COMSOL MULTIPHYSICS

STRUCTURAL MECHANICS MODULE

REFERENCE GUIDE

VERSION 3.4

COMSOL

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Structural Mechanics Module Reference Guide

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1

Introduction

The Structural Mechanics Module 3.4 is an optional package that extends the COMSOL Multiphysics modeling environment with customized user interfaces and functionality optimized for structural analysis. Like all modules in the COMSOL family, it provides a library of prewritten ready-to-run models that make it quicker and easier to analyze discipline-specific problems.

This particular module solves problems in the fields of structural and solid mechanics, adding special elements such as beams, plates, and shells. It provides static, eigenfrequency, time-dependent, quasi-static transient, parametric, linear buckling, and frequency response analysis capabilities. You can use both linear and nonlinear material models such as elasto-plastic models and include large deformation effects as well as contact and friction in an analysis. Material models can be isotropic, orthotropic, or fully anisotropic. Define loads, constraints, and material models in local, user-defined coordinate systems or in a global coordinate system. Piezoelectric materials can be analyzed with the constitutive relations on either stress-charge or strain-charge form.

All application modes in this module are fully multiphysics enabled, making it possible to couple to any other physics application mode in COMSOL Multiphysics or the other modules. Coupling structural analysis with thermal analysis is one example of multiphysics easily implemented with the Structural Mechanics

Module. Piezoelectric materials, coupling the electric field and strain in both directions are fully supported inside the module through special application modes solving for both the electric potential and displacement. Structural mechanics couplings are common in simulations done with COMSOL Multiphysics and occur in interaction with fluid flow (FSI), chemical reactions, acoustics, electric fields, magnetic fields, and optical wave propagation.

The underlying equations for structural mechanics are automatically available in all of the application modes—a feature unique to COMSOL Multiphysics. This also makes nonstandard modeling easily accessible. For example, you can change the constitutive equations to model hyperelastic material. The Structural Mechanics Module also features extensible material and beam cross-section libraries.

The documentation set for the Structural Mechanics Module consists of the *Structural Mechanics Module User's Guide*, the *Structural Mechanics Module Model Library,* and this *Structural Mechanics Module Reference Guide*. All books are available in PDF and HTML versions from the COMSOL Help Desk. This book contains reference information about application mode variables, command-line programming, and command-line functions that are specific to the Structural Mechanics Module (shape-function classes for special element types).

Typographical Conventions

All COMSOL manuals use a set of consistent typographical conventions that should make it easy for you to follow the discussion, realize what you can expect to see on the screen, and know which data you must enter into various data-entry fields. In particular, you should be aware of these conventions:

- A **boldface** font of the shown size and style indicates that the given word(s) appear exactly that way on the COMSOL graphical user interface (for toolbar buttons in the corresponding tooltip). For instance, we often refer to the **Model Navigator**, which is the window that appears when you start a new modeling session in COMSOL; the corresponding window on the screen has the title **Model Navigator**. As another example, the instructions might say to click the **Multiphysics** button, and the boldface font indicates that you can expect to see a button with that exact label on the COMSOL user interface.
- The names of other items on the graphical user interface that do not have direct labels contain a leading uppercase letter. For instance, we often refer to the Draw toolbar; this vertical bar containing many icons appears on the left side of the user interface during geometry modeling. However, nowhere on the screen will you see

the term “Draw” referring to this toolbar (if it were on the screen, we would print it in this manual as the **Draw** menu).

- The symbol **>** indicates a menu item or an item in a folder in the **Model Navigator**. For example, **Physics>Equation System>Subdomain Settings** is equivalent to: On the **Physics** menu, point to **Equation System** and then click **Subdomain Settings**. **COMSOL Multiphysics>Heat Transfer>Conduction** means: Open the **COMSOL Multiphysics** folder, open the **Heat Transfer** folder, and select **Conduction**.
- A `Code` (monospace) font indicates keyboard entries in the user interface. You might see an instruction such as “Type `1.25` in the **Current density** edit field.” The monospace font also indicates COMSOL Script codes.
- An *italic* font indicates the introduction of important terminology. Expect to find an explanation in the same paragraph or in the Glossary. The names of books in the COMSOL documentation set also appear using an italic font.

2

Application Modes Variables

This chapter provides listings of the application mode variables that you have access to in the Structural Mechanics Module's application modes.

Variables in the Application Modes

A large number of variables are available for use in expressions and postprocessing. This chapter lists the variables defined in each application mode. In addition to the variables listed herein, you have always access to variable related to the geometry and the mesh, for example.

The application mode variable tables are organized as follows:

- The **Name** column lists the names of the variables that you can use in the equations or for postprocessing. Almost all variables, such as stresses and strains, are also available as the amplitude and phase of those variables by appending `_amp` or `_ph` to the variable name. Exceptions are variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`. A single index *i* on the displacement, `u`*i*, means that `u`*i* runs over the available global displacements, for example (`u`, `v`, `w`) in 3D. A single index on other names, for example `s`*i*, means that *i* runs over the global space variables (`x`, `y`, `z`). A double index `s`*ij* means that *ij* runs over the combination of the space variables (`xy`, `yz`, `xz`). Exceptions to these conventions are noted in the tables. For example, `s`*i* means the principle stresses when *i* runs over (`1`, `2`, `3`). For elasto-plastic materials the plastic strain, effective strain, effective stress, principal stress, and all stress components have two different variables defined: the normally defined variable and the Gauss-point evaluated variable. Notationally, the latter are distinguished by an added suffix `Gp` to the variable name, for example, `sxGp` instead of `sx`. It is only possible to use the Gauss-point evaluated variables for postprocessing.
- The **Symbol** column lists the symbol notation for each variable.
- In the **Analysis** column you can see the availability of variables for the different analysis types. The following abbreviations are used:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Parametric	P
Time dependent	T
Eigenfrequency	E

- The **Domain** column lists whether variables are available on subdomains (S), boundaries (B), edges (E), points (P), or all domains (All).

- In the **Description** column you can find a short description for each variable.
- Where applicable, the **Expression** column lists the expression used for determining each variable.

Continuum Application Modes

Solid, Stress-Strain

A large number of variables are available for use in expressions and postprocessing. In addition to the variables in Table 2-1, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` is the amplitude of the normal stress in the x direction
- `ex_ph` is the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

Table 2-1 uses a convention where indices $i, j, \ldots$ (or *i*, *j*, …) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`u`*i*) refers to the global displacements (u, v, w).

For elasto-plastic materials the plastic strain, effective strain, effective stress, principal stress, and all stress components have two different variables defined: the normally defined variable and the Gauss-point evaluated variable. Notationally, the latter are distinguished by an added suffix `Gp` to the variable name, for example, `sxGp` instead of `sx`. It is only possible to use the Gauss-point evaluated variables for postprocessing.

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`u`*i*	u_i	All	All	x_i displacement	u_i
`u`*i*`t`	u_{it}	T	All	x_i velocity	u_{it}
`u`*i*`_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
`u`*i*`_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`u`*i*`_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`u`*i*`_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`u`*i*`_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
ui_tt	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
ui_tt_amp	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
ui_tt_ph	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
p	p	All	All	Pressure	p
p_amp	p_{amp}	F	All	Pressure amplitude	$\lvert p \rvert$
p_ph	p_{ph}	F	All	Pressure phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(p), 2\pi)$
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$
ei, eij	ε_i, ε_{ij}	All	S	Strain, global coord. system	Engineering or Green strain depending if small or large deformation.
epi, epij	$\varepsilon_{\mathrm{p}i}$, $\varepsilon_{\mathrm{p}ij}$	S T	S	Plastic strain, global coord. system	
epe	$\varepsilon_{\mathrm{pe}}$	S T	S	Effective plastic strain	
eil,eijl	$\varepsilon_{i\mathrm{l}}$, $\varepsilon_{ij\mathrm{l}}$	All	S	Strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$
ei_t, eij_t	ε_{it}, ε_{ijt}	F T	S	Velocity strain, global coord system	Engineering or Green strain time derivative depending if small or large deformation
ei_tl, eij_tl	$\varepsilon_{it\mathrm{l}}$, $\varepsilon_{ijt\mathrm{l}}$	F T	S	Velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon_t T_{\mathrm{coord}}$
si, sij	σ_i, τ_{ij}	All	S	Cauchy stress, global coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
sil, sijl	σ_i, τ_{ij}	All	S	Cauchy stress, user-defined coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
si_t, sij_t	σ_{it}, τ_{ijt}	F T	S	Time derivative of Cauchy stress, global coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
s*i*l_t, s*ij*l_t	σ_{ilt}, τ_{ijlt}	F T	S	Time derivative of Cauchy stress, user-defined local coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
S*i*, S*ij*	S_i, S_{ij}	All	S	Second Piola Kirchhoff stress, global coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
S*i*l, S*ij*l	S_{il}, S_{ijl}	All	S	Second Piola Kirchhoff stress, user-defined local coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
S*i*_t, S*ij*_t	S_{it}, S_{ijt}	T	S	Time derivative of second Piola Kirchhoff stress, global coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
S*i*l_t	S_{ilt}, S_{ijlt}	T	S	Time derivative of second Piola Kirchhoff stress, user-defined local coord. system	Defined differently depending of coordinate system, material model, and if mixed or displacement formulation, and if loss factor damping is used
P*i*, P*ij*	P_i, P_{ij}	All	S	First Piola Kirchhoff stress, global coord. system	Only defined for hyperelastic material. Defined differently if loss factor damping is used
s*i*	σ_i	All	S	Principal stresses, i=1,2,3	
e*i*	ε_i	All	S	Principal strains, i=1,2,3	
s*i*x*j*	σ_{ixj}	All	S	Principal stress directions, i,j=1,2,3	
e*i*x*j*	ε_{ixj}	All	S	Principal strain directions, i,j=1,2,3	
evol	$\varepsilon_{\mathrm{vol}}$	All	All	volumetric strain	Defined differently for small and large deformations
F*ij*	F_{ij}, i,j=1,2,3	All	All	Deformation gradient	$\frac{\partial \mathbf{x}}{\partial \mathbf{X}}$

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
c*ij*	c_{ij}, $i{,}j = 1{,}2{,}3$	All	All	Right Cauchy-Green symmetric tensor all components are defined	$F^T F$
invF*ij*	$\mathrm{inv}F_{ij}$, $i{,}j = 1{,}2{,}3$	All	All	Inverse of deformation gradient	F^{-1} (calculated symbolically from F_{ij})
detF	$\det F$	All	All	Determinant of deformation gradient	$\det F$
J	J	All	All	Volume ratio	$\det F$
Jel	J_{el}	All	All	Elastic volume ratio	Defined differently if thermal loads or not
I1	I_1	All	All	First strain invariant	$\mathrm{trace}(C^2) = C_{11}{}^2 + C_{22}{}^2 + C_{33}{}^2$
I2	I_2	All	All	Second strain invariant	$\frac{1}{2}(I_1^2 - \mathrm{trace}(C^2))$
I3	I_3	All	All	Third strain invariant	$J_{\mathrm{el}}{}^2$
II1	$\bar{I}_1$	All	All	First modified strain invariant	$I_1 J_{\mathrm{el}}{}^{-\frac{2}{3}} = I_1 I_3{}^{-\frac{1}{3}}$
II2	$\bar{I}_2$	All	All	Second modified strain invariant	$I_2 J_{\mathrm{el}}{}^{-\frac{4}{3}} = I_1 I_3{}^{-\frac{2}{3}}$
tresca	σ_{tresca}	All	S	Tresca stress	$\mathrm{max}(\mathrm{max}(\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert)), \lvert\sigma_1 - \sigma_3\rvert))$
mises	σ_{mises}	All	S	von Mises stress	
Ws	W_{s}	All	S	Strain energy density	Defined differently depending of material model and mixed or displacement formulation
Ent	S_{elast}	All	All	Entropy per unit volume	Defined only for small deformations and either no damping or loss factor damping. See definition in theory section
Qdamp	Q_{d}	F	All	Heat associated with mechanical losses in material	Defined only for loss factor damping $0.5\omega\eta\mathrm{Real}(\varepsilon \cdot \mathrm{Conj}(D\varepsilon))$
Ta*i*	Ta_i	All	B	Surface traction (force/area) in x_i-direction	Defined differently depending of large or small deformation

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
F*i*g	F_{ig}	All	All	Body load, face load, edge load, point load, in global x_i-direction	Defined differently depending of force definition
Ft*ij*	F_{tij}	All	B	Deformation gradient projected on the tangent plane	$\delta_{ij}+u_iTx_j$
wcn_cp*i*	w_{cn}	S P	B	Contact help variable for contact pair i	$\mathrm{nojac}(T_{np})-T_n$
wctx*j*_cp*i*	w_{ctj}	P	B	Contact help variable for contact pair i	See definition in theory section
slipx*j*_cp*i*	slip_{xj}	P	B	Slip vector x_j dir. reference frame, contact pair i	$\mathrm{map}(x_j)+x_j{}^m{}_{\mathrm{old}}$
slip_cp*i*	slip	P	B	Slip vector magnitude reference frame, contact pair i	$\mathrm{sqrt}\sum_j(\mathrm{slip}_{xj}{}^2)$
slipdxr*j*_cp*i*	slip_{xrj}	P	B	Slip vector x_{rj} dir. deformed frame, contact pair i	$\sum_k \mathrm{map}(F_{tij})\mathrm{slip}_{xj}$
slipd_cp*i*	slipd	P	B	Slip vector magnitude deformed frame, contact pair i	$\mathrm{sqrt}\left(\sum_j(\mathrm{slipd}_{xrj}{}^2)\right)$
Tnp_cp*i*	T_{np}	S P	B	Penalized contact pressure, contact pair i	See definition in theory section
Ttpx*j*_cp*i*	$T_{\mathrm{tp}j}$	P	B	Penalized friction traction x_j dir., contact pair i	See definition in theory section
Tttrialx*j*_cp*i*	$T_{\mathrm{ttrial}j}$	P	B	Trial friction force x_j dir., contact pair i	See definition in theory section
vslipxr*j*_cp*i*	$v_{\mathrm{sx}j}$	P	B	Slip velocity vector x_j dir., contact pair i	$\frac{\mathrm{slipd}_{xrj}}{t-t_{\mathrm{old}}}$

