-dimensional geometries or repeat N3 for 3-node triangular segments.
Mid-side Nodes 4 Words. Omitted unless NSEG < 0.	1	N5: Optional mid-side node ID.
	1	N6: Optional mid-side node ID.
	1	N7: Optional mid-side node ID.
	1	N8: Optional mid-side node ID.
⋮	4 or 8	⋮
NSEGth segment data	4 or 8	Last set of segment data
"State" Section 1 + |NSEG| words	1	Time
	1	Segment Pressure
	⋮	⋮
	1	Pressure of last segment
⋮	1	⋮
	NSEG	⋮

*LOAD_SEGMENT_FSILNK

Purpose: Apply distributed pressure loads from a previous ALE analysis to a specified segment set in the current analysis. This capability trades some of the model's accuracy for a large reduction in model size.

> NOTE: The deck for the "previous" run must include a *DATABASE_BINARY_FSILNK card to activate the creation of the fsilink file. Either the *LOAD_SEGMENT_-FSILNK card (this card) or the *DATABASE_BINARY_FSILNK card may be in an input deck, *but not both*.

Card 1	1	2	3	4	5	6	7	8
Variable	FILENAME							
Type	A80							

Card 2	1	2	3	4	5	6	7	8
Variable	NINT	LCID						
Type	I	I						
Default	none	0						

Coupling ID Cards. Read in NINT coupling IDs. Repeat this card as many times as necessary to input all NINT values.

Card 3	1	2	3	4	5	6	7	8
Variable	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8
Type	I	I						
Default	none	none						

VARIABLE	DESCRIPTION
FILENAME	Filename of the interface linking file.
NINT	Number of couplings for which the previous run provides pressure data.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). The curve referred to by LCID provides a scale factor as a function of time. The pressure data that is read in from the fsilnk file is scaled according to this value.
ID*i*	These must match COUPIDs from the *CONSTRAINED_LAGRANGE_IN_SOLID card from the previous runs. These IDs specify which of the first run's couplings are propagated into this run through pressure data read from the fsilnk file.

The algorithm:

This feature provides a method for using pressure time history data from *CONSTRAINED_LAGRANGE_IN_SOLID Lagrangian-to-ALE couplings in one calculation as pressure data for the same segment in subsequent calculations. The time range covered by the subsequent calculation *must* overlap the time range of the initial calculation.

First calculation: Write out pressure data.

1. Add a *DATABASE_BINARY_FSILNK card to the first run.

2. Specify filename for the fsilnk file by adding a command line argument to ls-dyna.

   ls-dyna … fsilnk=**fsi_filename** …

   Without a *DATABASE_BINARY_FSILNK card this command line argument will have no effect.

Format of fsilnk File:

WRITE: Job title (character*80 TITLE)
WRITE: Number of interfaces (integer NINTF)

For i = 1 to NINTF {

  WRITE: Number of segments in the i^{th} interface (integer NSEG[i])

  For j = 1 to NSEG[i] {

```
                WRITE: Connectivities of jth segment in the ith interface (integer*4)
        }
}
For n = 1 to number of time steps {
        WRITE: time value for the nth time step (real)
        For i = 1 to NINTF
                For j = 1 to NSEG[i] {
                        WRITE: Pressure for the jth segment of the ith interface (real)
                }
        }
}
```

Subsequent calculations: Read fsilnk File.

Include this keyword, *LOAD_SEGMENT_FSILNK, and be careful to remove the *DATABASE_BINARY_FSILNK keyword. Specify the name of the fsilnk file from the previous run on *LOAD_SEGMENT_FSILNK's first data card.

Then, at each time step, the pressure of the specified coupling IDs is set on the Lagrangian-mesh side from data in the fsilnk file. For times outside of the fsilnk file's range LS-DYNA extrapolates.

1. If current time is before the 1st fsilnk time, then pressure is set to 0.

2. If the current time is in the range of times in the fsilnk file, then the pressure is linearly interpolated from the data at the two time states in the fsilnk file bracketing the current time.

3. If the current time is after the last fsilnk time, then the pressure is set to the fsilnk pressure at last time step.

LOAD_SEGMENT_NONUNIFORM_*{OPTION}

To define an ID for the non-uniform segment loading the following option is available:

ID

If the ID option is used, an additional card is required.

Purpose: Apply a distributed load over one triangular or quadrilateral segment defined by three, four, six, or eight nodes. The loading and node numbering convention follows Figure 33-9.

ID Card. Additional card for ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Card Sets. Each segment is specified by a set of the following 3 cards. Include as many sets as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	LCID	SF	AT	DT	CID	V1	V2	V3
Type	I	F	F	F	I	F	F	F
Default	none	1.	0.	1.E+16	0	none	none	none

Card 2	1	2	3	4	5	6	7	8
Variable	N1	N2	N3	N4	N5	N6	N7	N8
Type	I	I	I	I	I	I	I	I
Default	none	none	none	none	none	none	none	none

Card 3	1	2	3	4	5	6	7	8
Variable	P1	P2	P3	P4	P5	P6	P7	P8
Type	F	F	F	F	F	F	F	F
Default	none	none	none	none	none	none	none	none

VARIABLE	DESCRIPTION
ID	Loading ID
HEADING	A description of the loading.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). For a load curve ID the load curve must provide pressure as a function of time. For a function ID, the function is expected to have seven arguments: current time minus the birth time, the current x, y, and z coordinates, and the initial x, y, and z coordinates. LT.0: Applies to 3, 4, 6 and 8-noded segments. With this option the load becomes a follower load, meaning that the direction of the load is constant with respect to the local segment coordinate system.
SF	Load curve scale factor
AT	Arrival / birth time for the traction load.
DT	Death time for the traction load
CID	Coordinate system ID
V1, V2, V3	Vector direction cosines relative to coordinate system CID defining the direction of the traction loading. Note that for LCID < 0 this vector rotates with the geometry of the segment.
N1	Node ID
N2	Node ID
N3	Node ID. Repeat N2 for two-dimensional geometries.

VARIABLE	DESCRIPTION
N4	Node ID. Repeat N2 for two-dimensional geometries or repeat N3 for 3-node triangular segments.
N5	Optional mid-side node ID (see Figure 33-12).
N6	Optional mid-side node ID (see Figure 33-12).
N7	Optional mid-side node ID (see Figure 33-12).
N8	Optional mid-side node ID (see Figure 33-12).
P1	Scale factor at node ID, N1.
P2	Scale factor at node ID, N2.
P3	Scale factor at node ID, N3.
P4	Scale factor at node ID, N4.
P5	Scale factor at node ID, N5.
P6	Scale factor at node ID, N6.
P7	Scale factor at node ID, N7.
P8	Scale factor at node ID, N8.

*LOAD_SEGMENT_SET_{OPTION}

To define an ID for the segment loading, the following option is available:

ID

If the ID is defined, an additional card is required.

Purpose: Apply the distributed pressure load over each segment in a segment set. See *LOAD_SEGMENT for a description of the pressure sign convention and remarks on higher order segment definitions.

ID Card. Additional card for the ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Segment Set Cards. Include as many segment set cards as necessary. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	SSID	LCID	SF	AT				
Type	I	I	F	F				
Default	none	none	1.	0.				
Remarks		1	2	3				

VARIABLE	DESCRIPTION
SSID	Segment set ID, see *SET_SEGMENT.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). For a load curve ID, the load curve must provide pressure as a function of time. For a function ID, the function for pressure has 10 arguments: time, the 3 current coordinates, the 3 reference coordinates, and the 3 velocities; that is,

VARIABLE	DESCRIPTION
	f(t,x,y,z,x0,y0,z0,vx,vy,vz). See Remark 1.
SF	Load curve scale factor
AT	Arrival time for pressure or birth time of pressure.

Remarks:

1. **Pressure functions.** If LCID is input as -1, then the Brode function is used to determine pressure for the segment set; see *LOAD_BRODE. If LCID is input as -2, then an empirical airblast function is used to determine the pressure for the segments; see *LOAD_BLAST.

2. **Load curve multipliers.** The load curve multipliers may be used to increase or decrease the pressure. The time value is not scaled.

3. **Activation time.** The activation time, AT, is the time during the solution that the pressure begins to act. Until this time, the pressure is ignored. The function value of the load curves will be evaluated at the offset time given by the difference of the solution time and AT, that is, (solution time-AT).

*LOAD_SEGMENT_SET_ANGLE

Purpose: Apply a traction load over a segment set that is dependent on the orientation of a vector. An example application is applying a pressure to a cylinder as a function of the crank angle in an automobile engine. The pressure and node numbering convention follows Figure 33-12.

Card Sets. Include as many sets of Cards 1 and 2 as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	IDSS	LCID	SCALE	IOPTP	IOPTD		
Type	I	I	I	F	I	I		
Default	none	none	none	1.	0	0		

Card 2	1	2	3	4	5	6	7	8
Variable	N1	N2	NA	NI				
Type	I	I	I	I				
Default	none	none	none	none				

VARIABLE	DESCRIPTION
ID	Loading ID
IDSS	Segment set ID.
LCID	Load curve or function ID defining the traction as a function of the angle. If IOPTP, defined below, is 0, define the abscissa between 0 and 2π radians or 0 and 360 degrees depending on IOPTD.
SCALE	Scale factor on value of the load curve or function.
IOPTP	Flag for periodicity of load curve LCID:

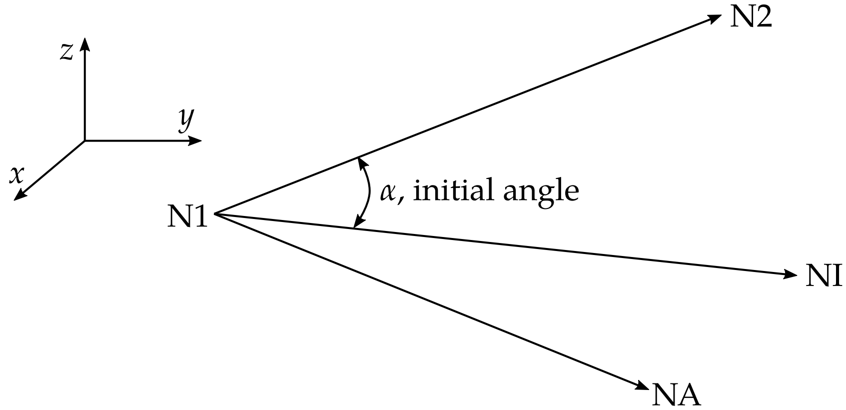

Figure 33-13. Orientation of rotating vector

VARIABLE	DESCRIPTION
	EQ.0: Requires the load curve to be defined between 0 and 2π. This is useful, for example, for modeling an engine that is running at a steady state since each rotation will experience the same loading.
	EQ.1: Load curve defined over the full range of angles for modeling a transient response. A different response is, therefore, permitted on the second and subsequent revolutions.
IOPTD	Flag for specifying angle units of the load curve LCID: EQ.0: Load curve or function argument is in radians. EQ.1: Load curve or function argument is in degrees.
N1	The node specifying the tail of the rotating vector. See Figure 33-13.
N2	The node specifying the head of the rotating vector. See Figure 33-13.
NA	The node specifying the head of the vector defining the axis of rotation. The node N1 specifies the tail. See Figure 33-13.
NI	The node specifying the orientation of the vector at an angle of zero. If the initial angle is zero, NI should be equal to N2. See Figure 33-13.