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`vslip_cp`*i*	v_s	P	B	Slip velocity magnitude, contact pair i	$\mathrm{sqrt}\left(\sum_j \mathrm{vslip}_{xrj}{}^2\right)$
`mu_cp`*i*	μ	S P	B	Frictional coefficient, contact pair i	See definition in theory section
`Ttcrit_cp`*i*	μ	P	B	Maximum friction traction, contact pair i	See definition in theory section
`gap_cp`*i*	g	S P	B	Gap distance including offsets, contact pair i	$\mathrm{Geomgap}_\mathrm{cpi} - \mathrm{offset}_\mathrm{cpi} - \mathrm{map}(\mathrm{offset}_\mathrm{cpi})$
`contact_cp`*i*	contact	S P	B	In contact variable, contact pair i	Defined differently depending on the pair setting
`friction_cp`*i*	friction	S P	B	Enabling friction variable, contact pair i	`contact_cp`*i*`_old`
`PML`*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, Cartesian PML	$\mathrm{sign}(x_i - X_{i0} + \mathrm{eps})\lvert x_i - X_{i0} + \mathrm{eps}\rvert^n \times L_{x_i}(1-i)/dx_i^n$ $n \equiv$ PML scaling exponent
`rx`	rx	F	S	r vector in PML cylinder, x-coord., cylindrical PML	$(y_\mathrm{axis}{}^2+z_\mathrm{axis}{}^2)(x-x_0) - (y_\mathrm{axis}(y-y_0)+z_\mathrm{axis}(z-z_0))x_\mathrm{axis}$
`ry`	ry	F	S	r vector in PML cylinder, y-coord., cylindrical PML	$(z_\mathrm{axis}{}^2+x_\mathrm{axis}{}^2)(y-y_0) - (z_\mathrm{axis}(z-z_0)+x_\mathrm{axis}(x-x_0))y_\mathrm{axis}$
`rz`	rz	F	S	r vector in PML cylinder, z-coord., cylindrical PML	$(x_\mathrm{axis}{}^2+y_\mathrm{axis}{}^2)(z-z_0) - (x_\mathrm{axis}(x-x_0)+y_\mathrm{axis}(y-y_0))z_\mathrm{axis}$
`normr`	normr	F	S	r vector in PML cylinder, norm, cylindrical PML	$[\mathrm{rx}^2+\mathrm{ry}^2+\mathrm{rz}^2]^{1/2}$
`R`	R	F	S	Scaled radial coordinate, cylindrical PML	$R_0 + (\mathrm{normr}-R_0)^n L_r(1-i)/dr^n$ $n \equiv$ PML scaling exponent

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`PML`*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, cylindrical PML	$x_i + (-1{+}R/\mathrm{normr})\mathrm{r}x_i +$ $(\mathbf{r}_{\mathrm{axis}}\cdot(\mathbf{x}-\mathbf{x}_0))/\lvert\mathbf{r}_{\mathrm{axis}}\rvert - Z_0)^n L_z(1-i)/dz^n -$ $\mathbf{r}_{\mathrm{axis}}\cdot(\mathbf{x}-\mathbf{x}_0)x_{i\mathrm{axis}}/\lvert\mathbf{r}_{\mathrm{axis}}\rvert^2$
`R`	R	F	S	Scaled radial coordinate, spherical PML	$R_0 + (\Delta_0 - R_0)^n(1-i)L_r/d_r^{\ n}$ $\Delta_0 \equiv [(x-x_0)^2+(y-y_0)^2+(z-z_0)^2]^{1/2}$ $n \equiv$ PML scaling exponent
`PML`*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, spherical PML	$R(x_i - x_{0i})/\Delta_0$
`J`*xixj*	$\mathbf{J}_{x_ix_j}$	F	S	PML transformation matrix, element x_ix_j	$\frac{\partial}{\partial x_j}\mathrm{PML}x_i$
`invJ`*xixj*		F	S	PML inverse transformation matrix, element x_ix_j	$(\mathbf{J}^{-1})_{x_ix_j}$
ui`PML`*xj*		F	S	$\mathrm{PML}x_j$ derivative of x_i displacement	$\sum_k \frac{\partial u_i}{\partial x_k}(\mathbf{J}^{-1})_{x_kx_j}$
`detJ`	$\lvert\mathbf{J}\rvert$	F	S	Determinant of PML transformation matrix	$\det(\mathbf{J})$

Plane Stress

A large number of variables are available for use in expressions and for postprocessing. In addition to the variables listed in Table 2-2, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` is the amplitude of the normal stress in the x direction
- `ex_ph` is the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

For elasto-plastic material the plastic strain, effective strain, effective stress, principal stress, and all stress components have two different variables defined. The normal defined variable and the Gauss point evaluated variable. The different being an added `Gp` to the variable name. Example, `sxGp` instead of `sx`. The Gauss point evaluated variables can only be used for postprocessing.

Table 2-2 uses a convention where indices $i, j, \ldots$ (or *i*, *j*, ...) run over the geometry's Cartesian coordinate axes, x and y. In particular, u_i (`ui`) refers to the global displacements (u, v).

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui`	u_i	All	All	x_i displacement	u_i
`uit`	u_{it}	T	All	x_i velocity	u_{it}
`ui_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
`p`	p	All	All	Pressure	p
`p_amp`	p_{amp}	F	All	Pressure amplitude	$\lvert p \rvert$
`p_ph`	p_{ph}	F	All	Pressure phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(p), 2\pi)$
`disp`	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$
`ei, ez, exy`	$\varepsilon_i, \varepsilon_z, \varepsilon_{xy}$	All	S	Strain global system	Engineering or Green strain depending if small or large deformation. ε_z defined differently if loss factor damping is used.

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`epi`, `epz`, `epxy`	$\varepsilon_{\mathrm{p}i}$, $\varepsilon_{\mathrm{p}z}$, $\varepsilon_{\mathrm{p}xy}$	S T	S	Plastic strain global system	
`epe`	$\varepsilon_{\mathrm{pe}}$	S T	S	Effective plastic strain	
`eil`, `exyl`	$\varepsilon_{i\mathrm{l}}$, $\varepsilon_{xy\mathrm{l}}$	All	S	Strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$
`ei_t`, `ez_t`, `exy_t`	ε_{it}, ε_{zt}, ε_{xyt}	F T	S	Velocity strain, global coord. system	Defined differently depending of small or large deformation and analysis type
`eil_t`, `exyl_t`	$\varepsilon_{i\mathrm{l}t}$, $\varepsilon_{xy\mathrm{l}t}$	F T	S	Velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon_t T_{\mathrm{coord}}$
`si`, `sxy`	σ_i, τ_{xy}	All	S	Cauchy stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`sil`, `sxyl`	$\sigma_{i\mathrm{l}}$, $\tau_{xy\mathrm{l}}$	All	S	Cauchy stress, user-defined coord. system	Defined differently depending of material model, and if loss factor damping is used
`si_t`, `sxy_t`	σ_{it}, τ_{xyt}	F T	S	Time derivative of Cauchy stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`sil_t`, `sxyl_t`	$\sigma_{i\mathrm{l}t}$, $\tau_{xy\mathrm{l}t}$	F T	S	Time derivative of Cauchy stress, user-defined coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`Si`, `Sxy`	S_i, S_{xy}	All	S	Second Piola Kirchhoff stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`Sil`, `Sxyl`	$S_{i\mathrm{l}}$, $S_{xy\mathrm{l}}$	All	S	Second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, and if loss factor damping is used

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Si_t, Sxy_t	S_{it}, S_{xyt}	T	S	Time derivative of second Piola Kirchhoff stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
Sil_t, Sxyl_t	S_{it}, S_{xy}	T	S	Time derivative of second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
Pi, Pij	P_i, P_{ij}	All	S	First Piola Kirchhoff stress, global coord. system	Only defined for hyperelastic material. Defined differently if loss factor damping is used
si	σ_i	All	S	Principal stresses, $i=1,2,3$	
ei	ε_i	All	S	Principal strains, $i=1,2,3$	
sixj	σ_{ixj}	All	S	Principal stress directions, $i, j=1,2,3$	
eixj	ε_{ixj}	All	S	Principal strain directions, $i, j=1,2,3$	
evol	$\varepsilon_{\mathrm{vol}}$	All	All	volumetric strain	Defined differently depending of small or large displacement
Fij	F_{ij}, $i,j=1,2,3$	All	All	Deformation gradient	$\frac{\partial \mathbf{x}}{\partial \mathbf{X}}$
cij	c_{ij}, $i,j=1,2,3$	All	All	Right Cauchy-Green symmetric tensor all components are defined	$F^T F$
detF	$\det F$	All	All	Determinant of deformation gradient	$\det F$
invFij	$\mathrm{inv}F_{ij}$, $i, j=1,2,3$	All	All	Inverse of deformation gradient	F^{-1} (calculated symbolically from F_{ij})
J	J	All	All	Volume ratio	$\det F$

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Jel	J_{el}	All	All	Elastic volume ratio	Defined differently if thermal loads or not
I1	I_1	All	All	First strain invariant	$\mathrm{trace}(C^2) = C_{11}{}^2 + C_{22}{}^2 + C_{33}{}^2$
I2	I_2	All	All	Second strain invariant	$\frac{1}{2}(I_1^2 - \mathrm{trace}(C^2))$
I3	I_3	All	All	Third strain invariant	$J_{\mathrm{el}}{}^2$
II1	$\bar{I}_1$	All	All	First modified strain invariant	$I_1 J_{\mathrm{el}}{}^{-\frac{2}{3}} = I_1 I_3{}^{-\frac{1}{3}}$
II2	$\bar{I}_2$	All	All	Second modified strain invariant	$I_2 J_{\mathrm{el}}{}^{-\frac{4}{3}} = I_1 I_3{}^{-\frac{2}{3}}$
tresca	σ_{tresca}	All	S	Tresca stress	$\max(\max\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert,$ $\lvert\sigma_1 - \sigma_3\rvert))$
mises	σ_{mises}	All	S	von Mises stress	
Ws	W_{s}	All	S	Strain energy density	Defined differently depending of material model and if mixed or displacement formulation
Ta*i*	Ta_i	All	B	Surface traction (force/area) in x_i direction	Defined differently depending of small or large deformation
F*i*g	F_{ig}	All	S	Point, Edge, Body load, in global x_i direction	Defined differently depending of force definition
Ft*ij*	F_{tij}	All	B	Deformation gradient projected on the tangent plane	$\delta_{ij} + u_i T x_j$
wcn_cp*i*	w_{cn}	S P	B	Contact help variable for contact pair i	$\mathrm{nojac}(T_{np}) - T_n$
wctx*j*_cp*i*	$w_{\mathrm{ct}j}$	P	B	Contact help variable for contact pair i	See definition in theory section
slipx*j*_cp*i*	slip_{xj}	P	B	Slip vector x_j dir. reference frame, contact pair i	$\mathrm{map}(x_j) + x_{j\mathrm{old}}^m$

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
slip_cp*i*	slip	P	B	Slip vector magnitude reference frame, contact pair i	$\mathrm{sqrt}\left(\sum_j \mathrm{slip}_{xj}{}^2\right)$
slipdxr*j*_cp*i*	slip_{xrj}	P	B	Slip vector xrj dir. deformed frame, contact pair i	$\sum_j \mathrm{map}(F_{tij})\mathrm{slip}_{xj}$
slipd_cp*i*	slipd	P	B	Slip vector magnitude deformed frame, contact pair i	$\mathrm{sqrt}\left(\sum_j \mathrm{slipd}_{xrj}{}^2\right)$
Tnp_cp*i*	T_{np}	S P	B	Penalized contact pressure, contact pair i	See definition in theory section
Ttpx*j*_cp*i*	T_{tpj}	P	B	Penalized friction force x_j dir., contact pair i	See definition in theory section
Tttr*i*alx*j*_cpi	$T_{\mathrm{ttrial}j}$	P	B	Trial friction force x_j dir., contact pair i	See definition in theory section
vslipxr*j*_cp*i*	$v_{\mathrm{s}xj}$	P	B	Slip velocity vector x_j dir., contact pair i	$\dfrac{\mathrm{slipd}_{xrj}}{t-t_{\mathrm{old}}}$
vslip_cp*i*	v_{s}	P	B	Slip velocity, contact pair i	$\mathrm{sqrt}\left(\sum_j (\mathrm{vslip}_{xrj}{}^2)\right)$
mu_cp*i*	μ	S P	B	Frictional coefficient, contact pair i	See definition in theory section
Ttcrit_cp*i*	μ	P	B	Maximum frictional traction, contact pair i	See definition in theory section
gap_cp*i*	g	S P	B	Gap distance including offsets, contact pair i	$\mathrm{Geomgap}_{\mathrm{cp}i}-\mathrm{offset}_{\mathrm{cp}i}-\mathrm{map}(\mathrm{offset}_{\mathrm{cp}i})$
contact_cp*i*	contact	S P	B	In contact variable, contact pair i	Defined differently depending on the pair setting

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`friction_cp`*i*	friction	S P	B	Enabling friction variable, contact pair i	`contact_cp`*i*`_old`
`PML`*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, Cartesian PML	$\mathrm{sign}(x_i - X_{i0} + \mathrm{eps})\lvert x_i - X_{i0} + \mathrm{eps}\rvert^n \times L_{x_i}(1-i)/dx_i^n$ $n \equiv$ PML scaling exponent
`R`	R	F	S	Scaled radial coordinate, cylindrical PML	$R_0 + (\delta_0 - R_0)^n L_r (1-i)/dr^n$ $n \equiv$ PML scaling exponent
`PML`*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, cylindrical PML	$R(x_i - x_{0i})/\delta_0$, $\delta_0 \equiv [(x-x_0)^2 + (y-y_0)^2]^{1/2}$
`J`*xixj*	$J_{x_i x_j}$	F	S	PML transformation matrix, element xx	$\frac{\partial}{\partial x_j}\mathrm{PML}x_i$
`invJ`*xixj*		F	S	PML inverse transformation matrix, element $x_i x_j$	$(\mathbf{J}^{-1})_{x_i x_j}$
`detJ`	$\lvert\mathbf{J}\rvert$	F	S	Determinant of PML transformation matrix	$\det(\mathbf{J})$
ui`PML`*xj*		F	S	$\mathrm{PML}x_j$ derivative of x_i displacement	$\sum_k \frac{\partial u_i}{\partial x_k}(\mathbf{J}^{-1})_{x_k x_j}$

Plane Strain

A large number of variables are available for use in expressions and for postprocessing. In addition to the variables in Table 2-3, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` is the amplitude of the normal stress in the x direction
- `ex_ph` is the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

For elasto-plastic material the plastic strain, effective strain, effective stress, principal stress, and all stress components have two different variables defined. The normal defined variable and the Gauss point evaluated variable. The different being an added `Gp` to the variable name. Example, `sxGp` instead of `sx`. It is only possible to use the Gauss point evaluated variables for postprocessing.

Table 2-3 uses a convention where indices $i, j, \ldots$ (or *i*, *j*, …) run over the geometry's Cartesian coordinate axes, x and y. In particular, u_i (`ui`) refers to the global displacements (u, v).