*LOAD_SEGMENT_SET_NONUNIFORM_{OPTION}

To define an ID for the non-uniform segment loading the following option is available:

ID

If the ID is defined, an additional card is required.

Purpose: Apply the traction load over one triangular or quadrilateral segment defined by three or four nodes. The pressure and node numbering convention follows Figure 33-12.

ID Card. Additional card for ID keyword option.

Optional	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Card Sets. Include as many pairs of Cards 1 and 2 as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	SSID	LCID	SF	AT	DT	ELTYPE		
Type	I	I	F	F	F	A		
Default	none	none	1.	0.	10^{16}	↓		

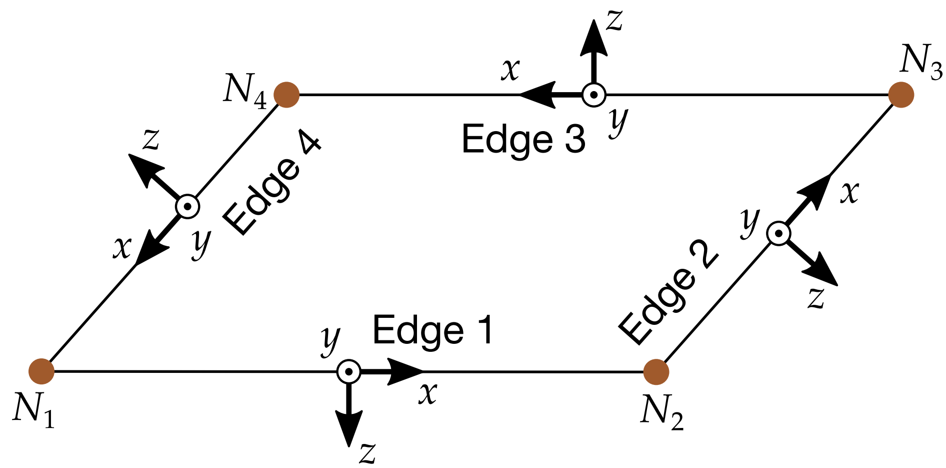

Figure 33-14. Local coordinates system for edge load.

Card 2	1	2	3	4	5	6	7	8
Variable	CID	V1	V2	V3				
Type	I	F	F	F				
Default	0	none	none	none				

VARIABLE	DESCRIPTION
ID	Loading ID
HEADING	A description of the loading.
SSID	Segment set ID.
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION). The seven arguments for the function are current time minus the birth time, the current x, y, and z coordinates, and the initial x, y, and z coordinates. LT.0: Applies to 3, 4, 6 and 8-noded segment sets. With this option the load becomes a follower load, meaning that the direction of the load is constant with respect to the local segment coordinate system. The local coordinate system for edge load, see ELTYPE, is shown in Figure 33-14.
SF	Load curve scale factor
AT	Arrival/birth time for pressure.

VARIABLE	DESCRIPTION
DT	Death time for pressure.
ELTYPE	Optional edge loading type. If left blank, pressure on the segment will be applied. EQ.EF1: Distributed force per unit length along edge 1, Figure 33-14. EQ.EF2: Distributed force per unit length along edge 2, Figure 33-14. EQ.EF3: Distributed force per unit length along edge 3, Figure 33-14. EQ.EF4: Distributed force per unit length along edge 4, Figure 33-14.
CID	Coordinate system ID
V1, V2, V3	Vector direction cosines relative to the coordinate system CID defining the direction of the traction loading. Note that for LCID < 0 this vector rotates with the geometry of the segment.

*LOAD_SEISMIC_SSI_OPTION1_{OPTION2}

Available options for *OPTION1* include:

NODE

SET

POINT

DECONV

OPTION2 allows an optional ID to be given:

ID

Purpose: Apply earthquake load due to free-field earthquake ground motion at certain locations — defined by either nodes or coordinates — on a soil-structure interface for use in earthquake soil-structure interaction analysis. The specified motions determine a set of effective forces in the soil elements adjacent to the soil-structure interface, according to the effective seismic input–domain reduction method [Bielak and Christiano (1984)].

Card Summary:

Card Sets. Include as many sets of the following cards (depending on the keyword options) as needed. This input ends at the next keyword ("*") card.

Card ID. Include this card if using the ID keyword option.

ID	HEADING

Card 1a. This card is included if the NODE or SET keyword option is used.

SSID	TYPEID	GMX	GMY	GMZ			

Card 1b. Include this card if using the POINT or DECONV keyword option.

SSID	XP	YP	ZP	GMX	GMY	GMZ

Card 2. This card is required.

SF	CID	BIRTH	DEATH	ISG	IGM	PSET	VDIR

Data Card Definitions:

ID Card. Additional card for the ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

VARIABLE	DESCRIPTION
ID	Optional ID. This ID does not need to be unique.
HEADING	An optional descriptor for the given ID.

Node and set Cards. Card 1 for keyword options NODE and SET:

Card 1a	1	2	3	4	5	6	7	8
Variable	SSID	TYPEID	GMX	GMY	GMZ			
Type	I	I	I	I	I			
Default	none	none	none	none	none			

Point Cards. Card 1 for keyword options POINT and DECONV.

Card 1b	1	2	3	4	5	6	7	8	9	10
Variable	SSID	XP		YP		ZP		GMX	GMY	GMZ
Type	I	F		F		F		I	I	I
Default	none	0.		0.		0.		none	none	none

VARIABLE	DESCRIPTION
SSID	Soil-structure interface ID.
TYPEID	Node ID (NID in *NODE) or nodal set ID (SID in *SET_NODE).

VARIABLE	DESCRIPTION
XP	x coordinate of ground motion location.
YP	y coordinate of ground motion location.
ZP	z coordinate of ground motion location.
GMX	Acceleration load curve or ground motion ID for motion in the (local) x-direction.
GMY	Acceleration load curve or ground motion ID for motion in the (local) y-direction.
GMZ	Acceleration load curve or ground motion ID for motion in the (local) z-direction.

Card 2	1	2	3	4	5	6	7	8
Variable	SF	CID	BIRTH	DEATH	ISG	IGM	PSET	VDIR
Type	F	I	F	F	I	I	I	I
Default	1.	0	0.	10^{28}	0	0	none	3

VARIABLE	DESCRIPTION
SF	Ground motion scale factor.
CID	Coordinate system ID; see *DEFINE_COORDINATE_SYSTEM.
BIRTH	Time at which specified ground motion is activated.
DEATH	Time at which specified ground motion is removed: EQ.0.0: default set to 10^{28}
ISG	Definition of soil-structure interface: EQ.0: SSID is the ID for the soil-structure interface defined by *INTERFACE_SSI_ID for a non-matching mesh between soil and structure. For the DECONV keyword option, ISG = 0 additionally flags that the free field within motion is computed at depth.

VARIABLE	DESCRIPTION
	EQ.1: SSID is the ID of the segment set on the soil side of the soil-structure interface. This segment set should be oriented toward the structure. For the DECONV, ISG = 1 additionally flags that the free-field outcrop motion is computed at depth.
IGM	Specification of ground motions GMX, GMY, GMZ: EQ.0: Ground motions are specified as acceleration load curves. See *DEFINE_CURVE EQ.1: Both ground accelerations and velocities specified using *DEFINE_GROUND_MOTION.
PSET	Soil part set through which ground motion travels (DECONV option only)
VDIR	Vertical direction (local if CID ≠ 0) for ground motion propagation (DECONV option only): EQ.-1: -x-direction EQ.-2: -y-direction EQ.-3: -z-direction EQ.1: x-direction EQ.2: y-direction EQ.3: z-direction

Remarks:

1. **Ground Motion at Soil-Structure Interface.** The ground motion at any node on a soil-structure interface is computed as follows:

   a) If the node coincides with a location where ground motion is specified, that ground motion is used for that node.

   b) If the node does not coincide with a location where ground motion is specified, the ground motion at that node along a particular degree of freedom is taken as a weighted average of all the ground motions set on the interface along that degree of freedom. The weights are inversely proportional to the node's distance from the ground motion location.

2. **Multiple Ground Motions.** Multiple ground motions specified at the same location are added together to obtain the resultant ground motion.

3. **Spatially-Uniform Ground Motion.** To model a spatially-uniform ground motion m on a soil-structure interface, set the ground motion at only one location on that interface. Specifying the ground motion at more than one point on a soil-structure interface results in spatially-varying ground motion on that interface.

4. **Deconvolution input.** The DECONV option provides a simplified ground motion input for a soil-structure interface that goes below the flat, top surface of the soil. The free-field ground motion can be set at the top of the soil or below the surface. The computation for the corresponding motion at interface nodes at depth assumes the free-field movement only propagates vertically. ISG = 0 flags that the within motion is computed, while ISG = 1 flags that the outcrop motion is calculated. Currently, this keyword option is available only when modeling the soil domain with either *MAT_ELASTIC or *MAT_BIOT_HYSTERETIC. Other materials can be supported upon request.

LOAD_SEISMIC_SSI_AUX_*{OPTION}

OPTION allows an optional ID to be given:

ID

Purpose: Apply earthquake load due to free-field earthquake ground motion on a soil-structure interface, where the free-field motions were recorded from a previous analysis using *INTERFACE_SSI_AUX or *INTERFACE_SSI_AUX_EMBEDDED. The specified motions are used to compute a set of effective forces in the soil elements adjacent to the soil-structure interface, according to the effective seismic input–domain reduction method [Bielak and Christiano (1984)].

This card supersedes the optional Card 3 in *INTERFACE_SSI

Card Sets. Include as many pairs of Cards 1 and 2 as necessary. This input ends at the next keyword ("*") card. If the ID keyword option is used, include a separate ID card for each pair.

ID Card. Additional card for the ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Card 1	1
Variable	FILENAME
Type	A80

Card 2	1	2	3	4	5	6	7	8
Variable	SSID	GMSET	SF	BIRTH	DEATH	ISG	MEMGM	
Type	I	I	F	F	F	I	I	
Default	none	none	1.	0.	10^{28}	0	2500000	

VARIABLE	DESCRIPTION
ID	Optional ID. This ID does not need to be unique.
HEADING	An optional descriptor for the given ID
FILENAME	Name of binary file containing recorded motions
SSID	Soil-structure interface ID
GMSET	Identifier for set of recorded motions; see *INTERFACE_SSI_AUX or *INTERFACE_SSI_AUX_EMBEDDED
SF	Recorded motion scale factor
BIRTH	Time at which specified recorded motion is activated
DEATH	Time at which specified recorded motion is removed. EQ.0.0: Set to the default, 10^{28}
ISG	Definition of soil-structure interface: EQ.0: SSID is an ID for the soil-structure interface defined by *INTERFACE_SSI_ID for a non-matching mesh between soil and structure. EQ.1: SSID is the ID of the segment set on the soil side of the soil-structure interface. This segment set should be oriented toward the structure.
MEMGM	Size in words of buffer allocated to read in recorded motions

Remarks:

1. **Binary File for Recorded Motions.** The free-field motions are read in from a binary file created in a previous run using *INTERFACE_SSI_AUX or *INTERFACE_SSI_AUX_EMBEDDED.

2. **Multiple Ground Motion Inputs.** Multiple ground motion files can be specified at the same interface. All the ground motions are added together to obtain the resultant free-field motion at that interface.

3. **Interface Geometry Match.** It is assumed that the nodes of the soil-structure interface lie on the surface of the interface used in the previous run to record the ground motion.

*LOAD_SHELL_*OPTION1*_*{OPTION2}*

Available options for *OPTION1* include:

ELEMENT

SET

Available options for *OPTION2* include:

ID

If the ID is defined, an additional card is required.

Purpose: Apply the distributed pressure load over a single shell element or a shell element set. The numbering of the shell nodal connectivities must follow the right hand rule with positive pressure acting in the negative *t*-direction. See Figure 33-12. This option applies to the three-dimensional shell elements only.

ID Card. Additional card for ID keyword option.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A70						

Shell Cards. Include as many of these cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	EID/ESID	LCID	SF	AT				
Type	I	I	F	F				
Default	none	none	1.	0.				

VARIABLE	DESCRIPTION
EID/ESID	Shell ID (EID) or shell set ID (ESID), see *ELEMENT_SHELL or *SET_SHELL.

VARIABLE	DESCRIPTION
LCID	Load curve ID, see *DEFINE_CURVE. EQ.-1: Brode function; see *LOAD_BRODE. EQ.-2: ConWep function; see *LOAD_BLAST.
SF	Load curve scale factor. See Remark 1.
AT	Arrival time for pressure or birth time of pressure.

Remarks:

1. **Multipliers.** The load curve multipliers may be used to increase or decrease the pressure. The time value is not scaled.

Example:

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$   *LOAD_SHELL_ELEMENT
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$  From a sheet metal forming example.  A blank is hit by a punch, a holder is
$  used to hold the blank on its sides.  All shells on the holder are given a
$  pressure boundary condition to clamp down on the blank.  The pressure
$  follows load curve 3, but is scaled by -1 so that it applies the load in the
$  correct direction.  The load starts at zero, but quickly rises to 5 MPa
$  after 0.001 sec.  (Units of this model are in: ton, mm, s, N, MPa, N-mm)
$
*LOAD_SHELL_ELEMENT
$
$...>....1....>....2....>....3....>....4....>....5....>....6....>....7....>....8
$      eid      lcid        sf        at
     30001         3 -1.00E+00       0.0
     30002         3 -1.00E+00       0.0
     30003         3 -1.00E+00       0.0
     30004         3 -1.00E+00       0.0
     30005         3 -1.00E+00       0.0
     30006         3 -1.00E+00       0.0
     30007         3 -1.00E+00       0.0
$
$  Note: Just a subset of all the shell elements of the holder is shown above,
$        in practice this list contained 448 shell element id's.
$
$
*DEFINE_CURVE
$     lcid      sidr      scla      sclo      offa      offo
         3
$
$          abscissa            ordinate
              0.000                 0.0
              0.001                 5.0
              0.150                 5.0
$
$
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
```

*LOAD_SPCFORC

Purpose: When used in a full-deck restart run, this card will apply the SPC constraint forces from the initial run on the corresponding degrees of freedom in the current run. This is useful when modeling unbounded domains using a non-reflecting boundary while incorporating static stresses computed in the initial run: the fixed constraints on the outer boundary in the initial static analysis are removed in the transient analysis and replaced by equivalent static forces.

While *BOUNDARY_NON_REFLECTING acts similarly if dynamic relaxation is used for the static analysis, this approach works for any method used to preload the model.

No parameters are necessary for this card.

*LOAD_SSA

Purpose: The Sub-Sea Analysis (SSA) capability allows a simple and efficient way of loading the structure to account for the effects of the primary shock wave and the subsequent bubble oscillations of an underwater explosion. It achieves its efficiency by approximating the pressure scattered by air and water-backed plates and the pressure transmitted through a water-back plate. The loading incorporates the plane wave approximation for direct shock response and the virtual mass approximation for bubble response. *LOAD_SSA does not implement a doubly asymptotic approximation of transient fluid-structure interaction.

Card 1	1	2	3	4	5	6	7	8
Variable	VS	DS	REFL	ZB	ZSURF	FPSID	PSID	NPTS
Type	F	F	I	F	F	I	I	I
Default	none	none	0	0.	0.	0	0	1

Card Sets. Include as many pairs of Cards 2 and 3 as necessary. This input ends at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	A	ALPHA	GAMMA	KTHETA	KAPPA			
Type	F	F	F	F	F			
Default	none	none	none	none	none			

Card 3	1	2	3	4	5	6	7	8
Variable	XS	YS	ZS	W	TDELY	RAD	CZ	
Type	F	F	F	F	F	F	F	
Default	none	none	none	none	none	none	none	

VARIABLE	DESCRIPTION
VS	Sound speed in fluid
DS	Density of fluid
REFL	Consider reflections from sea floor. EQ.0: off EQ.1: on
ZB	Z coordinate of sea floor if REFL = 1, otherwise, not used.
ZSURF	Z coordinate of sea surface
FPSID	Part set ID of parts subject to flood control. See Remark 2. Use the *SET_PART_COLUMN option where the parameters A1 and A2 must be defined as follows: Parameter A1: Flooding status: EQ.1.0: Fluid on both sides. EQ.2.0: Fluid outside, air inside. EQ.3.0: Air outside, fluid inside. EQ.4.0: Material or part is ignored. Parameter A2: Tubular outer diameter of beam elements. For shell elements this input must be greater than zero for loading.
PSID	Part set IDs of parts defining the wet surface. The elements defining these parts must have their outward normals pointing into the fluid. See Figure 33-15. EQ.0: all parts are included. GT.0: the part set ID.
NPTS	Number of integration points for computing pressure (1 or 4)
A	Shock pressure parameter
ALPHA	α, shock pressure parameter
GAMMA	γ, time constant parameter
KTHETA	K_θ, time constant parameter
KAPPA	κ, ratio of specific heat capacities

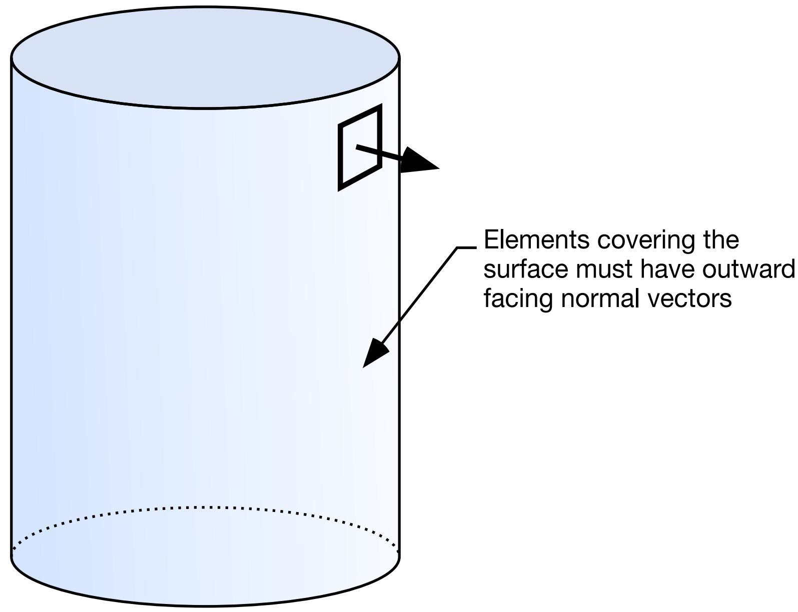

Figure 33-15. The shell elements interacting with the fluid must be numbered such that their outward normal vector points into the fluid media.

VARIABLE	DESCRIPTION
XS	*X* coordinate of charge
YS	*Y* coordinate of charge
ZS	*Z* coordinate of charge
W	Weight of charge
TDELY	Time delay before charge detonates
RAD	Charge radius
CZ	Charge depth

Remarks:

1. **Units.** SSA assumes the model is in MKS units. If it is in another system of units, *CONTROL_COUPLING should be used to account for the conversion.

2. **Flooding Status.** The "flooding status" is instrumental in determining how the model parts are loaded. If A1 = 1.0, the front of the plate as defined by the outward normal is exposed to the incident pressure. The back of the plate is not exposed to the incident pressure but feels a transmitted pressure that resists

plate motion. If A1 = 2.0, then the plate has fluid on the outside as determined by the outward normal. It is exposed to the incident pressure and feels the scattered pressure. No loading is applied to the back side. If A1 = 3.0, then air is on the front of the plate and water is on the back. Neither the front nor the back of the plate is exposed to the incident pressure, but the motion of the plate is resisted by pressure generated on the back of the plate when it moves. Transmitted pressures are assumed not to strike another plate.

3. **Pressure History of Primary Shockwave.** The pressure history of the primary shockwave at a point in space through which a detonation wave passes is given as:

$$P(t) = P_m e^{\frac{-t}{\theta}}$$

where P_m and the time constant θ below are functions of the type and weight W of the explosive charge and the distance Q from the charge.

$$P_{peak} = A\left[\frac{W^{1/3}}{Q}\right]^{\alpha}$$

$$\theta = K_\theta W^{1/3}\left[\frac{W^{1/3}}{Q}\right]^{\gamma}$$

where A, α, γ, and K_θ are constants for the explosive being used.

4. **Model Orientation.** The positive global Z-direction points vertically upward, from the sea floor to water surface. The finite element model must be oriented accordingly.

*LOAD_STEADY_STATE_ROLLING

Purpose: Steady state rolling analysis is a generalization of *LOAD_BODY, allowing the user to apply body loads to part sets due to translational and rotational accelerations in a manner that is more general than the *LOAD_BODY capability. *LOAD_STEADY_-STATE_ROLLING may be invoked multiple times as long as no part has the command applied more than once. Furthermore, the command may be applied to arbitrary meshes, that is, axisymmetric meshes are not required.

Card Sets. Include as many sets consisting of the following four cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	PSID						
Type	I	I						
Default	none	none						

Card 2	1	2	3	4	5	6	7	8
Variable	N1	N2	LCD1	LCD1R				
Type	I	I	I	I				
Default	0	0	0	LCD1				

Card 3	1	2	3	4	5	6	7	8
Variable	N3	N4	LCD2	LCD2R				
Type 4	I	I	I	I				
Default	0	0	0	LCD2				

Card 4	1	2	3	4	5	6	7	8
Variable	N5	N6	LCD3	LCD3R				
Type	I	I	I	I				
Default	0	0	0	LCD3				

VARIABLE	DESCRIPTION
ID	ID
PSID	Part set ID
N1	Node 1 defining rotational axis
N2	Node 2 defining rotational axis
LCD1	Load curve defining angular velocity around rotational axis.
LCD1R	Optional load curve defining angular velocity around rotational axis for dynamic relaxation. LCD1 is used during dynamic relaxation if LCD1R is not defined.
N3	Node 3 defining turning axis
N4	Node 4 defining turning axis
LCD2	Load curve defining angular velocity around turning axis.
LCD2R	Optional load curve defining angular velocity around turning axis for dynamic relaxation. LCD2 is used during dynamic relaxation if LCD2R is not defined.
N5	Node 5 defining translational direction
N6	Node 6 defining translational direction
LCD3	Load curve defining translational velocity in translational direction.
LCD3R	Optional load curve defining translational velocity in translational direction. LCD3 is used during dynamic relaxation if LCD3R is not defined.

Remarks:

1. **Model.** The steady state rolling capability adds inertial body loads in terms of a moving reference defined by the user input. The current coordinates are defined in terms of the displacement, u, and the moving reference frame, Y,

$$x_{SSR} = u + Y \quad \dot{x}_{SSR} = \dot{u} + \dot{Y} \quad \ddot{x}_{SSR} = \ddot{u} + \ddot{Y}$$
$$Y = R(\omega_2 t)[R(\omega_1 t)(X - X_O) - X_C] + Y_T(t)$$

where R is the rotation matrix obtained by integrating the appropriate angular velocity, the magnitude of the angular velocities ω_1 and ω_2 are defined by load curves LCD1 and LCD2 respectively, and the directions are defined by the current coordinates of the node pairs N1-N2 and N3-N4. The velocity corresponding to the translational term, $Y_T(t)$, is defined in magnitude by LCD3 and in direction by the node pair N5-N6. The initial coordinates of the nodes are X, X_O is the initial coordinate vector of node N1 and X_C is the initial coordinate vector of node N3. If data defining an angular velocity is not specified, the velocity is defaulted to zero, and R is the identity matrix. In a similar manner, if the translational velocity is not specified, it is defaulted to zero.

2. **Restrictions.** This capability is useful for initializing the stresses and velocity of tires during dynamic relaxation and rolling processes in manufacturing. It is available for solid formulations 1, 2, 10, 13, and 15, and for shell formulations 2, 4, 5, 6, 16, 25, 26, and 27. It is *not* available for beams and tshells. It is available for implicit and explicit simulations, but it is *not* available for eigenvalue problems. To invoke this keyword for dynamic relaxation, specify that the load curves are used during dynamic relaxation (SIDR = 1 or 2 on *DEFINE_CURVE). At the end of the dynamic relaxation, the velocities of the parts with this load are set to $\dot{x}_{\mathrm{SSR}}$ while the remaining parts are initialized according to the input file.

3. **Convergence and Stability.** Users must ensure that the appropriate load curves are turned on during the relaxation process, and if implicit dynamic relaxation is used, that sufficient constraints are applied during the initialization to remove any rigid body motion and that they are removed at the end of the dynamic relaxation. The implicit iteration convergence rate is often improved by adding the geometric stiffness matrix using *CONTROL_IMPLICIT_GENERAL. A consistent tangent matrix is available by using *CONTROL_IMPLICIT_GENERAL, and while it improves the convergence rate with problems with small strains, it is often unstable for problems with large strains. The *CONTROL_STEADY_STATE_ROLLING options should be used to ramp up the frictional forces to obtain smooth solutions and good convergence rates.

4. **Angular Velocity and Hoop Strain.** To obtain the free-rolling angular velocity, the tire should be first inflated, then brought into contact with the road while the frictional force is ramped up with a load curve and a large value of SCL_K