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui`	u_i	All	All	x_i displacement	u_i
`uit`	u_{it}	T	All	x_i velocity	u_{it}
`u_amp, v_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
`disp`	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$
`p`	p	All	All	Pressure	p
`p_amp`	p_{amp}	F	All	Pressure amplitude	$\lvert p \rvert$
`p_ph`	p_{ph}	F	All	Pressure phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(p), 2\pi)$

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
e*i*, exy	ε_i, ε_{xy}	All	S	Strain, global coord. system	Engineering or Green strain depending if small or large deformation
ep*i*, epxy	$\varepsilon_{\mathrm{p}i}$, $\varepsilon_{\mathrm{p}xy}$	S T	S	Plastic strain, global coord. system	
epe	$\varepsilon_{\mathrm{pe}}$	S T	S	Effective plastic strain, global coord. system	
e*i*l, exyl	$\varepsilon_{i\mathrm{l}}$, $\varepsilon_{xy\mathrm{l}}$	All	S	Strain, user-defined coord. system	${T_{\mathrm{coord}}}^T \varepsilon T_{\mathrm{coord}}$
e*i*_t, exy_t	ε_{it}, ε_{xyt}	F T	S	Velocity strain, global coord. system	Defined differently depending of small or large deformation and analysis type
e*i*l_t, exyl_t	$\varepsilon_{i\mathrm{l}t}$, $\varepsilon_{xy\mathrm{l}t}$	F T	S	Velocity strain, user-defined coord. system	${T_{\mathrm{coord}}}^T \varepsilon_t T_{\mathrm{coord}}$
s*i*, sz, sxy	σ_i, σ_z, τ_{xy}	All	S	Cauchy stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
s*i*l, sxyl	$\sigma_{i\mathrm{l}}$, $\tau_{xy\mathrm{l}}$	All	S	Cauchy stress, user-defined coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
s*i*_t, sz_t, sxy_t	σ_{it}, σ_z, τ_{xyt}	F T	S	Time derivative of Cauchy stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
s*i*l_t, sxyl_t	$\sigma_{i\mathrm{l}t}$, $\tau_{xy\mathrm{l}t}$	F T	S	Time derivative of Cauchy stress, user-defined coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
S*i*, Sz, Sxy	S_i, S_z, S_{xy}	All	S	Second Piola Kirchhoff stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Sil, Sxyl`	S_{il}, S_{xyl}	All	S	Second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`Si_t, Sz_t, Sxy_t`	S_{it}, S_{zt}, S_{xyt}	T	S	Time derivative of second Piola Kirchhoff stress, global coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`Sil_t, Sxyl_t`	S_{ilt}, S_{xylt}	T	S	Time derivative of second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, mixed or displacement formulation, coordinate system, and if small or large deformation, and if loss factor damping is used
`Pi, Pz, Pxy`	P_i, P_z, P_{xy}	All	S	First Piola Kirchhoff stress, global coord. system	Only defined for hyperelastic material. Defined differently if loss factor damping is used
`si`	σ_i	All	S	Principal stresses, $i=1,2,3$	
`ei`	ε_i	All	S	Principal strains, $i=1,2,3$	
`sixj`	σ_{ixj}	All	S	Principal stress directions, $i,j=1,2,3$	
`eixj`	ε_{ixj}	All	S	Principal strain directions, $i,j=1,2,3$	
`evol`	$\varepsilon_{\mathrm{vol}}$	All	All	volumetric strain	Defined differently for small and large displacement
`Fij`	F_{ij}, $i,j=1,2,3$	All	All	Deformation gradient	$\frac{\partial \mathbf{x}}{\partial \mathbf{X}}$

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`cij`	c_{ij}, $i,j=1,2,3$	All	All	Right Cauchy-Green symmetric tensor all components are defined	$F^T F$
`detF`	$\det F$	All	All	Determinant of deformation gradient	$\det F$
`invFij`	$\mathrm{inv}F_{ij}$, $i,j=1,2,3$	All	All	Inverse of deformation gradient	F^{-1} (calculated symbolically from F_{ij})
`J`	J	All	All	Volume ratio	$\det F$
`Jel`	J_{el}	All	All	Elastic volume ratio	Defined differently if thermal loads or not
`I1`	I_1	All	All	First strain invariant	$\mathrm{trace}(C^2) = C_{11}{}^2 + C_{22}{}^2 + C_{33}{}^2$
`I2`	I_2	All	All	Second strain invariant	$\frac{1}{2}(I_1^2 - \mathrm{trace}(C^2))$
`I3`	I_3	All	All	Third strain invariant	$J_{\mathrm{el}}{}^2$
`II1`	$\bar{I}_1$	All	All	First modified strain invariant	$I_1 J_{\mathrm{el}}{}^{-\frac{2}{3}} = I_1 I_3{}^{-\frac{1}{3}}$
`II2`	$\bar{I}_2$	All	All	Second modified strain invariant	$I_2 J_{\mathrm{el}}{}^{-\frac{4}{3}} = I_1 I_3{}^{-\frac{2}{3}}$
`tresca`	σ_{tresca}	All	S	Tresca stress	$\max(\max\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert, \lvert\sigma_1 - \sigma_3\rvert))$
`mises`	σ_{mises}	All	S	von Mises stress	
`Ws`	W_{s}	All	S	Strain energy density	Defined differently depending of material model and if mixed or displacement formulation
`Tai`	Ta_i	All	B	Surface traction (force/ area) in x_i-direction	Defined differently depending of the force definition

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
F*ig*	F_{ig}	All	S	Point, Edge, Body load in global x_i-direction	Defined differently depending on the force definition
Ft*ij*	F_{tij}	All	B	Deformation gradient projected on the tangent plane	$\delta_{ij} + u_i T x_j$
wcn_cp*i*	w_{cn}	SP	B	Contact help variable for contact pair i	$\mathrm{nojac}(T_{np}) - T_n$
wctx*j*_cp*i*	w_{ctj}	P	B	Contact help variable for contact pair i	See definition in theory section
slipx*j*_cp*i*	slip_{xj}	P	B	Slip vector x_j dir. reference frame, contact pair i	$\mathrm{map}(x_j) + x_{j\mathrm{old}}^m$
slip_cp*i*	slip	P	B	Slip vector magnitude reference frame, contact pair i	$\mathrm{sqrt}\left(\sum_j \mathrm{slip}_{xj}{}^2\right)$
slipdxr*j*_cp*i*	slip_{xrj}	P	B	Slip vector x_{rj} dir. deformed frame, contact pair i	$\sum_j \mathrm{map}(F_{tij})\mathrm{slip}_{xj}$
slipd_cp*i*	slipd	P	B	Slip vector magnitude deformed frame, contact pair i	$\mathrm{sqrt}\left(\sum_j (\mathrm{slipd}_{xrj}{}^2)\right)$
Tnp_cp*i*	T_{np}	SP	B	Penalized contact pressure, contact pair i	See definition in theory section

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Ttpx*j*_cp*i*	T_{tpj}	P	B	Penalized friction force x_j dir., contact pair i	See definition in theory section
Tttrialx*j*_cp*i*	$T_{\mathrm{ttrial}j}$	P	B	Trial friction force x_j dir., contact pair i	See definition in theory section
vslipxr*j*_cp*i*	$v_{\mathrm{s}xj}$	P	B	Slip velocity vector x_j dir., contact pair i	$\frac{\mathrm{slipd}_{xrj}}{t-t_{\mathrm{old}}}$
vslip_cp*i*	v_{s}	P	B	Slip velocity, contact pair i	$\mathrm{sqrt}\left(\sum_j(\mathrm{vslip}_{xrj}{}^2)\right)$
mu_cp*i*	μ	SP	B	Frictional coefficient, contact pair i	See definition in theory section
Ttcrit_cp*i*	μ	P	B	Maximum friction traction, contact pair i	See definition in theory section
gap_cp*i*	g	SP	B	Gap distance including offsets, contact pair i	$\mathrm{Geomgap}_{\mathrm{cpi}}-\mathrm{offset}_{\mathrm{cpi}}-\mathrm{map}(\mathrm{offset}_{\mathrm{cpi}})$
contact_cp*i*	contact	SP	B	In contact variable, contact pair i	Defined differently depending on the pair setting
friction_cp*i*	friction	SP	B	Enabling friction variable, contact pair i	contact_cp*i*_old
PML*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, Cartesian PML	$\mathrm{sign}(x_i-X_{i0}+\mathrm{eps})\lvert x_i-X_{i0}+\mathrm{eps}\rvert^n \times L_{x_i}(1-i)/dx_i^n$ $n \equiv$ PML scaling exponent
R	R	F	S	Scaled radial coordinate, cylindrical PML	$R_0+(\delta_0-R_0)^n L_r(1-i)/dr^n$ $n \equiv$ PML scaling exponent

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
PML*xi*	$\mathrm{PML}x_i$	F	S	PML coordinate x_i, cylindrical PML	$R(x_i - x_{0i})/\delta_0$, $\delta_0 \equiv [(x-x_0)^2+(y-y_0)^2]^{1/2}$
J*xixj*	$J_{x_ix_j}$	F	S	PML transformation matrix, element xx	$\frac{\partial}{\partial x_j}\mathrm{PML}x_i$
invJ*xixj*		F	S	PML inverse transformation matrix, element x_ix_j	$(\mathbf{J}^{-1})_{x_ix_j}$
detJ	$\|\mathbf{J}\|$	F	S	Determinant of PML transformation matrix	$\det(\mathbf{J})$
*ui*PML*xj*		F	S	PMLx_j derivative of x_i displacement	$\sum_k \frac{\partial u_i}{\partial x_k}(\mathbf{J}^{-1})_{x_kx_j}$

Axial Symmetry, Stress-Strain

A large number of variables are available for use in expressions and postprocessing. In addition to the variables in Table 2-4, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` is the amplitude of the normal stress in the x direction
- `ex_ph` is the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

For elasto-plastic material the plastic strain, effective strain, effective stress, principal stress, and all stress components have two different variables defined. The normal defined variable and the Gauss point evaluated variable. The different being an added

Gp to the variable name. Example, sxGp instead of sx. It is only possible to use the gauss point evaluated variables for postprocessing.

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
uor	uor	All	All	r displacement divided by r	uor
uaxi	uaxi	All	All	r displacement	$\mathrm{uor} \cdot r$
w	w	All	All	z displacement	w
uort	uor_t	T	All	r velocity divided by r	uor_t
uaxi_t	uaxi_t	T	All	r velocity	$\mathrm{uor}_t \cdot r$
w_t	w_t	T	All	z velocity	w_t
uaxi_amp	$\mathrm{uaxi}_{\mathrm{amp}}$	F	All	r displacement amplitude	$\lvert\mathrm{uaxi}\rvert$
w_amp	w_{amp}	F	All	z displacement amplitude	$\lvert w\rvert$
uaxi_ph	$\mathrm{uaxi}_{\mathrm{ph}}$	F	All	r displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(\mathrm{uaxi}), 2\pi)$
w_ph	w_{ph}	F	All	z displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(w), 2\pi)$
uaxi_t	uaxi_t	F	All	r velocity	$j\omega\,\mathrm{uaxi}$
w_t	w_t	F	All	z velocity	$j\omega w$
uaxi_t_amp	$\mathrm{uaxi}_{t\mathrm{amp}}$	F	All	r velocity amplitude	$\omega\,\mathrm{uaxi}_{\mathrm{amp}}$
w_t_amp	$w_{t\mathrm{amp}}$	F	All	z velocity amplitude	ωw_{amp}
uaxi_t_ph	$\mathrm{uaxi}_{t\mathrm{ph}}$	F	All	r velocity phase	$\mathrm{mod}(\mathrm{uaxi}_{\mathrm{ph}} + 90°, 360°)$
w_t_ph	$w_{t\mathrm{ph}}$	F	All	z velocity phase	$\mathrm{mod}(w_{\mathrm{ph}} + 90°, 360°)$
uaxi_tt	uaxi_{tt}	F	All	r acceleration	$-\omega^2\,\mathrm{uaxi}$
w_tt	w_{tt}	F	All	z acceleration	$-\omega^2 w$
uaxi_tt_amp	$\mathrm{uaxi}_{t\mathrm{amp}}$	F	All	r acceleration amplitude	$\omega^2\,\mathrm{uaxi}_{\mathrm{amp}}$
w_tt_amp	$w_{t\mathrm{amp}}$	F	All	z acceleration amplitude	$\omega^2 w_{\mathrm{amp}}$
uaxi_tt_ph	$\mathrm{uaxi}_{t\mathrm{ph}}$	F	All	r acceleration phase	$\mathrm{mod}(\mathrm{uaxi}_{\mathrm{ph}} + 180°, 360°)$

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
w_tt_ph	w_{tph}	F	All	z acceleration phase	$\mathrm{mod}(w_{\mathrm{ph}} + 180°, 360°)$
disp	disp	All	All	Total displacement	$\sqrt{\mathrm{uaxi}^2 + w^2}$
p	p	All	All	Pressure	p
p_amp	p_{amp}	F	All	Pressure amplitude	$\lvert p \rvert$
p_ph	p_{ph}	F	All	Pressure phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(p), 2\pi)$
er, ez, ephi, erz	ε_r, ε_z, ε_φ, ε_{rz}	All	S	Strain, global coord. system	Engineering or Green strain depending if small or large deformation
epr, epz, epphi, eprz	ε_{pr}, ε_{pz}, $\varepsilon_{p\varphi}$, ε_{prz}	S T	S	Plastic strain, global coord. system	
epe	$\varepsilon_{\mathrm{pe}}$	S T	S	Plastic strain, global coord. system	
eil, exyl	ε_{il},ε_{xyl}	All	S	Strains, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$
er_t, ez_t, ephi_t, erz_t	ε_{rt},ε_{zt}, $\varepsilon_{\varphi t}$, ε_{rzt}	F T	S	Velocity strain, global coord. system	Defined differently depending of small or large displacement
eil_t, exyl_t	ε_{ilt} ε_{xylt}	F T	S	Velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon_t T_{\mathrm{coord}}$
sr, sphi, sz, srz	σ_r, σ_φ, σ_z, τ_{rz}	All	S	Cauchy stress, global coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
sil, sxyl	σ_{il}, τ_{xyl}	All	S	Cauchy stress, user-defined coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
sr_t, sphi_t, sz_t, srz_t	σ_{rt}, $\sigma_{\varphi 1}$, σ_{zt}, σ_{rzt}	F T	S	Time derivative of Cauchy stress, global coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
s*il*_t, s*xyl*_t	σ_{ilt}, τ_{xylt}	F T	S	Time derivative of Cauchy stress, user-defined coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
Sr, Sphi, Sz, Srz	S_r, S_φ, S_z, S_{rz}	All	S	Second Piola Kirchhoff stress, global coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
S*il*, S*xyl*	S_{il}, S_{xyl}	All	S	Second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
Sr_t, Sphi_t, Sz_t, Srz_t	S_{rt}, $S_{\varphi t}$, S_{zt}, S_{rzt}	T	S	Time der. of second Piola Kirchhoff stress, global coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
S*il*_t, S*xyl*_t	S_{ilt}, S_{xylt}	T	S	Time der. of second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, coordinate system, mixed or displacement formulation, and small or large displacement, and if loss factor damping is used
P*i*, P*ij*	P_i, P_{ij}	All	S	First Piola Kirchhoff stress, global coord. system	Only defined for hyperelastic material. Defined differently if loss factor damping is used
s*i*	σ_i	All	S	Principal stresses, $i = 1, 2, 3$	
e*i*	ε_i	All	S	Principal strains, $i = 1, 2, 3$	
s*i*x*j*	σ_{ixj}	All	S	Principal stress directions, $i,j = 1, 2, 3$	
e*i*x*j*	ε_{ixj}	All	S	Principal strain directions, $i,j = 1, 2, 3$	
evol	$\varepsilon_{\mathrm{vol}}$	All	All	volumetric strain	Defined differently for small and large displacement