specified in *CONTROL_STEADY_STATE_ROLLING. The angular velocity of the tire is then slowly varied over a range that covers the free rolling velocity. The free rolling velocity is obtained when either the frictional force in the direction of rolling or the moment about the tire axis is near zero. For a tire with an initial radius of R and a translational velocity of V, the approximate value for the free rolling value of the rolling velocity is

$$\omega = \frac{V}{(1+\varepsilon)R} \ ,$$

where ε is the hoop strain of the rolling tire. For a first guess, the hoop strain can be set to 0.0, and the rolling velocity will be within 10% of the actual value. After the first calculation, a smaller range bracketing the free rolling velocity should be used in a second calculation to refine the free rolling velocity. An accurate value of the free rolling velocity is necessary for subsequent analyses, such as varying the slip angle of the tire.

5. **Slip Angle.** A time varying slip angle can be specified by moving one of the nodes defining the direction vector of the translational velocity. To check that the stiffness scale factor in *CONTROL_STEADY_STATE_ROLLING is high enough, a complete cycle from a zero slip angle to a maximum value, then back to zero, should be performed. If the loading and unloading values are reasonably close, then the stiffness scale factor is adequate.

*LOAD_STIFFEN_PART_{OPTION}

Available options include:

<BLANK>

SET

Purpose: Staged construction. Available for solid, shell, thick shell, and beam elements. See also *DEFINE_STAGED_CONSTRUCTION_PART, which provides an alternative, simpler input method for the same capability.

Construction Cards. Include as many of these cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID/PSID	LC	(blank)	STGA	STGR			
Type	I	I		I	I			
Default	none	0		0	0			

VARIABLE	DESCRIPTION
PID	Part ID (or Part Set ID for the SET keyword option)
LC	Load curve defining factor as a function of time. See Remark 5.
STGA	Construction stage at which part is added (optional)
STGR	Construction stage at which part is removed (optional)

Remarks:

1. **Removing and Adding Parts.** For parts that are initially present but are removed during the analysis (for example, soil that is excavated), the stiffness factor starts at 1.0. Before the part is deleted, the stiffness factor should ramp down to a small value, such as 10^{-6}, over a duration long enough to avoid introducing shock or dynamic effects. The elements of a part introduced during the construction, such as retaining walls, are initially present in the model; however, the factor for this part is initially set to a low value, such as 10^{-6}. The stiffness factor increases to 1.0 when the part is added. A factor that increases from 10^{-6} to 1.0

and then reduces back to 10^{-6} can be used for temporary retaining walls, props, etc.

2. **Increasing and Decreasing Factor.** When the factor is increasing, it applies *only* to the stiffness and strength of the material in response to *subsequent* strain increments, not to any existing stresses. When the factor is decreasing, it applies to existing stresses as well as to the stiffness and strength.

3. **Compatible Material Models.** This feature works with all material models when used only to *reduce* the stiffness (e.g. parts that are excavated, not parts that are added during construction). When used to *increase* the stiffness from an initial low value, this feature works for most material types but not for hyperelastic types as well as certain others. There is no error check at present to detect STIFFEN_PART being used with an inappropriate material model. Symptoms of resulting problems would include non-physically large stresses when a part stiffens due to the accumulated strains in the "dormant" material since the start of the analysis.

4. **Gravity Factor.** This feature is generally used with *LOAD_GRAVITY_PART. The same curve is often used for the stiffness factor and the gravity factor.

5. **Factor Curve.** There are 3 methods for defining the factor as a function of time:

   a) LC overrides STGA and STGR if LC is non-zero.

   b) STGA and STGR refer to stages at which the part is added and removed: the stages are defined in *DEFINE_CONSTRUCTION_STAGES. If STGA is zero, the part has full stiffness at time zero. If not, it starts with a value equal to FACT (on *CONTROL_STAGED_CONSTRUCTION) and increases immediately to 1.0 at the start of stage STGA. If STGR is zero, the stiffness factor continues at 1.0 until the end of the analysis. If not, it ramps down from 1.0 to FACT over the ramp time at the start of stage STGR.

   c) *DEFINE_STAGED_CONSTRUCTION_PART can be used instead of *LOAD_STIFFEN_PART to define this loading. During initialization, a *LOAD_STIFFEN_PART card will be created, and the effect is the same as using the STGA and STGR method described above. In many cases using *DEFINE_STAGED_CONSTRUCTION_PART is more convenient than this keyword.

*LOAD_SUPERPLASTIC_FORMING

Purpose: Perform superplastic forming (SPF) analysis. This option can be applied to 2D and 3D solid elements and to 3D shell elements, and has been implemented for both explicit and implicit analyses. The pressure loading controlled by the load curve ID given below is scaled to maintain a constant maximal strain rate or other target value.

This option must be used with material model 64, *MAT_RATE_SENSITIVE_POWER-LAW_PLASTICITY, for strain rate sensitive, powerlaw plasticity. For the output of data, see *DATABASE_SUPERPLASTIC_FORMING. Mass scaling is recommended in SPF applications.

New options to compute the target value with various averaging techniques and autojump options to control the simulation are implemented. Strain-rate speedup is also available. See Remarks 5, 6, and 7 for details.

Card Sets. Include as many sets consisting of the following four cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	LCP1	CSP1	NCP1	LCP2	CSP2	NCP2	PCTS1	PCTS2
Type	I	I	F	I	I	F	F	F
Default	none	none	none	optional	optional	optional	100.0	100.0
Remarks				1	1	1		

Card 2	1	2	3	4	5	6	7	8
Variable	ERATE	SCMIN	SCMAX	NCYL	NTGT	LEVEL	TSRCH	AT
Type	F	F	F	I	I	I	F	F
Default	none	none	none	0	1	0	none	0.0
Remarks				2		5		

Card 3	1	2	3	4	5	6	7	8
Variable	TPEAK	TNEG	TOSC	POSC	PDROP	RILIM	RDLIM	STR
Type	F	F	F	F	F	F	F	F
Default	10.0	5.0	10.0	1.0	2.0	1.0	1.0	0.0
Remarks								6

Card 4	1	2	3	4	5	6	7	8
Variable	THRES	LOWER	UPPER	TFACT	NTFCT	BOX		
Type	F	F	F	F	I	I		
Default	5.0	90.0	99.0	1.0	10	0		
Remarks				7	7	8		

VARIABLE	DESCRIPTION
LCP1	Load curve number for Phase I pressure loading; see *DEFINE_-CURVE. The scaled version of this curve as calculated by LS-DYNA is output to curve1. See Remark 3.
CSP1	Contact surface number to determine completion of Phase I.
NCP1	Percent of nodes in contact to terminate Phase I; see *CONTACT_*OPTION*.
LCP2	Load curve number for Phase II pressure loading (reverse); see *DEFINE_CURVE. The scaled version of this curve as calculated by LS-DYNA is output to curve2. See Remark 3.
CSP2	Contact surface to determine completion of Phase II; see *CONTACT_OPTION.
NCP2	Percent of nodes in contact to terminate Phase II.

VARIABLE	DESCRIPTION
PCTS1	Percentage of nodes-in-contact to active autojump in Phase I forming.
PCTS2	Percentage of nodes-in-contact to active autojump in Phase II forming.
ERATE	Desired target value. If it's strain rate, this is the time derivative of the logarithmic strain.
SCMIN	Minimum allowable value for load curve scale factor. To maintain the target value, the pressure curve is scaled. In the case of a snap through buckling the pressure may be removed completely. By putting a value here the pressure will continue to act but at a value given by this scale factor multiplying the pressure curve.
SCMAX	Maximum allowable value for load curve scale factor. Generally, it is a good idea to put a value here to keep the pressure from going to unreasonable values after full contact has been attained. When full contact is achieved the strain rates will approach zero and pressure will go to infinity unless it is limited or the calculation terminates.
NCYL	Number of cycles for monotonic pressure after reversal.
NTGT	Type of the target (controlling) variable: EQ.1: strain rate. EQ.2: effective stress.
LEVEL	Criterion to compute averaged maximum of controlling variable: EQ.0: no average used. GE.1: averaging over neighbors of element with peak value of the controlling variable. This parameter determines the level of neighbor search. EQ.-1: averaging over elements within selective range of peak controlling variable.
TSRCH	Time interval to conduct neighbors search.
AT	Time when SPF Phase I simulation starts.
TPEAK	Additional run time to terminate simulation when maximum pressure is reached.

VARIABLE	DESCRIPTION
TNEG	Additional run time to terminate simulation when percentage change of nodes-in-contact is zero or negative.
TOSC	Additional run time to terminate simulation when percentage change of nodes-in-contact oscillates within a specific value.
POSC	Percentage change to define the oscillation of percentage of nodes-in-contact.
PDROP	Drop in percentage of nodes-in-contact from the maximum to terminate simulation after the specified termination percentage has been reached.
STR	Autojump option or strike-through time (period of time without autojump check): EQ.0: no autojump EQ.-1: autojump controlled by peak pressure EQ.-2: autojump controlled by percentage of nodes in contact EQ.-3: autojump controlled by both above GT.0: strike-through time, then same as STR = -3
THRES	Threshold percentage that gives the threshold value above which elements are considered for average.
LOWER	Lower percentile of elements above the threshold value to be included for average.
UPPER	Upper percentile of elements above the threshold value to be included for average.
RILIM	Maximum percentage change for pressure increment.
RDLIM	Maximum percentage change for pressure decrement.
TFACT	Strain rate speedup factor.
NTFCT	Number of computing cycles to ramp up speedup.
BOX	Box ID or Box Set ID. See Remark 8. GT.0: Box ID; see *DEFINE_BOX. LT.0: |BOX| is box set ID; see *SET_BOX.

Remarks:

1. **Second Phase.** Optionally, a second phase can be defined. In this second phase a *unique* set of pressure segments must be defined whose pressure is controlled by LCP2. During the first phase, the pressure segments of LCP2 are inactive, and likewise, during the second phase the pressure segments of the first phase are inactive. When shell elements are used, the complete set of pressure segments can be repeated in the input with a sign reversal used on the load curve. When solid elements are used, the pressure segments for each phase, in general, must be unique.

2. **NCYCL.** This is an ad hoc parameter which should probably not be used.

3. **Output Files.** There are three output files pressure, curve1, and curve2 from the SPF simulation, and they may be plotted using ASCII → superpl in LS-PrePost. The file curve2 is created only if the second phase is active. The time interval for writing out these files is controlled by *DATABASE_SUPERPLASTIC_FORMING. The files curve1 and curve2 contain the adjusted pressure histories calculated by SPF solver. The file pressure contains time histories of scaling factor, maximal target value, averaged target value, and percentage of contact.

4. **Contact.** The constraint method contact, *CONTACT_CONSTRAINT_NODES_TO_SURFACE, is recommended for superplastic forming simulations since the penalty methods are not as reliable when mass scaling is applied. Generally, in superplastic simulations mass scaling is used to enable the calculation to be carried out in real time.