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Fij`	F_{ij}, $i, j=1,2,3$	All	All	Deformation gradient	$\frac{\partial \mathbf{x}}{\partial \mathbf{X}}$
`cij`	c_{ij}, $i, j=1,2,3$	All	All	Right Cauchy-Green symmetric tensor all components are defined	$F^T F$
`detF`	$\det F$	All	All	Determinant of deformation gradient	$\det F$
`invFij`	$\mathrm{inv}F_{ij}$, $i, j=1,2,3$	All	All	Inverse of deformation gradient	F^{-1} (calculated symbolically from F_{ij})
`J`	J	All	All	Volume ratio	$\det F$
`Jel`	J_{el}	All	All	Elastic volume ratio	Defined differently if thermal loads or not
`I1`	I_1	All	All	First strain invariant	$\mathrm{trace}(C^2) = C_{11}{}^2 + C_{22}{}^2 + C_{33}{}^2$
`I2`	I_2	All	All	Second strain invariant	$\frac{1}{2}(I_1^2 - \mathrm{trace}(C^2))$
`I3`	I_3	All	All	Third strain invariant	$J_{\mathrm{el}}{}^2$
`II1`	$\bar{I}_1$	All	All	First modified strain invariant	$I_1 J_{\mathrm{el}}{}^{-\frac{2}{3}} = I_1 I_3{}^{-\frac{1}{3}}$
`II2`	$\bar{I}_2$	All	All	Second modified strain invariant	$I_2 J_{\mathrm{el}}{}^{-\frac{4}{3}} = I_1 I_3{}^{-\frac{2}{3}}$
`tresca`	σ_{tresca}	All	S	Tresca stress	$\max(\max(\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert)),$ $\lvert\sigma_1 - \sigma_3\rvert))$
`mises`	σ_{mises}	All	S	von Mises stress	
`Ws`	W_{s}	All	S	Strain energy density	Defined differently depending on material model and if mixed or displacement formulation
`Tar, Taz`	Ta_r, Ta_z	All	B	Surface traction (force/area) in r and z directions	Defined differently depending on small or large deformation

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Frg, Fzg	F_{rg}, F_{zg}	All	All	Body, edge, point load in global r and z directions	Defined differently depending on force definition
PMLr	PMLr	F	S	PML coordinate r, cylindrical PML	$R_0+\|r-R_0+\mathrm{eps}\|^n L_r(1-i)/dr^n$ $n \equiv$ PML scaling exponent
PMLz	PMLz	F	S	PML coordinate z, cylindrical PML	$\mathrm{sign}(z-z_0)\|z-Z_0+\mathrm{eps}\|^n L_z(1-i)/dz^n$
R	R	F	S	Scaled radial coordinate, spherical PML	$R_0+\|\Delta_0-R_0\|^n L_r(1-i)/dr^n$ $\Delta_0 \equiv [(x-x_0)^2+(y-y_0)^2]^{1/2}$ $n \equiv$ PML scaling exponent
PMLr	PMLr	F	S	PML coordinate r, spherical PML	Rr/δ_0 $\delta_0 \equiv [r^2+(z-z_0)^2]^{1/2}$
PMLz	PMLz	F	S	PML coordinate z, spherical PML	$(z-z_0)R/\delta_0$
J*xixj*	$\mathbf{J}_{ij}$	F	S	PML transformation matrix, element ij; x_i,x_j=r,z	$\frac{\partial}{\partial x_j}\mathrm{PML}x_i$
invJ*xixj*		F	S	PML inverse transformation matrix, element ij; x_i,x_j=r,z	$(\mathbf{J}^{-1})_{x_ix_j}$
detJ	$\|\mathbf{J}\|$	F	S	Determinant of PML transformation matrix	$\det(\mathbf{J})$
PMLuor	PMLuor	F	S	r displacement divided by PMLr	$\mathrm{uor}\cdot r/\mathrm{PML}r$
PMLuorr	PMLuor_r	F	S	r derivative of PMLuor	$\left(\left(\frac{\partial}{\partial r}\mathrm{uor}\right)r+\mathrm{uor}+\frac{\mathrm{uor}\cdot r\cdot J_{rr}}{\mathrm{PML}r}\right)/(\mathrm{PML}r)$
PMLuorPMLr		F	S	PMLr derivative of PMLuor	$\mathrm{PMLuor}_r(\mathbf{J}^{-1})_{rr}+\mathrm{uor}_z\cdot r(\mathbf{J}^{-1})_{zr}/\mathrm{PML}r$
PMLuorPMLz		F	S	PMLz derivative of PMLuor	$\mathrm{PMLuor}_r(\mathbf{J}^{-1})_{rz}+\mathrm{uor}_z\cdot r(\mathbf{J}^{-1})_{zz}/\mathrm{PML}r$
uaxiPMLr		F	S	PMLr derivative of r displacement	$u_r(\mathbf{J}^{-1})_{rr}+u_z(\mathbf{J}^{-1})_{zr}$

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
uaxiPMLz		F	S	$\mathrm{PML}z$ derivative of r displacement	$u_r(\mathbf{J}^{-1})_{rz}+u_z(\mathbf{J}^{-1})_{zz}$
wPMLr		F	S	$\mathrm{PML}r$ derivative of z displacement	$w_r(\mathbf{J}^{-1})_{rr}+w_z(\mathbf{J}^{-1})_{zr}$
wPMLz		F	S	PMLz derivative of z displacement	$w_r(\mathbf{J}^{-1})_{rz}+w_z(\mathbf{J}^{-1})_{zz}$

Plates, Beams, Trusses, and Shells

Mindlin Plate

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp`, the amplitude of the normal stress in the x direction
- `ex_ph`, the phase of the normal strain in the x direction

The exception being variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, `s1`, etc.

The table uses a convention where indices $i, j, \ldots$ (or `i`, `j`, …) run over the geometry's Cartesian coordinate axes, x and y. The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T
Eigenfrequency	E

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`w`	w	All	All	z displacement	w
`thx`*`i`*	θ_{xi}	All	All	x_i rotation	θ_{xi}
`wt`	w_t	T	All	z velocity	w_t
`thx`*`i`*`t`	θ_{xit}	T	All	x_i angular velocity	θ_{xit}
`w_amp`	w_{amp}	F	All	z displacement amplitude	$\|w\|$

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
thx*i*_amp	$\theta_{xi\mathrm{amp}}$	F	All	x_i rotation amplitude	$\lvert\theta_{xi}\rvert$
w_ph	w_{ph}	F	All	z displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(w), 2\pi)$
thx*i*_ph	$\theta_{xi\mathrm{ph}}$	F	All	x_i rotation phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(\theta_{xi}), 2\pi)$
w_t	w_t	F	All	z velocity	$j\omega w$
thx*i*_t	θ_{xit}	F	All	x_i angular velocity	$j\omega\theta_{xi}$
w_t_amp	$w_{t\mathrm{amp}}$	F	All	z velocity amplitude	ωw_{amp}
thx*i*_t_amp	$\theta_{xit\mathrm{amp}}$	F	All	x_i angular velocity amplitude	$\omega\theta_{xi\mathrm{amp}}$
w_t_ph	$w_{it\mathrm{ph}}$	F	All	z velocity phase	$\mathrm{mod}(w_{\mathrm{ph}} + 90°, 360°)$
thx*i*_t_ph	$\theta_{xit\mathrm{ph}}$	F	All	x_i angular velocity phase	$\mathrm{mod}(\theta_{xi\mathrm{ph}} + 90°, 360°)$
w_tt	w_{tt}	F	All	z acceleration	$-\omega^2 w$
thx*i*_tt	θ_{xitt}	F	All	x_i angular acceleration	$-\omega^2\theta_{xi}$
w_tt_amp	$w_{tt\mathrm{amp}}$	F	All	z acceleration amplitude	$\omega^2 w_{\mathrm{amp}}$
thx*i*_tt_amp	$\theta_{xitt\mathrm{amp}}$	F	All	x_i angular acceleration amplitude	$\omega^2\theta_{xi\mathrm{amp}}$
w_tt_ph	$w_{tt\mathrm{ph}}$	F	All	z acceleration phase	$\mathrm{mod}(w_{\mathrm{ph}} + 180°, 360°)$
thx*i*_tt_ph	$\theta_{xitt\mathrm{ph}}$	F	All	x_i angular acceleration phase	$\mathrm{mod}(\theta_{xi\mathrm{ph}} + 180°, 360°)$
totrot	totrot	All	All	Total rotation	$\sqrt{\sum_i (\mathrm{real}(\theta_{xi}))^2}$

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
postheight	z	All	S	Postprocessing height for stress and strain evaluation	Dependent on the settings on the postprocessing page
ex	ε_x	All	S	ε_x normal strain global coord. system	$z\frac{\partial\theta_y}{\partial x}$
ey	ε_y	All	S	ε_y normal strain global coord. system	$-z\frac{\partial\theta_x}{\partial y}$
exy	ε_{xy}	All	S	ε_{xy} shear strain global coord. system	$\frac{z}{2}\left(\frac{\partial\theta_y}{\partial y}-\frac{\partial\theta_x}{\partial x}\right)$
eyz	ε_{yz}	All	S	ε_{yz} shear strain global coord. system	$\frac{5}{8}\gamma_{yz}\left(1-\frac{4z^2}{\mathrm{th}^2}\right)$
exz	ε_{xz}	All	S	ε_{xz} shear strain global coord. system	$\frac{5}{8}\gamma_{xz}\left(1-\frac{4z^2}{\mathrm{th}^2}\right)$
exl	$\varepsilon_{x\mathrm{l}}$	All	S	ε_x normal strain local coord. system	$z\left(\frac{\partial\theta_y}{\partial x}\right)_{\mathrm{l}}$
eyl	$\varepsilon_{y\mathrm{l}}$	All	S	ε_y normal strain local coord. system	$-z\left(\frac{\partial\theta_x}{\partial y}\right)_{\mathrm{l}}$
exyl	$\varepsilon_{xy\mathrm{l}}$	All	S	ε_{xy} shear strain local coord. system	$\frac{z}{2}\left(\frac{\partial\theta_y}{\partial y}-\frac{\partial\theta_x}{\partial x}\right)_{\mathrm{l}}$
eyzl	$\varepsilon_{yz\mathrm{l}}$	All	S	ε_{yz} shear strain global coord. system	$\frac{5}{8}\gamma_{yz\mathrm{l}}\left(1-\frac{4z^2}{\mathrm{th}^2}\right)$
exzl	$\varepsilon_{xz\mathrm{l}}$	All	S	ε_{xz} shear strain global coord. system	$\frac{5}{8}\gamma_{xz\mathrm{l}}\left(1-\frac{4z^2}{\mathrm{th}^2}\right)$

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Mxip`	$M_{xi\mathrm{p}}$	All	S	$M_{xi\mathrm{p}}$ plate bending moment global system	If material is defined in global coord. sys. $\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left(\Theta-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$ With loss factor damping in global coord. sys. $\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left((1+j\eta)\Theta-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$ If material is defined in user def. coord. sys. $T_\mathrm{coord}M_\mathrm{pl}T_\mathrm{coord}{}^T$
`Mxyp`	$M_{xy\mathrm{p}}$	All	S	$M_{xy\mathrm{p}}$ plate torsional moment global system	If material is defined in global coord. sys. $\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left(\Theta-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$ With loss factor damping in global coord. sys. $\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left((1+j\eta)\Theta-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$ If material is defined in user def. coord. sys. $T_\mathrm{coord}M_\mathrm{pl}T_\mathrm{coord}{}^T$
`Mxipl`	$M_{xi\mathrm{pl}}$	All	S	$M_{xi\mathrm{p}}$ plate bending moment local system	$\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left(\Theta_l-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$ With loss factor damping $\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left((1+j\eta)\Theta_l-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$
`Mxypl`	$M_{xy\mathrm{pl}}$	All	S	$M_{xy\mathrm{p}}$ plate torsional moment local system	$\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left(\Theta_\mathrm{l}-\frac{\alpha_\mathrm{vec}\Delta T}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$ With loss factor damping $\frac{(\mathrm{th})^3}{12}\left[D_\mathrm{p}\left((1+j\eta)\Theta_\mathrm{l}-\frac{\alpha_\mathrm{vec}\Delta \mathrm{T}}{\mathrm{th}}-\Theta_i\right)\right]+M_{\mathrm{p}i}$

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Qx*i*p	$Q_{xi\mathrm{p}}$	All	S	$Q_{xi\mathrm{p}}$ plate shear force global system	If material is defined in global coord. sys. $$D_{\mathrm{s}}\left[\begin{bmatrix}\gamma_{yz}\\\gamma_{xz}\end{bmatrix}-\begin{bmatrix}\gamma_{yzi}\\\gamma_{xzi}\end{bmatrix}\right]+Q_{\mathrm{p}i}$$ With loss factor damping in global coord. sys. $$D_{\mathrm{s}}\left[(1+j\eta)\begin{bmatrix}\gamma_{yz}\\\gamma_{xz}\end{bmatrix}-\begin{bmatrix}\gamma_{yzi}\\\gamma_{xzi}\end{bmatrix}\right]+Q_{\mathrm{p}i}$$ If material is defined in user def. coord. sys. $$\begin{bmatrix}Q_{x\mathrm{p}}\\Q_{y\mathrm{p}}\end{bmatrix}=T\begin{bmatrix}Q_{x\mathrm{p}}\\Q_{y\mathrm{p}}\end{bmatrix}_{\mathrm{l}}$$
Qx*i*pl	$Q_{xi\mathrm{p}}$	All	S	$Q_{xi\mathrm{p}}$ plate shear force local system	$$\mathrm{th}\cdot D_{\mathrm{s}}\left[\begin{bmatrix}\gamma_{yz}\\\gamma_{xz}\end{bmatrix}_{\mathrm{l}}-\begin{bmatrix}\gamma_{yzi}\\\gamma_{xzi}\end{bmatrix}\right]+Q_{\mathrm{p}i}$$ With loss factor damping $$\mathrm{th}\cdot D_{\mathrm{s}}\left[(1+j\eta)\begin{bmatrix}\gamma_{yz}\\\gamma_{xz}\end{bmatrix}_{\mathrm{l}}-\begin{bmatrix}\gamma_{yzi}\\\gamma_{xzi}\end{bmatrix}\right]+Q_{\mathrm{p}i}$$
sx	σ_x	All	S	σ_x normal stress global coord. system	$12\frac{M_{x\mathrm{p}}}{\mathrm{th}^3}z$
sy	σ_y	All	S	σ_y normal stress global coord. system	$12\frac{M_{y\mathrm{p}}}{\mathrm{th}^3}z$
sxy	τ_{xy}	All	S	τ_{xy} shear stress global coord. system	$12\frac{M_{xy\mathrm{p}}}{\mathrm{th}^3}z$
sxl	$\sigma_{x\mathrm{l}}$	All	S	σ_x normal stress local coord. system	$12\frac{M_{x\mathrm{pl}}}{\mathrm{th}^3}z$