5. **Averaging Algorithms.** In order to reduce the oscillation in pressure, the maximal target value used to adjust the pressure load is calculated by a special averaging algorithm. There are two options available:

   a) *Averaging over neighbors of element with maximum target value*: In this method, the element that has the maximum strain rate or other controlling variable is stored in each cycle of the computation. The elements close to the element with the maximum value are searched and stored in an array. The averaged maximal target value is computed over the neighboring elements. The user can input an integer number to control the level of neighbor search, which will affect the total number of elements for average. Because the neighbor search is time consuming, the user can input a time interval to limit the occurrence of searching. The neighbor search is conducted only when the simulation time reaches the specified time or the element with maximum target value falls out of the array of neighbors.

   b) *Averaging over elements within selective range of target value:* In this method, all elements that have target value above a threshold value (a threshold percentage of maximum target value) are sorted according to their target value, and the elements between the user specified lower percentile and upper percentile are selected to compute the average of the maximal target value.

6. **Autojump.** The SPF simulation can be controlled by various autojump options. When autojump conditions are met, the SPF simulation will be either terminated or continued from phase I to phase II simulation. The autojump check can be held inactive by setting a strikethrough time. In this case the SPF simulation will continue for that period of time and only be interrupted when the percentage of nodes-in-contact reaches 100% for a specified time. The available autojump conditions are:

   a) *Peak pressure is reached and stays for certain time:* The peak pressure is determined by the maximum allowable scale factor and the load curve. The simulation will continue for a user specified time before termination.

   b) *User specified percentage of nodes-in-contact is reached:* The simulation will be terminated or continued to Phase II automatically if one of the following conditions is met:

      i) If the change of the percentage of nodes-in-contact is zero or negative for a specified time.

      ii) If the percentage of nodes-in-contact oscillates in a specified range for a specified time.

      iii) If the percentage of nodes-in-contact drops more than a specified value from the maximum value recorded.

      iv) If the percentage of nodes-in-contact reaches a user specified stop value.

7. **Computation Time.** In order to speed up the simulation of the superplastic forming process, we scale down the computation time. By doing this we increase the strain rate allowed in the SPF process, resulting in reduced simulation time. However, caution should be utilized with this speedup as it may affect the accuracy of the results. We recommend no or small strain rate speedup for simulations with complex geometry or tight angles.

8. **Critical Regions.** If the user knows the area(s) in the workpiece that are critical in the SPF process, he can use the box option to limit the region(s) where the elements are checked for computing the average of the maximal target value.

*LOAD_SURFACE_STRESS_{OPTION}

Available options include:

<BLANK>

SET

Purpose: This keyword modifies the behavior of shell elements causing them to pass pressure-type loads to material models 37 and 125 (see Remarks 1 and 2); shells usually omit such effects.

With this keyword, LS-DYNA calculates segment pressures from contact and applied pressure loads on both the upper and lower surfaces of the shell and applies them as negative local *z*-stresses during the simulation. It is found in some cases this capability can improve the accuracy of metal forming simulations.

Card Sets. Include as many sets consisting of the following three cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	PID/PSID							
Type	I							

Card 2	1	2	3	4	5	6	7	8
Variable	LSCID1	LSCID2	LSCID3	LSCID4	LSCID5	LSCID6	LSCID7	LSCID8
Type	I	I	I	I	I	I	I	I

Card 3	1	2	3	4	5	6	7	8
Variable	USCID1	USCID2	USCID3	USCID4	USCID5	USCID6	USCID7	USCID8
Type	I	I	I	I	I	I	I	I

VARIABLE	DESCRIPTION
PID/PSID	Part ID or, if option SET is active, part set ID.
LSCID*n*	Lower surface contact IDs. Up to eight IDs can be defined. These contacts definitions contribute to the pressure acting on the lower surface of the shell. If the pressure on the lower surface is due to applied pressure loads, specify a value -1 instead of a contact ID. Only one of the LSCID*n* may be set to -1. Lower surface of a part is on the opposite side of the shell element normals, which must be made consistent (in LS-PrePost).
USCID*n*	Upper surface contact IDs. Up to eight IDs can be defined. These contacts definitions contribute to the pressure acting on the upper surface of the shell. If the pressure on the upper surface is due to applied pressure loads, specify a value of -1 instead of a contact ID. Only one of the USCID*n* may be set to -1. Upper surface of a part is on the same side of the shell element normals, which must be made consistent (in LS-PrePost).

Remarks:

1. **MAT_TRANSVERSLY_ANISOTROPIC_ELASTIC_PLASTIC (37).** This keyword can be used with *MAT_037 when ETAN is set to a negative value (see *MAT_037 manual pages), which triggers normal stresses (local z-stresses) resulting either from sliding contact or applied pressure to be considered in the shell formulation. The normal stresses can be significant in male die radius and corners in forming of Advanced High Strength Steels (AHSS). The negative local z-stresses are written to the d3plot files after Revision 97158 and can be plotted in LS-PrePost by selecting z-stress under *FCOMP* → *Stress* and select *local* under *FCOMP*.

2. **MAT_KINEMATIC_HARDENING_TRANSVERSLY_ANISOTROPIC (125).** This keyword can also be used in a simulation with *MAT_125 to account for the normal stresses (see *MAT_125 manual pages). For this material inserting this keyword *anywhere* in the input deck will invoke the shell normal stress calculation.

LOAD_THERMAL_*OPTION

Available options include:

BINOUT

CONSTANT

CONSTANT_ELEMENT_*OPTION*

CONSTANT_NODE

D3PLOT

LOAD_CURVE

RSW

TOPAZ

VARIABLE

VARIABLE_ELEMENT_*OPTION*

VARIABLE_NODE

VARIABLE_SHELL_*OPTION*

Purpose: To define nodal temperatures that thermally load the structure. Nodal temperatures defined by the *LOAD_THERMAL_*OPTION* method are all applied in a structural only analysis. They are ignored in a thermal only or coupled thermal/structural analysis, see *CONTROL_THERMAL_*OPTION*.

All the *LOAD_THERMAL options cannot be used in conjunction with each other. Only those of the same thermal load type, as defined below in column 2, may be used together.

*LOAD_THERMAL_CONSTANT	- Thermal load type 1
*LOAD_THERMAL_ELEMENT	- Thermal load type 1
*LOAD_THERMAL_CONSTANT_NODE	- Thermal load type 1
*LOAD_THERMAL_LOAD_CURVE	- Thermal load type 2
*LOAD_THERMAL_TOPAZ	- Thermal load type 3
*LOAD_THERMAL_VARIABLE	- Thermal load type 4
*LOAD_THERMAL_VARIABLE_ELEMENT	- Thermal load type 4

*LOAD_THERMAL_VARIABLE_NODE - Thermal load type 4

*LOAD_THERMAL_VARIABLE_SHELL - Thermal load type 4

*LOAD_THERMAL_BINOUT

Purpose: Nodal temperatures computed in one or more prior simulations are used to load a mechanical-only analysis. Each of the prior simulations can either be a thermal-only or coupled thermal/structural analysis. The temperatures are read from the TPRINT section in the binary database binout or any other file containing the necessary information in LSDA-format. The data is mapped based on the nodal IDs.

Card 1	1	2	3	4	5	6	7	8
Variable	DEFTEMP							
Type	F							
Default	0.							

Card Sets. Include as many sets consisting of the following two cards as desired. This input ends at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	FILENAME							
Type	A80							

Card 3	1	2	3	4	5	6	7	8
Variable	STARTT	TSF	TMPOFF	NIDOFF				
Type	F	F	F	I				
Default	0.	1.	0.	0				

VARIABLE	DESCRIPTION
DEFTEMP	Default temperature applied to nodes that do not have temperature information provided in the binout file(s)
FILENAME	Name of the file that contains the temperature information

VARIABLE	DESCRIPTION
STARTT	Start time, t_{start}, for the temperature mapping. Until this time the nodal temperature for the first step provided in the file is used.
TSF	Time scale factor, α_t, which represents the speed-up factor of the mechanical analysis to the previous thermal analysis
TMPOFF	Temperature offset that is added to the temperature data in the specified LSDA input file.
NIDOFF	Offset to the user node IDs. The input value is added to the IDs as specified in the LSDA file before mapping temperature information.

Remarks:

1. **Overview of keyword.** This feature provides a method for using temperature data from a previous thermal-only or even as coupled thermal/structural analysis as an external thermal load for a mechanical-only simulation. For any node of the mechanical model, the algorithm searches for temperature data in the given files. This search is based on the user node ID. If no information is found, the default temperature is assumed. Therefore, the algorithm requires only a partial overlap of the meshes.

2. **Thermal and mechanical simulation time.** Each of the thermal results can be applied starting at different simulation times, t_{start}, of the mechanical run. Furthermore, the algorithm allows running an artificially accelerated mechanical analysis. It takes into account possibly different acceleration factors, α_t, for each of the thermal runs. Those factors are equivalent to the parameter TSF as given in the keyword *CONTROL_THERMAL_SOLVER. As a result, a time, t_{th}, in the thermal run corresponds to

$$t_{\text{mech}} = t_{\text{start}} + \frac{t_{\text{th}}}{\alpha_t} \ .$$

3. **Temperature information file.** With this keyword, binary LSDA files must be specified as input. The files should provide the same information as the TPRINT section in the binary database binout. More details for this output are defined in *DATABASE_*OPTION*.

*LOAD_THERMAL_CONSTANT

Purpose: Define the constant temperature that is applied to a given nodal set. The reference temperature state is assumed to be a null state with this option. A nodal temperature state, read in and held constant throughout the analysis, dynamically loads the structure. Thus, the temperature defined can also be seen as a relative temperature to a surrounding or initial temperature.

Card Sets. Include as many sets consisting of the following two cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	NSID	NSIDEX	BOXID					
Type	I	I	I					
Default	{all}	0	0					

Card 2	1	2	3	4	5	6	7	8
Variable	T	TE						
Type	F	F						
Default	0.	0.						

VARIABLE	DESCRIPTION
NSID	Nodal set ID containing nodes for initial temperature EQ.0: all nodes are included
NSIDEX	Nodal set ID containing nodes that are exempted from the imposed temperature (optional).
BOXID	All nodes in box which belong to NSID are initialized. Others are excluded (optional).
T	Temperature

VARIABLE	DESCRIPTION
TE	Temperature of exempted nodes (optional)

LOAD_THERMAL_CONSTANT_ELEMENT_*OPTION