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
syl	σ_{yl}	All	S	σ_y normal stress local coord. system	$12\frac{M_{ypl}}{\mathrm{th}^3}z$
sxyl	τ_{xy}	All	S	τ_{xy} shear stress global coord. system	$12\frac{M_{xypl}}{\mathrm{th}^3}z$
s*i*	σ_i	All	S	Principal stresses, $i = 1, 2, 3$	
e*i*	ε_i	All	S	Principal strains, $i = 1, 2, 3$	
s*i*x*j*	σ_{ixj}	All	S	Principal stress directions, $i,j = 1, 2, 3$	
e*i*x*j*	ε_{ixj}	All	S	Principal strain directions, $i,j = 1, 2, 3$	
tresca	σ_{tresca}	All	S	Tresca stress	$\max(\max\lvert\sigma_1-\sigma_2\rvert, \lvert\sigma_2-\sigma_3\rvert, \lvert\sigma_1-\sigma_3\rvert))$
mises	σ_{mises}	All	S	von Mises stress	
Fzg	F_{zg}	All	S	Body, edge, point load, in global z dir.	Defined differently depending on how the force is defined

TABLE 2-5: MINDLIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Mxig`	M_{xig}	All	S	Body, edge, point moment, in global x_i dir.	Defined differently depending on how the moment is defined
`Ws`	W_s	All	S	Strain energy density	If global coordinate system $\frac{1}{2}\left(\frac{\partial\theta_y}{\partial x}M_{x\mathrm{p}}-\frac{\partial\theta_x}{\partial y}M_{y\mathrm{p}}+\left(\frac{\partial\theta_y}{\partial y}-\frac{\partial\theta_x}{\partial x}\right)M_{xy\mathrm{p}}\right)$ $\frac{1}{2}(\gamma_{yz}Q_{y\mathrm{p}}+\gamma_{xz}Q_{x\mathrm{p}})$ If other coordinate system $\frac{1}{2}\left(\frac{\partial\theta_{y1}}{\partial x}M_{x1\mathrm{p}}-\frac{\partial\theta_{x1}}{\partial y}M_{y1\mathrm{p}}+\left(\frac{\partial\theta_{y1}}{\partial y}-\frac{\partial\theta_{x1}}{\partial x}\right)M_{xy1\mathrm{p}}\right)$ $\frac{1}{2}(\gamma_{yz1}Q_{y\mathrm{p}}+\gamma_{xz1}Q_{1x\mathrm{p}})$

In-Plane Euler Beam

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below almost all application mode parameters are available as variables. Some variables are different for different analyses, which is seen in the Analysis column. For frequency response analysis, a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `M_amp`, the amplitude of the bending moment
- `sn_ph`, the phase of the axial stress

The exception to this scheme consists of variables defined using a nonlinear operator such as `snmax`, `snmin`, `disp`, etc.

The table below uses a convention where the index$i$ (or `i`) runs over the geometry's Cartesian coordinate axes, x and y. In particular, u_i (`ui`) refers to the global displacements (u, v). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F

ANALYSIS	ABBREVIATION
Time dependent	T
Eigenfrequency	E

TABLE 2-6: IN-PLANE EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
ui	u_i	All	All	x_i displacement	u_i
th	θ	All	All	z rotation	θ
uit	u_{it}	T	All	x_i velocity	u_{it}
tht	θ_t	T	All	z angular velocity	θ_t
ui_amp	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
th_amp	θ_{amp}	F	All	z rotation amplitude	$\lvert\theta\rvert$
ui_ph	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
th_ph	θ_{ph}	F	All	z rotation phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(\theta), 2\pi)$
ui_t	u_{it}	F	All	x_i velocity	$j\omega u_i$
th_t	θ_t	F	All	z angular velocity	$j\omega\theta$
ui_t_amp	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
th_t_amp	$\theta_{t\mathrm{amp}}$	F	All	z angular velocity amplitude	$\omega\theta_{\mathrm{amp}}$
ui_t_ph	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
th_t_ph	$\theta_{t\mathrm{ph}}$	F	All	z angular velocity phase	$\mathrm{mod}(\theta_{\mathrm{ph}} + 90°, 360°)$
ui_tt	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
th_tt	θ_{tt}	F	All	z angular acceleration	$-\omega^2\theta$

TABLE 2-6: IN-PLANE EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`th_tt_amp`	$\theta_{tt\mathrm{amp}}$	F	All	z angular acceleration amplitude	$\omega^2 \theta_{\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
`th_tt_ph`	$\theta_{tt\mathrm{ph}}$	F	All	z angular acceleration phase	$\mathrm{mod}(\theta_{\mathrm{ph}} + 180°, 360°)$
`disp`	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))}^2$
`N`	N	All	B	Axial force	$EA\left[\left(\frac{\partial u_{\mathrm{axi}}}{\partial s} - \left(\frac{\partial u_{\mathrm{axi}}}{\partial s}\right)_i\right) - \alpha(T - T_{\mathrm{ref}})\right] + N_i$ With loss factor damping in frequency response analysis $EA\left[\left((1 + j\eta)\frac{\partial u_{\mathrm{axi}}}{\partial s} - \left(\frac{\partial u_{\mathrm{axi}}}{\partial s}\right)_i\right) - \alpha(T - T_{\mathrm{ref}})\right] + N_i$
`M`	M	All	B	Moment	$-EI\left[\frac{\partial\theta}{\partial s} - \left(\frac{\partial\theta}{\partial s}\right)_i - \alpha\frac{\Delta T}{h}\right] + M_i$ With loss factor damping in frequency response analysis $-EI\left[(1 + j\eta)\frac{\partial\theta}{\partial s} - \left(\frac{\partial\theta}{\partial s}\right)_i - \alpha\frac{\Delta T}{h}\right] + M_i$
`T`	T	All	B	Shear force	$EI_{yy}\frac{\partial^2\theta}{\partial s^2}$ With loss factor damping in frequency response analysis $EI_{yy}(1 + j\eta)\frac{\partial^2\theta}{\partial s^2}$
`sn`	σ_n	All	B	Axial stress	$E\frac{\partial u_{\mathrm{axi}}}{\partial s}$

TABLE 2-6: IN-PLANE EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
en	ε_n	All	B	Axial strain	$\frac{\partial u_{\mathrm{axi}}}{\partial s}$
sbtop	σ_{btop}	All	B	Bending stress at top of section	$\frac{Mh_z}{2I_{yy}}$
sbbot	σ_{bbot}	All	B	Bending stress at bottom of section	$-\frac{Mh_z}{2I_{yy}}$
snmax	$\sigma_{n\max}$	All	B	Max normal stress	$\max(\mathrm{real}(\sigma_n+\sigma_{\mathrm{btop}}), \mathrm{real}(\sigma_n+\sigma_{\mathrm{bbot}}))$
snmin	$\sigma_{n\min}$	All	B	Min normal stress	$\min(\mathrm{real}(\sigma_n+\sigma_{\mathrm{btop}}), \mathrm{real}(\sigma_n+\sigma_{\mathrm{bbot}}))$
N_t	N_t	All	B	Time derivative of axial force	$EA\left[\left(\frac{\partial u_{t\mathrm{axi}}}{\partial s}\right)\right]$ With loss factor damping in frequency response analysis $j\omega EA\left[(1+j\eta)\frac{\partial u_{\mathrm{axi}}}{\partial s}\right]$
M_t	M_t	All	B	Time derivative of moment	$-EI_{yy}\frac{\partial\theta_t}{\partial s}$ With loss factor damping in frequency response analysis $-j\omega EI_{yy}(1+j\eta)\frac{\partial\theta}{\partial s}$
Fig	F_{ig}	All	B P	Edge, point load in global x_i direction	Defined differently depending on how the force is defined and what analysis type
Mzg	M_{zg}	All	B P	Edge, point moment in z direction	Defined differently depending on how the moment is defined and what analysis type
Ws	W_s	All	B	Strain energy density	$-\frac{1}{2}(\theta_s M - uvtsN)$

3D Euler Beam

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below almost all application mode parameters are available as variables. Some variables are different for different analyses, which is seen in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `Myl_amp`, the amplitude of the bending moment in the local y direction
- `sn_ph`, the phase of the axial stress

The exception to this scheme consists of variables defined using a nonlinear operator such as `snmax`, `snmin`, `disp`, and so on.

The table below uses a convention where indices $i, j, \ldots$ (or `i`, `j`, …) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`ui`) refers to the global displacements (u, v, w). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T
Eigenfrequency	E

TABLE 2-7: 3D EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui`	u_i	All	All	x_i displacement	u_i
`thi`	θ_i	All	All	x_i rotation	θ_i
`uit`	u_{it}	T	All	x_i velocity	u_{it}
`thit`	θ_{it}	T	All	x_i angular velocity	θ_{it}
`ui_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\|u_i\|$
`thi_amp`	$\theta_{i\mathrm{amp}}$	F	All	x_i rotation amplitude	$\|\theta_i\|$

TABLE 2-7: 3D EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`thi_ph`	$\theta_{i\mathrm{ph}}$	F	All	x_i rotation phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(\theta_i), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`thi_t`	θ_{it}	F	All	x_i angular velocity	$j\omega\theta_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`thi_t_amp`	$\theta_{it\mathrm{amp}}$	F	All	x_i angular velocity amplitude	$\omega\theta_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`thi_t_ph`	$\theta_{it\mathrm{ph}}$	F	All	x_i angular velocity phase	$\mathrm{mod}(\theta_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`thi_tt`	θ_{itt}	F	All	x_i angular acceleration	$-\omega^2\theta_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`thi_tt_amp`	$\theta_{itt\mathrm{amp}}$	F	All	x_i angular acceleration amplitude	$\omega^2\theta_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
`thi_tt_ph`	$\theta_{itt\mathrm{ph}}$	F	All	x_i angular acceleration phase	$\mathrm{mod}(\theta_{i\mathrm{ph}} + 180°, 360°)$
`disp`	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))}^2$

TABLE 2-7: 3D EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
totrot	totrot	All	All	Total rotation	$\sqrt{\sum_i (\mathrm{real}(\theta_i))^2}$
N	N	All	E	Axial force	$EA\left[\left(\frac{\partial u_{\mathrm{axi}}}{\partial s}-\left(\frac{\partial u_{\mathrm{axi}}}{\partial s}\right)_i\right)-\alpha(T-T_{\mathrm{ref}})\right]+N_i$ With loss factor damping in frequency response analysis $EA\left[\left((1+j\eta)\frac{\partial u_{\mathrm{axi}}}{\partial s}-\left(\frac{\partial u_{\mathrm{axi}}}{\partial s}\right)_i\right)-\alpha(T-T_{\mathrm{ref}})\right]+N_i$
Mxl	M_{xl}	All	E	Torsional moment local x direction	$\frac{E}{2(1+\upsilon)}J\left[\frac{\partial\theta_{xl}}{\partial s}-\left(\frac{\partial\theta_{xl}}{\partial s}\right)_i\right]+M_{xi}$ With loss factor damping in frequency response analysis $\frac{E}{2(1+\upsilon)}J\left[(1+j\eta)\frac{\partial\theta_{xl}}{\partial s}-\left(\frac{\partial\theta_{xl}}{\partial s}\right)_i\right]+M_{xi}$
Myl	M_{xl}	All	E	Bending moment local y direction	$EI_{yy}\left[\frac{\partial\theta_{yl}}{\partial s}-\left(\frac{\partial\theta_{yl}}{\partial s}\right)_i-\alpha\frac{\Delta T_z}{h_z}\right]+M_{yi}$ With loss factor damping in frequency response analysis $EI_{yy}\left[(1+j\eta)\frac{\partial\theta_{yl}}{\partial s}-\left(\frac{\partial\theta_{yl}}{\partial s}\right)_i-\alpha\frac{\Delta T_z}{h_z}\right]+M_{yi}$
Mzl	M_{xl}	All	E	Bending moment local z direction	$EI_{zz}\left[\frac{\partial\theta_{zl}}{\partial s}-\left(\frac{\partial\theta_{zl}}{\partial s}\right)_i-\alpha\frac{\Delta T_y}{h_y}\right]+M_{zi}$ With loss factor damping in frequency response analysis $EI_{zz}\left[(1+j\eta)\frac{\partial\theta_{zl}}{\partial s}-\left(\frac{\partial\theta_{zl}}{\partial s}\right)_i-\alpha\frac{\Delta T_y}{h_y}\right]+M_{zi}$
Tyl	T_y	All	E	Shear force local y direction	$-EI_{zz}\frac{\partial^2\theta_{zl}}{\partial s^2}$ With loss factor damping in frequency response analysis $-EI_{zz}(1+j\eta)\frac{\partial^2\theta_{zl}}{\partial s^2}$