Available options include:

BEAM

SHELL

SOLID

TSHELL

Purpose: Define a uniform element temperature that remains constant for the duration of the calculation. The reference temperature state is assumed to be a null state. An element temperature, read in and held constant throughout the analysis, dynamically loads the structure. The defined temperature can also be seen as a relative temperature to a surrounding or initial temperature.

Element Cards. Include as many cards in this format as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	EID	T						
Type	I	F						
Default	none	0.						

VARIABLE	DESCRIPTION
EID	Element ID
T	Temperature, see Remark 1.

Remarks:

1. **Reference Temperature.** The temperature range for the constitutive constants in the thermal materials must include the reference temperature of zero. If not, termination will occur with a temperature out-of-range error immediately after the execution phase is entered.

*LOAD_THERMAL_CONSTANT_NODE

Purpose: Define nodal temperature that remains constant for the duration of the calculation. The reference temperature state is assumed to be a null state with this option. A nodal temperature state, read in and held constant throughout the analysis, dynamically loads the structure. Thus, the temperature defined can also be seen as a relative temperature to a surrounding or initial temperature.

Node Cards. Include as many cards in this format as desired. This input ends at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	NID	T						
Type	I	F						
Default	none	0.						

VARIABLE	DESCRIPTION
NID	Node ID
T	Temperature, see Remark 1.

Remarks:

1. **Reference Temperature.** The temperature range for the constitutive constants in the thermal materials must include the reference temperature of zero. If not, termination will occur with a temperature out-of-range error immediately after the execution phase is entered.

*LOAD_THERMAL_D3PLOT

Purpose: Temperatures computed in a prior thermal-only analysis are used to load a mechanical-only analysis. The rootname of the d3plot database from the thermal-only analysis is specified on the execution line of the mechanical-only analysis using T = tpf, where tpf is that rootname, such as T = d3plot.

Warnings:

1. If using a double precision LS-DYNA executable in making the two runs, do not write the d3plot data using 32ieee format in the thermal-only run, that is, the environment variable LSTC_BINARY must not be set.

2. The rootnames of the d3plot databases from the two runs must not conflict. Such conflict can be avoided, for example, by using jobid = *jobname* on the execution line of the second (mechanical-only) run.

*LOAD_THERMAL_LOAD_CURVE

Purpose: Nodal temperatures will be uniform throughout the model and will vary according to a load curve. The temperature at time = 0 becomes the reference temperature for the thermal material. The reference temperature is obtained from the optional curve for dynamic relaxation if this curve is used. The load curve option for dynamic relaxation is useful for initializing preloads.

Thermal Load Curve Cards. Include as many cards in this format as desired. This input ends at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	LCID	LCIDDR						
Type	I	I						
Default	none	0						

VARIABLE	DESCRIPTION
LCID	Load curve ID, see *DEFINE_CURVE, to define temperature as a function of time.
LCIDDR	An optional load curve ID, see *DEFINE_CURVE, to define temperature as a function of time during the dynamic relaxation phase.

*LOAD_THERMAL_RSW

Purpose: Define thermal loading conditions within an ellipsoidal region of the solid or shell structure for structural-only simulation. Temperatures are prescribed to nodes found in a region defined by this keyword. The load condition is tailored to represent the so-called weld nuggets evolving during resistive spot welding (RSW) processes and surrounding heat affected zones. For any node that is not part of a spot weld region, a default temperature is assumed.

Card Summary:

Card 1. This card is required.

DEFTEMP							

Card 2. Include as many sets of Cards 2 through 4 as needed (Card 4 is only included in the set if OPTION = 1). This input ends at the next keyword ("*") card.

SID	OPTION	NID1	NID2	TDEATH	TBIRTH	LOC	GEOUP

Card 3. Include in set with Card 2.

DIST	H1	H2	R	TEMPC	TEMPB	LCIDT	

Card 4. Include in set with Cards 2 and 3 if OPTION = 1 on Card 2.

HZ1	HZ2	RZ	TEMPZB				

Data Card Definitions:

Card 1	1	2	3	4	5	6	7	8
Variable	DEFTEMP							
Type	F							
Default	0.							

VARIABLE	DESCRIPTION
DEFTEMP	Default temperature outside the nuggets and heat affected zones

Include as many sets of Cards 2 through 4 as needed (Card 4 is only included in the set if OPTION = 1). This input ends at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	SID	OPTION	NID1	NID2	TDEATH	TBIRTH	LOC	GEOUP
Type	I	I	I	I	F	F	I	I
Default	none	0	none	none	10^{20}	0.	0	0

VARIABLE	DESCRIPTION
SID	Node set ID; see *SET_NODE_*OPTION*. Nodes in the set will be checked to see if they are in the nugget or heat affected zone. If they are, the load will be applied. The load will not be applied to nodes in these regions if they are not included in the set.
OPTION	Option for heat affected zone around the weld nugget: EQ.0: No heat affected zone EQ.1: Ellipsoidal region considered
NID1	Node defining the tail of the orientation vector (axis of rotation of the ellipsoidal region) and the base for positioning of the nugget. See Remarks 1 and 2.
NID2	Node defining the head of the orientation vector (axis of rotation of the ellipsoidal region). See Remarks 1 and 2.
TDEATH	Deactivation time for temperature boundary condition. At this point in time, the temperature constraint is removed.
TBIRTH	Activation time for temperature boundary condition. Before this point in time, the temperature constraint is ignored.
LOC	Application of surface for thermal shell elements; see parameter, THSHEL, in the *CONTROL_SHELL input: EQ.-1: Lower surface of thermal shell element EQ.0: Middle surface of thermal shell element EQ.1: Upper surface of thermal shell element

VARIABLE	DESCRIPTION
GEOUP	Number of times the geometry of the spot weld is updated between TBIRTH and TDEATH EQ.0: Update geometry every time step

Geometry and Temperature Card. Include in set with Card 2.

Card 3	1	2	3	4	5	6	7	8
Variable	DIST	H1	H2	R	TEMPC	TEMPB	LCIDT	
Type	F	F	F	F	F	F	I	
Default	0.	0.	0.	0.	0.	0.	none	

VARIABLE	DESCRIPTION
DIST	Position of center of nugget on the axis of rotation. Parameter defines the distance to NID1 along the orientation vector. See Remark 1.
H1	Half width h_1 of nugget in the lower half, meaning in direction to NID1. See Remark 2.
H2	Half width h_2 of nugget in the upper half, meaning in direction to NID2. See Remark 2.
R	Radius r_{weld} of the nugget in surface normal to orientation vector. See Remark 2.
TEMPC	Base temperature at the center of the nugget. See Remark 3.
TEMPB	Base temperature at the boundary of the nugget. See Remark 3.
LCIDT	|LCIDT| refers to the load curve ID prescribing the temperature evolution in the nugget as a function of time. The abscissa of the load curve will be normalized between the birth and death times of the boundary condition. GT.0: The ordinate values of the load curve scale the respective base temperature of a particular point. EQ.0: No temperature evolution. Base temperatures are used.

VARIABLE	DESCRIPTION
	LT.0: The ordinate values of the load curve are used to define a linear combination between the temperature at the birth time and the base temperature of a particular point. Load curve ordinate values should range between 0.0 and 1.0. We recommend LCIDT < 0 to ensure a smooth temperature evolution.
	See Remark 3.

Heat Affected Zone Card. Include in set with Cards 2 and 3 if OPTION = 1 on Card 2.

Card 4	1	2	3	4	5	6	7	8
Variable	HZ1	HZ2	RZ	TEMPZB				
Type	R	F	F	R				
Default	0.	0.	0.	0.				

VARIABLE	DESCRIPTION
HZ1	Half width h_{z1} of heat affected zone in the lower half, meaning in direction to NID1. See Remark 4.
HZ2	Half width h_{z2} of heat affected zone in the upper half, meaning in direction to NID1. See Remark 4.
RZ	Radius r_{haz} of the heat affected zone in surface normal to orientation vector. See Remark 4.
TEMPBZ	Base temperature at the boundary of the heat affected zone. See Remark 4.

Remarks:

1. **Positioning.** The position of the center of the nugget is defined starting from a base node (NID1). It is then translated by a distance DIST along the orientation vector **v** of the nugget. Vector **v** points from NID1 to NID2. See Figure 33-16.

2. **Geometry of the Nugget.** Orientation vector **v** defines the axis of rotational symmetry for the ellipsoidal region, which reflects the weld nugget. The radius around this axis is defined by r_{weld}. The nugget consists of two half ellipsoids

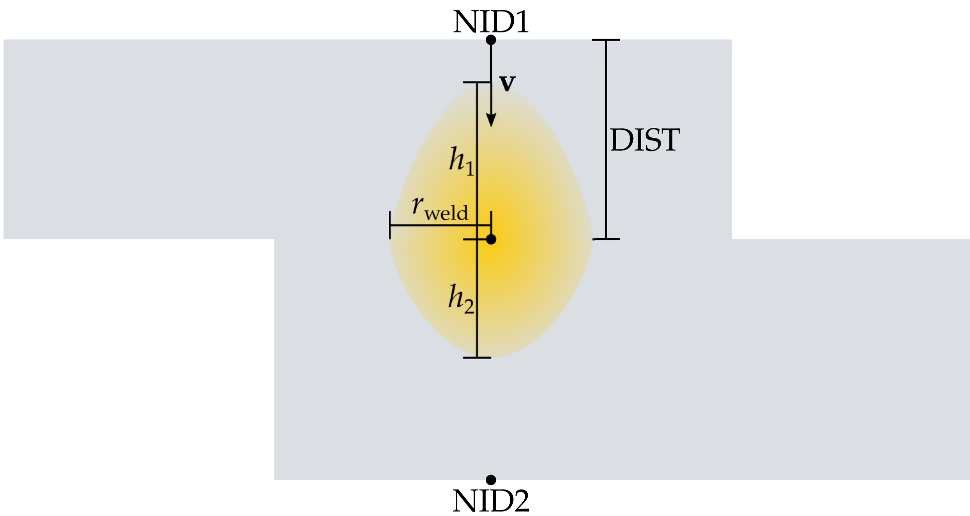

Figure 33-16. Example of geometry for OPTION = 0

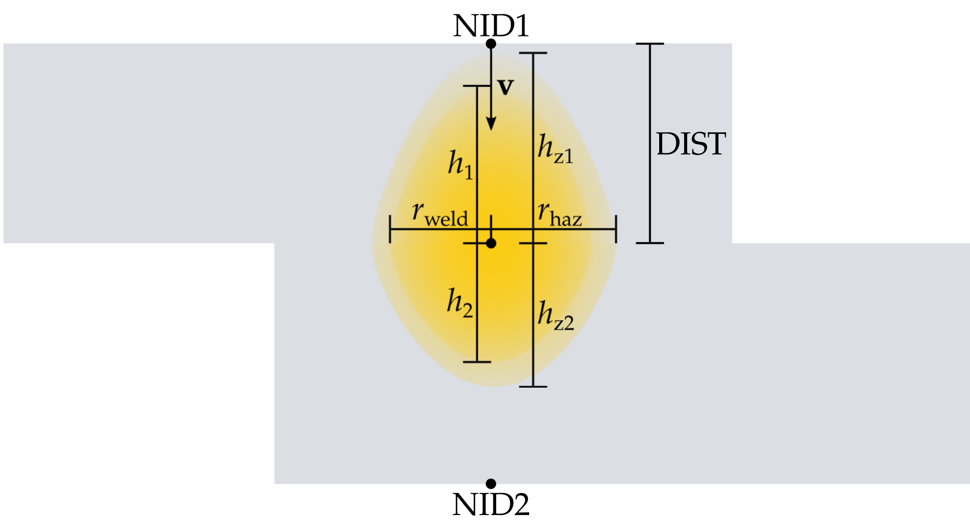

Figure 33-17. Example of geometry with OPTION = 1 (heat affected zone)

of possibly different height. The lower half, i.e. the half between NID1 and the center, has a height of h_1, wheras the upper half has a height of h_2. See Figure 33-16.

3. **Prescribing Temperature Values.** You can prescribe the base temperatures at the boundary and the center of the nugget with TEMPC and TEMPB, respectively. In between LS-DYNA calculates the base temperature in the nugget, $T_{\mathrm{nug},b}(x,y,z)$, with a quadratic interpolation.

   For this loading condition, you must provide activation and deactivation times, t_{ac} and t_{deac}, respectively. With LCIDT, you can specify the temperatures as a function, $\theta(\tilde{t})$, of the normalized time, $\tilde{t} = (t - t_{\mathrm{ac}})/(t_{\mathrm{deac}} - t_{\mathrm{ac}})$, within this time span. For positive values of field LCIDT, a simple scaling is applied:

$$T_{\mathrm{nug}}(x,y,z,t) = T_{\mathrm{nug},b}(x,y,z) \times \theta(\tilde{t}(t)) \ .$$

For negative values of LCIDT, a smooth evolution of the temperature from the birth time is ensured, so we recommend this type of load curve. The temperature is given by:

$$T_{\mathrm{nug}}(x,y,z,t) = T_{\mathrm{ac}}(x,y,z) + \left(T_{\mathrm{nug},b}(x,y,z) - T_{\mathrm{ac}}(x,y,z)\right) \times \theta(\tilde{t}) \ .$$

Here T_{ac} corresponds to the temperature of a particular point right before the birth time.

4. **Heat affected Zone.** With input field OPTION set to 1, the prescribed load expands to a heat affected zone that has the same general shape definition as the weld nugget described in Remark 2. The dimensions are here given by r_{haz}, h_{z1}, and h_{z2}. See Figure 33-17.

   You can prescribe the base temperature value at the boundary of the heat affected zone. LS-DYNA finds the base temperature in the heat affected zone, $T_{\mathrm{HAZ},b}(x,y,z)$ with a linear interpolation between the base boundary temperature of the nugget and the base boundary temperature of the heat affected zone. The load curve LCIDT governs the temperature evolution of the heat affected zone as described in Remark 3.

*LOAD_THERMAL_TOPAZ

Purpose: Nodal temperatures will be read in from the TOPAZ3D database. This file is defined on the execution line by the specification: T=**tpf**, where **tpf** is a binary database file (such as T3PLOT).

*LOAD_THERMAL_VARIABLE

Purpose: Define nodal temperature using node set(s) and temperature as a function of time curve(s).