TABLE 2-7: 3D EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Tzl`	T_z	All	E	Shear force local z direction	$EI_{yy}\frac{\partial^2\theta_{yl}}{\partial s^2}$ With loss factor damping in frequency response analysis $EI_{yy}(1+j\eta)\frac{\partial^2\theta_{yl}}{\partial s^2}$
`sn`	σ_n	All	E	Axial stress	$E\frac{\partial u_{\mathrm{axi}}}{\partial s}$
`en`	ε_n	All	E	Axial strain	$\frac{\partial u_{\mathrm{axi}}}{\partial s}$
`sbytop`	σ_{bytop}	All	E	Bending stress at y top fiber	$-\frac{M_{z1}h_y}{2I_{zz}}$
`sbybot`	σ_{bybot}	All	E	Bending stress at y bottom fiber	$\frac{M_{z1}h_y}{2I_{zz}}$
`sbztop`	σ_{bztop}	All	E	Bending stress at z top fiber	$\frac{M_{y1}h_z}{2I_{yy}}$
`sbzbot`	σ_{bzbot}	All	E	Bending stress at z bottom fiber	$-\frac{M_{y1}h_z}{2I_{yy}}$
`snmaxy`	$\sigma_{n\mathrm{maxy}}$	All	E	Max normal stress y fiber	$\mathrm{max}(\mathrm{real}(\sigma_n+\sigma_{\mathrm{bytop}}), \mathrm{real}(\sigma_n+\sigma_{\mathrm{bybot}}))$
`snminy`	$\sigma_{n\mathrm{miny}}$	All	E	Min normal stress y fiber	$\mathrm{min}(\mathrm{real}(\sigma_n+\sigma_{\mathrm{bytop}}), \mathrm{real}(\sigma_n+\sigma_{\mathrm{bybot}}))$
`snmaxz`	$\sigma_{n\mathrm{maxz}}$	All	E	Max normal stress z fiber	$\mathrm{max}(\mathrm{real}(\sigma_n+\sigma_{\mathrm{bztop}}), \mathrm{real}(\sigma_n+\sigma_{\mathrm{bzbot}}))$
`snminz`	$\sigma_{n\mathrm{minz}}$	All	E	Min normal stress z fiber	$\mathrm{min}(\mathrm{real}(\sigma_n+\sigma_{\mathrm{bztop}}), \mathrm{real}(\sigma_n+\sigma_{\mathrm{bzbot}}))$

TABLE 2-7: 3D EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
N_t	N_t	All	E	Time derivative of axial force	$EA\left[\left(\frac{\partial u_{t\mathrm{axi}}}{\partial s}\right)\right]$ With loss factor damping in frequency response analysis $EA\left[(1+j\eta)j\omega\frac{\partial u_{\mathrm{axi}}}{\partial s}\right]$
Mxl_t	$M_{x\mathrm{l}t}$	All	E	Time derivative of torsional moment local x direction	$\frac{E}{2(1+\nu)}J\frac{\partial\theta_{x\mathrm{l}t}}{\partial s}$ With loss factor damping in frequency response analysis $\frac{E}{2(1+\nu)}J(1+j\eta)j\omega\frac{\partial\theta_{x\mathrm{l}}}{\partial s}$
Myl_t	$M_{y\mathrm{l}t}$	All	E	Time derivative of bending moment local y direction	$EI_{yy}\frac{\partial\theta_{y\mathrm{l}t}}{\partial s}$ With loss factor damping in frequency response analysis $EI_{yy}(1+j\eta)j\omega\frac{\partial\theta_{y\mathrm{l}}}{\partial s}$
Mzl_t	$M_{z\mathrm{l}t}$	All	E	Time derivative of bending moment local z direction	$EI_{zz}\frac{\partial\theta_{z\mathrm{l}t}}{\partial s}$ With loss factor damping in frequency response analysis $EI_{zz}(1+j\eta)j\omega\frac{\partial\theta_{z\mathrm{l}}}{\partial s}$
F*i*g	F_{ig}	All	E	Edge, point load in global x_i direction	Different depending on how the force is defined and what analysis type
M*i*g	M_{ig}	All	E	Edge, point moment in global x_i direction	Different depending on how the moment is defined and what analysis type
F*i*local	$F_{i\mathrm{local}}$	All	E P	Edge/point load in local x_i direction	Different depending on how the moment is defined and what analysis type

TABLE 2-7: 3D EULER BEAM APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Milocal	$M_{i\text{local}}$	All	E P	Edge/point moment in local x_i direction	Different depending on how the force is defined and what analysis type
Ws	W_s	All	E	Strain energy density	$\frac{1}{2}(\theta_{xs}M_{x1} + \theta_{ys}M_{y1} + \theta_{zs}M_{z1} + uvwtsN)$

In-Plane Truss

A large number of variables are available for use in expressions and for postprocessing purposes. almost all application mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

`en_amp` is the amplitude of the axial strain

- `sn_ph` is the phase of the axial stres

Table 2-8 uses a convention where indices $i, j, \ldots$ (or `i`, `j`, …) run over the geometry's Cartesian coordinate axes, x and y. In particular, u_i (`ui`) refers to the global displacements (u, v). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T
Eigenfrequency	E

TABLE 2-8: IN PLANE TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
ui	u_i	All	All	x_i displacement	u_i
uit	u_{it}	T	All	x_i velocity	u_{it}
ui_amp	$u_{i\text{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$

TABLE 2-8: IN PLANE TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
`disp`	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$
`xn`	x_n	All	B	Parameter along edge only used for linear constraint	$\frac{x(x_2-x_1)+y(y_2-y_1)}{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}}$
`exixjT`	ε_{xixjT}	All	B	Tangential strain tensor	If large deformation $\frac{1}{2}\left(\left.\frac{\partial u_i}{\partial x_j}\right\|_T + \left.\frac{\partial u_j}{\partial x_i}\right\|_T + \left.\frac{\partial u_k}{\partial x_i}\right\|_T \cdot \left.\frac{\partial u_k}{\partial x_j}\right\|_T\right)$ else $\frac{1}{2}\left(\left.\frac{\partial u_i}{\partial x_j}\right\|_T + \left.\frac{\partial u_j}{\partial x_i}\right\|_T\right)$
`en`	ε_n	All	B	Axial strain	$t_x(\varepsilon_{xT}t_x + \varepsilon_{xyT}t_y) + t_y(\varepsilon_{xyT}t_x + \varepsilon_{yT}t_y)$
`sn`	σ_n	All	B	Axial stress	$E(\varepsilon_n - \alpha(T - T_{\mathrm{ref}}) - \varepsilon_{ni}) + \sigma_{ni}$

TABLE 2-8: IN PLANE TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
exixjT_t	ε_{xixjTt}	T	B	Tangential strain rate tensor	If large deformation $\frac{1}{2}\left(\left.\frac{\partial ut_i}{\partial x_j}\right\|_T + \left.\frac{\partial ut_j}{\partial x_i}\right\|_T + \left.\frac{\partial ut_k}{\partial x_i}\right\|_T \cdot \left.\frac{\partial u_k}{\partial x_j}\right\|_T + \left.\frac{\partial u_k}{\partial x_i}\right\|_T \cdot \left.\frac{\partial ut_k}{\partial x_j}\right\|_T\right)$ else $\frac{1}{2}\left(\left.\frac{\partial ut_i}{\partial x_j}\right\|_T + \left.\frac{\partial ut_j}{\partial x_i}\right\|_T\right)$
exixjT_t	ε_{xixjTt}	F	B	Tangential strain rate tensor	$\frac{1}{2}\left(\left.\frac{\partial u_i}{\partial x_j}\right\|_T + \left.\frac{\partial u_j}{\partial x_i}\right\|_T\right) j\omega$
exixjT_b	$\varepsilon_{xixjT\mathrm{b}}$	Buckling	B	Tangential strain buckling tensor	$\frac{1}{2}\left(\left.\frac{\partial ut_k}{\partial x_i}\right\|_T \cdot \left.\frac{\partial u_k}{\partial x_j}\right\|_T + \left.\frac{\partial u_k}{\partial x_i}\right\|_T \cdot \left.\frac{\partial ut_k}{\partial x_j}\right\|_T\right)$
en_t	ε_{nt}	F T	B	Axial strain rate	$t_x(\varepsilon_{xTt}t_x + \varepsilon_{xyTt}t_y) + t_y(\varepsilon_{xyTt}t_x + \varepsilon_{yTt}t_y)$
en_b	$\varepsilon_{n\mathrm{b}}$	F T	B	Axial buckling strain	$t_x(\varepsilon_{xT\mathrm{b}}t_x + \varepsilon_{xyT\mathrm{b}}t_y) + t_y(\varepsilon_{xyT\mathrm{b}}t_x + \varepsilon_{yT\mathrm{b}}t_y)$
sn_t	σ_{nt}	F T	B	Axial stress rate	$E\varepsilon_{nt}$
N	N	All	B	Axial force	$A\sigma_n$
Fig	F_{ig}	S T E	B P	Edge, point load in global x_i direction	If global coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \end{bmatrix}$ If other coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \end{bmatrix} = T_{\mathrm{coord}} \begin{bmatrix} F_x \\ F_y \end{bmatrix}$

TABLE 2-8: IN PLANE TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Fig	F_{ig}	F	B P	Edge, point load in global x_i direction	If global coordinate system $F_{ig} = F_i F_{i\mathrm{Amp}} e^{jF_{iPh}\frac{\pi}{180}}$ If other coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \end{bmatrix} = T_{\mathrm{coord}} \begin{bmatrix} F_x F_{x\mathrm{Amp}} e^{jF_{xiPh}\frac{\pi}{180}} \\ F_y F_{y\mathrm{Amp}} e^{jF_{yPh}\frac{\pi}{180}} \end{bmatrix}$
Ws	W_s	All	B	Strain energy density	$\frac{A}{2}(\varepsilon_n \sigma_n)$

3D Truss

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below almost all application mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

`en_amp` is the amplitude of the bending moment in the local *y* direction

- `sn_ph` is the phase of the axial stress

Table 2-9 uses a convention where indices $i, j, \ldots$ (or `i`, `j`, …) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`ui`) refers to the global displacements (u, v, w). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T
Eigenfrequency	E

TABLE 2-9: 3D TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui`	u_i	All	All	x_i displacement	u_i
`uit`	u_{it}	T	All	x_i velocity	u_{it}
`ui_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
`disp`	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$

TABLE 2-9: 3D TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
xn	x_n	All	E	Parameter along edge only used for linear constraint	$\frac{x(x_2-x_1)+y(y_2-y_1)+z(z_2-z_1)}{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2}}$
exixjT	ε_{xixjT}	All	E	Tangential strain tensor	If large deformation $\frac{1}{2}\left(\left.\frac{\partial u_i}{\partial x_j}\right\|_T+\left.\frac{\partial u_j}{\partial x_i}\right\|_T+\left.\frac{\partial u_k}{\partial x_i}\right\|_T\cdot\left.\frac{\partial u_k}{\partial x_j}\right\|_T\right)$ else $\frac{1}{2}\left(\left.\frac{\partial u_i}{\partial x_j}\right\|_T+\left.\frac{\partial u_j}{\partial x_i}\right\|_T\right)$
en	ε_n	All	E	Axial strain	$t_x(\varepsilon_{xT}t_x+\varepsilon_{xyT}t_y+\varepsilon_{xzT}t_z)+t_y(\varepsilon_{xyT}t_x+\varepsilon_{yT}t_y+\varepsilon_{yzT}t_z)+t_z(\varepsilon_{xzT}t_x+\varepsilon_{yzT}t_y+\varepsilon_{zT}t_z)$
sn	σ_n	All	E	Axial stress	$E(\varepsilon_n-\alpha(T-T_{\mathrm{ref}})-\varepsilon_{ni})+\sigma_{ni}$
exixjT_t	ε_{xixjTt}	T	E	Tangential strain rate tensor	If large deformation $\frac{1}{2}\left(\left.\frac{\partial ut_i}{\partial x_j}\right\|_T+\left.\frac{\partial ut_j}{\partial x_i}\right\|_T+\left.\frac{\partial ut_k}{\partial x_i}\right\|_T\cdot\left.\frac{\partial u_k}{\partial x_j}\right\|_T+\left.\frac{\partial u_k}{\partial x_i}\right\|_T\cdot\left.\frac{\partial ut_k}{\partial x_j}\right\|_T\right)$ else $\frac{1}{2}\left(\left.\frac{\partial ut_i}{\partial x_j}\right\|_T+\left.\frac{\partial ut_j}{\partial x_i}\right\|_T\right)$
exixjT_t	ε_{xixjTt}	F	E	Tangential strain rate tensor	$\frac{1}{2}\left(\left.\frac{\partial u_i}{\partial x_j}\right\|_T+\left.\frac{\partial u_j}{\partial x_i}\right\|_T\right)j\omega$
exixjT_b	$\varepsilon_{xixjT\mathrm{b}}$	Buckling	E	Tangential strain buckling tensor	$\frac{1}{2}\left(\left.\frac{\partial ut_k}{\partial x_i}\right\|_T\cdot\left.\frac{\partial u_k}{\partial x_j}\right\|_T+\left.\frac{\partial u_k}{\partial x_i}\right\|_T\cdot\left.\frac{\partial ut_k}{\partial x_j}\right\|_T\right)$

TABLE 2-9: 3D TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
en_t	ε_{nt}	F T	E	Axial strain rate	$t_x(\varepsilon_{xTt}t_x + \varepsilon_{xyTt}t_y + \varepsilon_{xzTt}t_z) +$ $t_y(\varepsilon_{xyTt}t_x + \varepsilon_{yTt}t_y + \varepsilon_{yzTt}t_z) +$ $t_z(\varepsilon_{xzTt}t_x + \varepsilon_{yzTt}t_y + \varepsilon_{zTt}t_z)$
en_b	$\varepsilon_{n\mathrm{b}}$	F T	E	Axial buckling strain	$t_x(\varepsilon_{xT\mathrm{b}}t_x + \varepsilon_{xyT\mathrm{b}}t_y + \varepsilon_{xzT\mathrm{b}}t_z) +$ $t_y(\varepsilon_{xyT\mathrm{b}}t_x + \varepsilon_{yT}t_y + \varepsilon_{yzT\mathrm{b}}t_z) +$ $t_z(\varepsilon_{xzT\mathrm{b}}t_x + \varepsilon_{yzT\mathrm{b}}t_y + \varepsilon_{zT\mathrm{b}}t_z)$
sn_t	σ_{nt}	F T	E	Axial stress rate	$E\varepsilon_{nt}$
N	N	All	E	Axial force	$A\sigma_n$
Fig	F_{ig}	S T E	E P	Edge, point load in global x_i direction	If global coordinate system $\begin{bmatrix} F_{x\mathrm{g}} \\ F_{x\mathrm{g}} \\ F_{z\mathrm{g}} \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix}$ If other coordinate system $\begin{bmatrix} F_{x\mathrm{g}} \\ F_{y\mathrm{g}} \\ F_{z\mathrm{g}} \end{bmatrix} = T_{\mathrm{coord}} \begin{bmatrix} F_x \\ F_y \\ F_y \end{bmatrix}$

TABLE 2-9: 3D TRUSS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Fig`	F_{ig}	F	E/P	Edge, point load in global x_i direction	If global coordinate system $F_{ig} = F_i F_{i\mathrm{Amp}} e^{jF_{iPh}\frac{\pi}{180}}$ If other coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \\ F_{zg} \end{bmatrix} = T_{\mathrm{coord}} \begin{bmatrix} F_x F_{x\mathrm{Amp}} e^{jF_{xiPh}\frac{\pi}{180}} \\ F_y F_{y\mathrm{Amp}} e^{jF_{yPh}\frac{\pi}{180}} \\ F_z F_{z\mathrm{Amp}} e^{jF_{zPh}\frac{\pi}{180}} \end{bmatrix}$
`Ws`	W_s	All	E	Strain energy density	$\frac{A}{2}(\varepsilon_n \sigma_n)$

Shell

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below almost all application mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

`sx_amp`, the amplitude of the normal stress in the x direction.

- `ex_ph`, the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, `s1`, and so on.

The table below uses a convention where indices $i, j, \ldots$ (or `i`, `j`, ...) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`ui`) refers to the global displacements (u, v, w). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T
Eigenfrequency	E

TABLE 2-10: SHELL APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
ui	u_i	All	All	x_i displacement	u_i
thi	θ_i	All	All	x_i rotation	θ_i
uit	u_{it}	T	All	x_i velocity	u_{it}
thit	θ_{it}	T	All	x_i angular velocity	θ_{it}
ui_amp	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
thi_amp	$\theta_{i\mathrm{amp}}$	F	All	x_i rotation amplitude	$\lvert \theta_i \rvert$
ui_ph	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
thi_ph	$\theta_{i\mathrm{ph}}$	F	All	x_i rotation phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(\theta_i), 2\pi)$
ui_t	u_{it}	F	All	x_i velocity	$j\omega u_i$
thi_t	θ_{it}	F	All	x_i angular velocity	$j\omega\theta_i$
ui_t_amp	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
thi_t_amp	$\theta_{it\mathrm{amp}}$	F	All	x_i angular velocity amplitude	$\omega\theta_{i\mathrm{amp}}$
ui_t_ph	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$

TABLE 2-10: SHELL APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
th*i*_t_ph	θ_{itph}	F	All	x_i angular velocity phase	$\mathrm{mod}(\theta_{iph}+90°, 360°)$
u*i*_tt	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
th*i*_tt	θ_{itt}	F	All	x_i angular acceleration	$-\omega^2\theta_i$
u*i*_tt_amp	u_{ittamp}	F	All	x_i acceleration amplitude	$\omega^2 u_{iamp}$
th*i*_tt_amp	θ_{ittamp}	F	All	x_i angular acceleration amplitude	$\omega^2\theta_{iamp}$
u*i*_tt_ph	u_{ittph}	F	All	x_i acceleration phase	$\mathrm{mod}(u_{iph}+180°, 360°)$
th*i*_tt_ph	θ_{ittph}	F	All	x_i angular acceleration phase	$\mathrm{mod}(\theta_{iph}+180°, 360°)$
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$
totrot	totrot	All	All	Total rotation	$\sqrt{\sum_i (\mathrm{real}(\theta_i))^2}$
postheight	z	All	B	Postprocessing height for stress and strain evaluation	Dependent on the settings on the postprocessing page
s*i*	σ_i	All	B	σ_i normal stress global coord. system	$D(\varepsilon-\alpha_{\mathrm{vec}}(T-T_{\mathrm{ref}}))$ With loss factor damping in frequency response analysis $D((1+j\eta)\varepsilon-\alpha_{\mathrm{vec}}(T-T_{\mathrm{ref}}))$
s*ij*	τ_{ij}	All	B	τ_{ij} shear stress global coord. system	$D(\varepsilon-\alpha_{\mathrm{vec}}(T-T_{\mathrm{ref}}))$ With loss factor damping in frequency response analysis $D((1+j\eta)\varepsilon-\alpha_{\mathrm{vec}}(T-T_{\mathrm{ref}}))$

TABLE 2-10: SHELL APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`s`*`i`*`l`	σ_i	All	B	σ_i normal stress shell local coord. system	$D(\varepsilon_l - \alpha_{\mathrm{vec}}(T - T_{\mathrm{ref}}))$ With loss factor damping in frequency response analysis $D((1 + j\eta)\varepsilon_l - \alpha_{\mathrm{vec}}(T - T_{\mathrm{ref}}))$
`s`*`ij`*`l`	τ_{ij}	All	B	τ_{ij} shear stress shell local coord. system	$D(\varepsilon_l - \alpha_{\mathrm{vec}}(T - T_{\mathrm{ref}}))$ With loss factor damping in frequency response analysis $D((1 + j\eta)\varepsilon_l - \alpha_{\mathrm{vec}}(T - T_{\mathrm{ref}}))$
`s`*`i`*	σ_i	All	B	Principal stresses, $i = 1,2,3$	
`e`*`i`*	ε_i	All	B	ε_i normal strain global system	Defined by the `elshell_arg2` element
`e`*`ij`*	ε_{ij}	All	B	ε_{ij} shear strain global coord. system	Defined by the `elshell_arg2` element
`e`*`i`*`l`	ε_{il}	All	B	ε_{il} normal strain user defined coord. system	Defined by the `elshell_arg2` element
`e`*`ij`*`l`	ε_{ijl}	All	B	ε_{ijl} shear strain user defined coord. system	Defined by the `elshell_arg2` element
`e`*`i`*	ε_i	All	B	Principal strains, $i = 1,2,3$	
`s`*`i`*`x`*`j`*	σ_{ixj}	All	B	Principal stress directions, $i,j = 1,2,3$	
`e`*`i`*`x`*`j`*	ε_{ixj}	All	B	Principal strain directions, $i,j = 1,2,3$	
`tresca`	σ_{tresca}	All	B	Tresca stress	$\max(\max(\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert)),$ $\lvert\sigma_1 - \sigma_3\rvert))$

TABLE 2-10: SHELL APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`mises`	σ_{mises}	All	B	von Mises stress	
`Nxil`	$N_{xi\mathrm{l}}$	All	B	Local in-plane normal force x_i dir.	Defined by the `elshell_arg2` element
`Nxyl`	$N_{xy\mathrm{l}}$	All	B	Local in-plane shear force	Defined by the `elshell_arg2` element
`Mxil`	$M_{xi\mathrm{l}}$	All	B	Local bending moment x_i direction	Defined by the `elshell_arg2` element
`Mxyl`	$M_{xy\mathrm{l}}$	All	B	Local torsion moment	Defined by the `elshell_arg2` element
`Qxil`	$Q_{xi\mathrm{l}}$	All	B	Local out of-plane shear force x_i direction	Defined by the `elshell_arg2` element
`exilxj`	$e_{xi\mathrm{l}xj}$	All	B	Local shell coordinate system base vectors	Defined by the `elshell_arg2` element
`Fig`	F_{ig}	All	B E P	Body,edge, point load in global x_i direction	Defined differently depending on how the force is defined and what analysis type
`Mig`	M_{ig}	All	B E P	Body, edge, point moment in global x_i direction	Defined differently depending on how the moment is defined and what analysis type
`Filocal`	$F_{i\mathrm{local}}$	All	B E P	Body, edge, point load in local x_i direction	Defined differently depending on how the force is defined and what analysis type
`Milocal`	$M_{i\mathrm{local}}$	All	B E P	Body, edge, point moment in local x_i direction	Defined differently depending on how the moment is defined and what analysis type

Piezoelectric Application Modes

Piezo Solid

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below, almost all application mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` represents the amplitude of the normal stress in the x direction
- `ex_ph` represents the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

a convention where indices i, j, ... (or *i*, *j*, ...) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`ui`) refers to the global displacements (u, v, w). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T

VARIABLES

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
u*i*	u_i	All	All	x_i displacement	u_i
V	V	All	All	Electric potential	V
u*i*t	u_{it}	T	All	x_i velocity	u_{it}
u*i*_amp	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
u*i*_ph	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
V_amp	V_{amp}	F	All	Electric potential amplitude	$\lvert V \rvert$
V_ph	V_{ph}	F	All	Electric potential phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(V), 2\pi)$
u*i*_t	u_{it}	F	All	x_i velocity	$j\omega u_i$
u*i*_t_amp	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
u*i*_t_ph	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
u*i*_tt	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
u*i*_tt_amp	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
u*i*_tt_ph	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))}^2$
e*i*	ε_i	All	S	ε_i normal strain global coord. system	$\frac{\partial u_i}{\partial x_i}$
e*ij*	ε_{ij}	All	S	ε_{ij} shear strain global coord. system	$\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$
E*i*	E_i	All	S	Electric field	$-\left(\frac{\partial V}{\partial x_i}\right)$
normE	E_i	All	S	Electric field	$\sqrt{\mathbf{E} \cdot \mathbf{E}}$
e*i*l	ε_{il}	All	S	ε_{il} normal strain, user-defined coord. system	${T_{\mathrm{coord}}}^T \varepsilon T_{\mathrm{coord}}$
e*ij*l	ε_{ijl}	All	S	ε_{ijl} shear strain, user-defined coord. system	${T_{\mathrm{coord}}}^T \varepsilon T_{\mathrm{coord}}$

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Eil`	E_{il}	All	S	Electric field, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\mathbf{E}$
`Vil`	V_{il}	All	S	Electric potential gradient, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\nabla V$
`ei_t`	ε_{it}	T	S	ε_{it} normal velocity strain, global system	$\frac{\partial u_{it}}{\partial x_i}$
`ei_t`	ε_{it}	F	S	ε_{it} normal velocity strain, global system	$\frac{\partial u_i}{\partial x_i} j\omega$
`eij_t`	ε_{ijt}	T	S	ε_{ijt} shear velocity strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u_{it}}{\partial x_j} + \frac{\partial u_{jt}}{\partial x_i}\right)$
`eij_t`	ε_{ijt}	F	S	ε_{ijt} shear velocity strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) j\omega$
`eil_t`	ε_{ilt}	F T	S	ε_{ilt} normal velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\varepsilon_t T_{\mathrm{coord}}$
`eijl_t`	ε_{ijlt}	F T	S	ε_{ijlt} shear velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\varepsilon_t T_{\mathrm{coord}}$
`cE`	c_E	All	S	Stiffness matrix components	s_E^{-1}, if material is specified on strain-charge form, calculated by a special inverting-matrices element.

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
e	e	All	S	Piezoelectric coupling matrix, if material is specified on strain-charge form	ds_E^{-1}
epsilonT	ε_T	All	S	Electric permittivity with stress field constant	$\varepsilon_0\varepsilon_{rT}$
epsilonS	ε_S	All	S	Electric permittivity with strain field constant	If material defined on stress-charge from $\varepsilon_0\varepsilon_{rS}$ If material defined on strain-charge from $\varepsilon_0\varepsilon_{rT} - d \cdot s_E^{-1} \cdot d^t$
D	D	All	S	Stiffness matrix components	For isotropic and anisotropic material
epsilon	ε_e	All	S	Electric permittivity matrix components	$\varepsilon_0\varepsilon_r$, for isotropic and anisotropic material
sigma	σ_e	freq	S	Electric conductivity matrix components	For isotropic and anisotropic material
s*i*	σ_i	All	S	σ_i normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1 + j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1 + j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}^T$

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
D*i*	D_i	All	S	Electric displacement, x_i component	If material defined in global coord. sys. $e\varepsilon + \varepsilon_S \mathbf{E}$ or $\varepsilon_e \mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}} \mathbf{D}_l$
J*i*	J_i	T F	S	Total current density, x_i component	$J_{d,i} + J_{p,i}$ or $J_{d,i}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}} \mathbf{J}_l$
Jd*i*	$J_{d,i}$	T	S	Displacement current density, x_i component	$\frac{\partial D_i}{\partial t}$
Jd*i*	$J_{d,i}$	F	S	Displacement current density, x_i component	$j\omega D_i$
Jp*i*	$J_{p,i}$	T F	S	Potential current density, x_i component	$\sigma_e \mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}} \mathbf{J}_l$
s*ij*	τ_{ij}	All	S	τ_{ij} shear stress, global coord. system	If material defined in global coord. sys. $c_E \varepsilon - e^t \mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1 + j\eta) c_E \varepsilon - e^t \mathbf{E}$ or $(1 + j\eta) D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}} \sigma_l T_{\mathrm{coord}}{}^T$
s*i*l	σ_i	All	S	σ_i normal stress, user-defined local coord. system	$c_E \varepsilon_l - e^t \mathbf{E}_l$ or $D\varepsilon_l$ With loss factor damping in frequency response analysis $(1 + j\eta) c_E \varepsilon_l - e^t \mathbf{E}_l$ or $(1 + j\eta) D\varepsilon_l$
D*i*l	D_{il}	All	S	Electric displacement, x_i component, local coord. sys.	$e\varepsilon_l + \varepsilon_S \mathbf{E}_l$ or $\varepsilon_e \mathbf{E}_l$

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
J*il*	J_{il}	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,il}+J_{p,il}$ or $J_{d,il}$
Jd*il*	$J_{d,il}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{il}}{\partial t}$
Jd*il*	$J_{d,il}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{il}$
Jp*il*	$J_{p,il}$	F	S	Potential current density, x_i component, local coord. sys.	$\sigma_e\mathbf{E}_l$
s*ij*l	τ_{ij}	All	S	τ_{ij} shear stress, user-defined local coord. system	$c_E\varepsilon_l - e^t\mathbf{E}_l$ or $D\varepsilon_l$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon_l - e^t\mathbf{E}_l$ or $(1+j\eta)D\varepsilon_l$
s*i*_t	σ_{it}	F T	S	σ_{it} time derivative of normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_t$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}{}^T$
s*ij*_t	τ_{ijt}	T	S	τ_{ijt} time derivative of shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}{}^T$

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`s`*i*`l_t`	σ_{ilt}	F T	S	σ_{ilt} time derivative of normal stress, user-defined local coord. system	$c_E \varepsilon_{lt}$ or $D\varepsilon_{lt}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E \varepsilon_l$ or $(1+j\eta)j\omega D\varepsilon_l$
`s`*ij*`l_t`	τ_{ijlt}	F T	S	τ_{ijlt} time derivative of shear stress, user-defined local coord. system	$c_E \varepsilon_{lt}$ or $D\varepsilon_{lt}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E \varepsilon_l$ or $(1+j\eta)j\omega D\varepsilon_l$
`s`*i*	σ_i	All	S	Principal stresses, i=1,2,3	Defined by elpric element
`e`*i*	ε_i	All	S	Principal strains, i=1,2,3	Defined by elpric element
`s`*i*`x`*j*	σ_{ixj}	All	S	Principal stress directions, i,j=1,2,3	Defined by elpric element
`e`*i*`x`*j*	ε_{ixj}	All	S	Principal strain directions, i,j=1,2,3	Defined by elpric element
`tresca`	σ_{tresca}	All	S	Tresca stress	$\max(\max(\lvert\sigma_1-\sigma_2\rvert, \lvert\sigma_2-\sigma_3\rvert)), \lvert\sigma_1-\sigma_3\rvert))$
`mises`	σ_{mises}	All	S	von Mises stress	
`normD`	$\lvert\mathbf{D}\rvert$	All	S	Electric displacement, norm	$\sqrt{\mathbf{D}\cdot\mathbf{D}}$

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Ws	W_s	All	S	Strain energy density	If material properties defined in global coord. sys. $0.5\sigma\cdot\varepsilon$ $\frac{\sigma\cdot\varepsilon}{2}$, $\frac{1}{2}\mathrm{real}(\sigma\cdot\mathrm{conj}(\varepsilon))$ in frequency response analyses If material properties defined in local user-defined coord. sys. $\frac{\sigma_l\cdot\varepsilon_l}{2}$, $\frac{1}{2}\mathrm{real}(\sigma_l\cdot\mathrm{conj}(\varepsilon_l))$ in freq. resp.
We	W_e	All	S	Electric energy density	If material properties defined in global coord. sys. $\mathbf{E}\cdot\mathbf{D}/2$, $\mathrm{real}(\mathrm{conj}(\mathbf{E})\cdot\mathbf{D})/2$ in freq. resp. If material properties defined in local user-defined coord. sys. $\mathbf{E}_l\cdot\mathbf{D}_l/2$, $\mathrm{real}(\mathrm{conj}(\mathbf{E}_l)\cdot\mathbf{D}_l)/2$ in freq. resp.
Ta*i*	Ta_i	All	B	Surface traction (force/area) in x_i direction	$\begin{bmatrix}\mathrm{Ta}_x\\\mathrm{Ta}_y\\\mathrm{Ta}_z\end{bmatrix}=\begin{bmatrix}\sigma_x & \tau_{xy} & \tau_{xz}\\\tau_{xy} & \sigma_y & \tau_{yz}\\\tau_{xz} & \tau_{yz} & \sigma_z\end{bmatrix}\begin{bmatrix}n_x\\n_y\\n_z\end{bmatrix}$
nD	nD	All	B	Surface charge density	$\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{D}_{\mathrm{down}}-\mathbf{D}_{\mathrm{up}})$
nJ	nJ	F T	B	Current density outflow	$\mathbf{n}\cdot\mathbf{J}$
nJs	nJs	F	B	Source current density	Only for unsymmetric electric currents. $\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{J}_{\mathrm{down}}-\mathbf{J}_{\mathrm{up}})$ or, with weak constraints, the Lagrange multiplier for V.