Card Sets. Include as many sets consisting of the following two cards as desired. This input ends at the next keyword ("*") card.

Card 1	1	2	3	4	5	6	7	8
Variable	NSID	NSIDEX	BOXID					
Type	I	I	I					
Default	{all}	{Ø}	0					

Card 2	1	2	3	4	5	6	7	8
Variable	TS	TB	LCID	TSE	TBE	LCIDE	LCIDR	LCIDEDR
Type	F	F	I	F	F	I	I	I
Default	0.	0.	none	0.	0.	↓	none	↓
Remark	1	1	1	1	1			

VARIABLE	DESCRIPTION
NSID	Nodal set ID containing nodes (see *SET_NODE_*OPTION*): EQ.0: all nodes are included.
NSIDEX	Nodal set ID containing nodes that are exempted (optional), (see *SET_NODE_OPTION).
BOXID	All nodes in box which belong to NSID are initialized. Others are excluded.
TS	Scaled temperature.
TB	Base temperature.

VARIABLE	DESCRIPTION
LCID	Load curve ID (see *DEFINE_CURVE) or function ID (see *DEFINE_FUNCTION and Remark 2) that multiplies the scaled temperature.
TSE	Scaled temperature of the exempted nodes (optional).
TBE	Base temperature of the exempted nodes (optional).
LCIDE	Load curve ID that multiplies the scaled temperature of the exempted nodes (optional), (see *DEFINE_CURVE).
LCIDR	Load curve ID that multiplies the scaled temperature during the dynamic relaxation phase
LCIDEDR	Load curve ID that multiplies the scaled temperature of the exempted nodes (optional) during the dynamic relaxation phase.

Remarks:

1. **Temperature Model.** The total temperature is defined as

$$T = \mathrm{TB} + \mathrm{TS} \times f(t) \ ,$$

where $f(t)$ is the current value of the load curve, TS is the scaled temperature, and TB is the base temperature. The initial temperature and thus the reference temperature for a thermal loading is consistently defined by $T_0 = \mathrm{TB} + \mathrm{TS} \times f(0)$.

2. ***DEFINE_FUNCTION for LCID.** If LCID references a function ID, then the following function arguments are allowed: $f(x0, y0, z0, x, y, z, t)$, where $x0$, $y0$ and $z0$ are the original coordinates; x, y and z are the current coordinates; and t is the solution time

3. **Thermal Strain.** The rate of thermal strain is based on the rate of temperature change. In other words, the thermal load arises from change in total temperature. Furthermore, the calculation of the thermal strain from the coefficient of thermal expansion depends on the material model, and some material models, e.g., *MAT_255, may offer multiple options. Temperature-dependent material properties are based on the total temperature.

LOAD_THERMAL_VARIABLE_BEAM_*{OPTION}

Available options include:

<BLANK>

SET

Purpose: Define a known temperature time history as a function of the section coordinates for Hughes-Liu beam elements. To set the temperature for the whole element see *LOAD_THERMAL_VARIABLE_ELEMENT_BEAM.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	EID/SID	IPOLAR					
Type	I	I	I					
Default	none	none	0					

Temperature Cards. Include as many cards in the following format as desired. See Remarks 2 and 3. This input ends at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	TBASE	TSCALE	TCURVE	TCURDR	SCOOR	TCOOR		
Type	F	F	I	I	F	F		
Default	0.	1.0	0	TCURVE	none	none		

VARIABLE	DESCRIPTION
ID	Load case ID
EID/SID	Beam ID or beam set ID
IPOLAR	Flag to use polar coordinates instead of rectangular coordinates. GT.0: The coordinates SCOOR and TCOOR are given in polar coordinates. See Remark 3.
TBASE	Base temperature

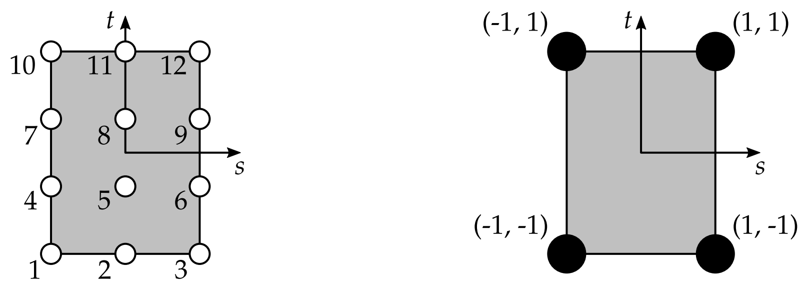

Figure 0-1. Figure illustrating point ordering.

VARIABLE	DESCRIPTION
TSCALE	Constant scale factor applied to temperature from curve
TCURVE	Curve ID for temperature as a function of time
TCURDR	Curve ID for temperature as a function of time used during dynamic relaxation
SCOOR	Normalized coordinate in local *s*-direction (-1.0 to +1.0)
TCOOR	Normalized coordinate in local *t*-direction (-1.0 to +1.0)

Remarks:

1. **Temperature Curve.** The temperature T is defined as:

$$\mathrm{T} = \mathrm{TBASE} + \mathrm{TSCALE} \times f(t)$$

where $f(t)$ is the current ordinate value of the curve. If the curve is undefined, then T = TBASE at all times.

2. **Cross Section Coordinates.** At least four points (four Card 2's) must be defined in a rectangular grid since each edge can have a different temperature history. The required order of the points is as shown in Figure 0-1. First, define the bottom row of points (most negative *t*), left to right in order of increasing *s*. Then increment *t* to define the next row of points, left-to-right in order of increasing *s*, and so on. The *s*-*t* axes are in the plane of the beam cross-section with the *s*-axis in the plane of nodes N1, N2, N3 defined in *ELEMENT_BEAM.

3. **Polar Cross Section Coordinates.** For this option only two points (two Card 2's) must be defined for the center and edge of the section because the temperature changes are assumed to only be in the radial direction. For the polar option, SCOOR is the non-dimensional radius R/R_0 where R_0 is the outer radius of the section; and TCOOR is defined as θ/π, where θ is the angle in radians from the *s*-axis and ranges from $-\pi$ to π.

4. **Integration Point Temperatures.** Temperatures will be assigned to the integration points by linear interpolation from the points defined using this command.

LOAD_THERMAL_VARIABLE_ELEMENT_*OPTION

Available options include:

BEAM

SHELL

SOLID

TSHELL

Purpose: Define element temperature that is variable during the calculation. The reference temperature state is assumed to be the temperature at time = 0.0 with this option.

Element Cards. Include as many cards in the following format as desired. This input ends at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	EID	TS	TB	LCID				
Type	I	F	F	I				
Default	none	0.	0.	none				

VARIABLE	DESCRIPTION
EID	Element ID
TS	Scaled temperature
TB	Base temperature
LCID	Load curve ID defining a scale factor that multiplies the scaled temperature as a function of time (see *DEFINE_CURVE).

Remarks:

1. The temperature is defined as:

$$T = \mathrm{TB} + \mathrm{TS} \times f(t)$$

   where $f(t)$ is the current value of the load curve, TS is the scaled temperature, and TB is the base temperature

*LOAD_THERMAL_VARIABLE_NODE

Purpose: Define nodal temperature that is variable during the calculation. A nodal temperature state read in and varied according to the load curve dynamically loads the structure.

Node Cards. Include as many cards in the following format as desired. This input ends at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	NID	TS	TB	LCID				
Type	I	F	F	I				
Default	none	0.	0.	none				

VARIABLE	DESCRIPTION
NID	Node ID
TS	Scaled temperature
TB	Base temperature
LCID	Load curve ID that multiplies the scaled temperature, (see *DEFINE_CURVE).

Remarks:

1. The temperature is defined as:

$$T = \mathrm{TB} + \mathrm{TS} \times f(t)$$

where $f(t)$ is the current value of the load curve, TS is the scaled temperature, and TB is the base temperature. The initial temperature and thus the reference temperature for a thermal loading is consistently defined by $T_0 = \mathrm{TB} + \mathrm{TS} \times f(0)$.

*LOAD_THERMAL_VARIABLE_SHELL_{OPTION}

Available options include:

<BLANK>

SET

Purpose: Define a known temperature time history as a function of the through-thickness coordinate for the shell elements.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	EID/SID						
Type	I	I						
Default	none	none						

Temperature Cards. Include as many cards of this type as desired. This input ends at the next keyword ("*") card.

Card 2	1	2	3	4	5	6	7	8
Variable	TBASE	TSCALE	TCURVE	TCURDR	ZCO			
Type	F	F	I	I	F			
Default	0.0	1.0	Rem 1	TCURVE	none			

VARIABLE	DESCRIPTION
ID	Load case ID
EID/SID	Shell ID or shell set ID
TBASE	Base temperature
TSCALE	Constant scale factor applied to temperature from curve
TCURVE	Curve ID for temperature as a function of time

VARIABLE	DESCRIPTION
TCURDR	Curve ID for temperature as a function of time used during dynamic relaxation
ZCO	Normalized through-thickness coordinate (-1.0 to +1.0). See Remarks 2 and 3.

Remarks:

1. **Temperature Definition.** The temperature T is defined as:

$$T = \mathrm{TBASE} + \mathrm{TSCALE} \times f(t) ,$$

where $f(t)$ is the current ordinate value of the curve. If the curve is undefined, then $T = \mathrm{TBASE}$ at all times.

2. **Through-Thickness Coordinate.** Through-thickness points must be defined in order of increasing ZCO (-1.0 to +1.0). ZCO = +1.0 is the top surface of the element, that is, the element surface in the positive outward normal vector direction from the mid-plane.

3. **Shell Temperature Distribution.** At least two points (two Card 2's) must be defined. Temperatures will be assigned in the through-thickness direction by linear interpolation from the points defined using this command. If the element has multiple in-plane integration points, the same temperature distribution is used at each in-plane integration point.

4. **LOAD_THERMAL_NODE.** If a shell's temperature distribution is defined using this card, any values defined by *LOAD_THERMAL_NODE are ignored for that shell.

*LOAD_VOLUME_LOSS

Purpose: To represent the effect of tunneling on surrounding structures, it is common to assume that a pre-defined fraction (e.g., 2%) of the volume occupied by the tunnel is lost during the construction process. This feature is available for solid elements only.

Part Set Cards. Include as many of these cards as desired. This input ends at the next keyword ("*") card.

Card	1	2	3	4	5	6	7	8
Variable	PSID	COORD	LCUR	FX	FY	FZ	PMIN	FACTOR
Type	I	I	I	F	F	F	F	F
Default	none	global	0	1	1	1	-10^{20}	.01

VARIABLE	DESCRIPTION
PSID	Part Set ID
COORD	Coordinate System ID (default - global coordinate system)
LCUR	Curve ID containing volume fraction lost as a function of time
FX	Fraction of strain occurring in x-direction
FY	Fraction of strain occurring in y-direction
FZ	Fraction of strain occurring in z-direction
PMIN	(Leave blank)
FACTOR	Feedback factor

Remarks:

1. **Volume Loss Algorithm.** Volume loss is modeled by a process similar to thermal contraction: if the material is unrestrained, it will shrink while remaining unstressed; if restrained, stresses will become more tensile. Typically, the material surrounding the tunnel offers partial restraint; the volume loss algorithm adjusts the applied "thermal" strains to attempt to achieve the desired volume loss. Optionally, FX, FY and FZ may be defined: these will be treated as ratios

for the x, y and z strains; this feature can be used to prevent contraction parallel to the tunnel axis.

2. **Output.** The total volume of all the parts in the part set is monitored and output at the time-history interval (on *DATABASE_BINARY_D3THDT) to a file named vloss_output. This file contains lines of data (*time, volume1, volume2, volume3…*) where *volume1* is the total volume of elements controlled by the first *LOAD_VOLUME_LOSS card, *volume2* is the total volume of elements controlled by the second *LOAD_VOLUME_LOSS card, etc.

3. **Material Models.** This feature works only with material types that use incremental strains to compute stresses. Thus, hyperelastic materials (e.g. MAT_027) are excluded, as are certain foam material types (e.g. MAT_083).

4. **Feedback Factor.** The feedback factor (see FACTOR field) controls how strongly the algorithm tries to impose the desired change of volumetric strain. The default value is recommended. If the volumetric response appears noisy or unstable, it may be necessary to reduce FACTOR. Alternatively, if the actual volumetric strain changes much more slowly than the input curve, it may be necessary to increase FACTOR.