TABLE 2-11: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Fig`	F_{ig}	All	All	Body load, face load, edge load, point load, in global x_i direction	If global coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \\ F_{zg} \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix}$ If other coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \\ F_{zg} \end{bmatrix} = T_{\mathrm{coord}} \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix}$
`smon`	smon	All	S	Structural equation available	1 or 0
`eson`	eson	All	S	Electrical equation available	1 or 0

Piezo Plane Stress

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below, almost all application mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` represents the amplitude of the normal stress in the x direction.
- `ex_ph` represents the phase of the normal strain in the x direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

The table uses a convention where indices $i, j, \ldots$ (or `i`, `j`, ...) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`ui`) refers to the global displacements (u, v, w). The Analysis column employs the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T

VARIABLES

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui`	u_i	All	All	x_i displacement	u_i
`V`	V	All	All	Electric potential	V
`uit`	u_{it}	T	All	x_i velocity	u_{it}
`ui_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i\rvert$
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`V_amp`	V_{amp}	F	All	Electric potential amplitude	$\lvert V\rvert$
`V_ph`	V_{ph}	F	All	Electric potential phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(V), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))}^2$
ei	ε_i	All	S	ε_i normal strain, global coord. system	$\frac{\partial u_i}{\partial x_i}$
ez	ε_z	All	S	ε_z normal strain, out of the xy-plane	$\frac{\left(\sum_j e_{j3}E_j - \sum_{k=1,2,4} (c_E)_{3k}\varepsilon_k\right)}{(c_E)_{33}}$ or $\frac{-\sum_{k=1,2,4} (D)_{3k}\varepsilon_k}{(D)_{33}}$ With loss factor damping in frequency response analysis $\frac{\left(\sum_j e_{j3}E_j - \sum_{k=1,2,4} (1+j\eta)(c_E)_{3k}\varepsilon_k\right)}{(1+j\eta)(c_E)_{33}}$ or $\frac{-\sum_{k=1,2,4} (1+j\eta)(c_E)_{3k}\varepsilon_k}{(1+j\eta)(c_E)_{33}}$
exy	ε_{xy}	All	S	ε_{xy} shear strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)$
Ei	E_i	All	S	Electric field	$-\left(\frac{\partial V}{\partial x_i}\right)$
normE	E_i	All	S	Electric field	$\sqrt{\mathbf{E} \cdot \mathbf{E}}$
eil	ε_{il}	All	S	ε_{il} normal strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$
eijl	ε_{ijl}	All	S	ε_{ijl} shear strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Eil	E_{il}	All	S	Electric field, user-defined coord. system	$T_{\mathrm{coord}}{}^T\mathbf{E}$
Vil	V_{il}	All	S	Electric potential gradient, user-defined coord. system	$T_{\mathrm{coord}}{}^T\nabla V$
ei_t	ε_{it}	T	S	ε_{it} normal velocity strain, global system	$\frac{\partial u_{it}}{\partial x_i}$
ez_t	ε_z	F T	S	ε_z normal velocity strain out of the xy-plane	$\frac{\left(-\sum_{k=1,2,4}(M)_{3k}\varepsilon_{kt}\right)}{(M)_{33}}$ (M is c_E or D)
ei_t	ε_{it}	F	S	ε_{it} normal velocity strain, global system	$\frac{\partial u_i}{\partial x_i}j\omega$
exy_t	ε_{xyt}	T	S	ε_{xyt} shear velocity strain global coord. system	$\frac{1}{2}\left(\frac{\partial u_t}{\partial y}+\frac{\partial v_t}{\partial x}\right)$
exy_t	ε_{xyt}	F	S	ε_{xyt} shear velocity strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)j\omega$
eil_t	ε_{ilt}	F T	S	ε_{ilt} normal velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T\varepsilon_t T_{\mathrm{coord}}$
exyl_t	ε_{xylt}	F T	S	ε_{xylt} shear velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T\varepsilon_t T_{\mathrm{coord}}$
cE	c_E	All	S	Stiffness matrix components	s_E^{-1}, if material is specified on strain-charge form, calculated by a special inverting-matrices element.

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
e	e	All	S	Piezoelectric coupling matrix, if material is specified on strain-charge form	ds_E^{-1}
epsilonT	ε_T	All	S	Electric permittivity with stress field constant	$\varepsilon_0\varepsilon_{rT}$
epsilonS	ε_S	All	S	Electric permittivity with strain field constant	If material defined on stress-charge from $\varepsilon_0\varepsilon_{rS}$ If material defined on strain-charge from $\varepsilon_0\varepsilon_{rT} - d \cdot s_E^{-1} \cdot d^t$
D	D	All	S	Stiffness matrix components	For isotropic and anisotropic material
epsilon	ε_e	All	S	Electric permittivity matrix components	$\varepsilon_0\varepsilon_r$, for isotropic and anisotropic material
sigma	σ_e	freq	S	Electric conductivity matrix components	For isotropic and anisotropic material
s*i*	σ_i	All	S	σ_i normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1 + j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1 + j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}{}^T$

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Di	D_i	All	S	Electric displacement, x_i component	If material defined in global coord. sys. $e\varepsilon + \varepsilon_S\mathbf{E}$ or $\varepsilon_e\mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{D}_\mathrm{l}$
Ji	J_i	T F	S	Total current density, x_i component	$J_{d,i} + J_{p,i}$ or $J_{d,i}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{J}_\mathrm{l}$
Jdi	$J_{d,i}$	T	S	Displacement current density, x_i component	$\frac{\partial D_i}{\partial t}$
Jdi	$J_{d,i}$	F	S	Displacement current density, x_i component	$j\omega D_i$
Jpi	$J_{p,i}$	T F	S	Potential current density, x_i component	$\sigma_e\mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{J}_\mathrm{l}$
sij	τ_{ij}	All	S	τ_{ij} shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_\mathrm{l}T_{\mathrm{coord}}{}^T$
sil	σ_i	All	S	σ_i normal stress, user-defined local coord. system	$c_E\varepsilon_\mathrm{l} - e^t\mathbf{E}_\mathrm{l}$ or $D\varepsilon_\mathrm{l}$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon_\mathrm{l} - e^t\mathbf{E}_\mathrm{l}$ or $(1+j\eta)D\varepsilon_\mathrm{l}$
Dil	$D_{i\mathrm{l}}$	All	S	Electric displacement, x_i component, local coord. sys.	$e\varepsilon_\mathrm{l} + \varepsilon_S\mathbf{E}_\mathrm{l}$ or $\varepsilon_e\mathbf{E}_\mathrm{l}$

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
J*i*l	$J_{i\mathrm{l}}$	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,i\mathrm{l}} + J_{p,i\mathrm{l}}$ or $J_{d,i\mathrm{l}}$
Jd*i*l	$J_{d,i\mathrm{l}}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{i\mathrm{l}}}{\partial t}$
Jd*i*l	$J_{d,i\mathrm{l}}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{i\mathrm{l}}$
Jp*i*l	$J_{p,i\mathrm{l}}$	F	S	Potential current density, x_i component, local coord. sys.	$\sigma_e \mathbf{E}_\mathrm{l}$
s*ij*l	τ_{ij}	All	S	τ_{ij} shear stress, user-defined local coord. system	$c_E \varepsilon_\mathrm{l} - e^t \mathbf{E}_\mathrm{l}$ or $D\varepsilon_\mathrm{l}$ With loss factor damping in frequency response analysis $(1 + j\eta)c_E\varepsilon_\mathrm{l} - e^t\mathbf{E}_\mathrm{l}$ or $(1 + j\eta)D\varepsilon_\mathrm{l}$
s*i*_t	σ_{it}	F T	S	σ_{it} time derivative of normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1 + j\eta)j\omega c_E\varepsilon_t$ or $(1 + j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_\mathrm{coord}\sigma_{\mathrm{l}t}T_\mathrm{coord}{}^T$
s*ij*_t	τ_{ijt}	T	S	τ_{ijt} time derivative of shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1 + j\eta)j\omega c_E\varepsilon$ or $(1 + j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_\mathrm{coord}\sigma_{\mathrm{l}t}T_\mathrm{coord}{}^T$

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
s*i*l_t	σ_{ilt}	F T	S	σ_{ilt} time derivative of normal stress, user-defined local coord. system	$c_E\varepsilon_{lt}$ or $D\varepsilon_{lt}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_l$ or $(1+j\eta)j\omega D\varepsilon_l$
s*ij*l_t	τ_{ijlt}	F T	S	τ_{ijlt} time derivative of shear stress, user-defined local coord. system	$c_E\varepsilon_{lt}$ or $D\varepsilon_{lt}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_l$ or $(1+j\eta)j\omega D\varepsilon_l$
s*i*	σ_i	All	S	Principal stresses, $i = 1, 2, 3$	Defined by elpric element
e*i*	ε_i	All	S	Principal strains, $i = 1, 2, 3$	Defined by elpric element
s*i*x*j*	σ_{ixj}	All	S	Principal stress directions, $i, j = 1, 2, 3$	Defined by elpric element
e*i*x*j*	ε_{ixj}	All	S	Principal strain directions, $i, j = 1, 2, 3$	Defined by elpric element
tresca	σ_{tresca}	All	S	Tresca stress	$\mathrm{max}(\mathrm{max}(\lvert\sigma_1-\sigma_2\rvert, \lvert\sigma_2-\sigma_3\rvert), \lvert\sigma_1-\sigma_3\rvert))$
mises	σ_{mises}	All	S	von Mises stress	
normD	normD	All	S	Electric displacement, norm	$\sqrt{\mathbf{D}\cdot\mathbf{D}}$

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Ws	W_s	All	S	Strain energy density	If material properties defined in global coord. sys. $\frac{\sigma\cdot\varepsilon}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\sigma\cdot\mathrm{conj}(\varepsilon))\mathrm{th}$ in freqency resp. If material properties defined in local user-defined coord. sys. $\frac{\sigma_1\cdot\varepsilon_1}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\sigma_1\cdot\mathrm{conj}(\varepsilon_1))\mathrm{th}$ in freq. resp.
We	W_e	All	S	Electric energy density	If material properties defined in global coord. sys. $\frac{\mathbf{E}\cdot\mathbf{D}}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\mathrm{conj}(\mathbf{E})\cdot\mathbf{D})\mathrm{th}$ in freqency resp. If material properties defined in local user-defined coord. sys. $\frac{\mathbf{E}_1\cdot\mathbf{D}_1}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\mathrm{conj}(\mathbf{E}_1)\cdot\mathbf{D}_1)\mathrm{th}$ in frequency response analyses.
Ta*i*	Ta_i	All	B	Surface traction (force/area) in x_i direction	$\begin{bmatrix}\mathrm{Ta}_x\\ \mathrm{Ta}_y\end{bmatrix}=\begin{bmatrix}\sigma_x & \tau_{xy}\\ \tau_{xy} & \sigma_y\end{bmatrix}\begin{bmatrix}n_x\\ n_y\end{bmatrix}$
nD	nD	All	B	Surface charge density	$\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{D}_{\mathrm{down}}-\mathbf{D}_{\mathrm{up}})$
nJ	nJ	F T	B	Current density outflow	$\mathbf{n}\cdot\mathbf{J}$
nJs	nJs	F	B	Source current density	Only for unsymmetric electric currents. $\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{J}_{\mathrm{down}}-\mathbf{J}_{\mathrm{up}})$ or, with weak constraints, the Lagrange multiplier for V.

TABLE 2-12: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Fig	F_{ig}	All	All	Body load, edge load, point load, in global x_i direction	If global coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \end{bmatrix} = \begin{bmatrix} F_x \\ F_z \end{bmatrix}$ If other coordinate system $\begin{bmatrix} F_{xg} \\ F_{yg} \end{bmatrix} = T_{\mathrm{coord}} \begin{bmatrix} F_x \\ F_y \end{bmatrix}$
smon	smon	All	S	Structural equation available	1 or 0
eson	eson	All	S	Electrical equation available	1 or 0

Piezo Plane Strain

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sx_amp` represents the amplitude of the normal stress in the x direction
- `ex_ph` represents the phase of the normal strain in the x direction.

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`.

The table uses a convention where indices $i, j, \ldots$ (or `i`, `j`, ...) run over the geometry's Cartesian coordinate axes, x, y, and z. In particular, u_i (`ui`) refers to the global displacements (u, v, w). The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T

VARIABLES

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui`	u_i	All	All	x_i displacement	u_i
`V`	V	All	All	Electric potential	V
`uit`	u_{it}	T	All	x_i velocity	u_{it}
`ui_amp`	$u_{i\mathrm{amp}}$	F	All	x_i displacement amplitude	$\lvert u_i \rvert$
`ui_ph`	$u_{i\mathrm{ph}}$	F	All	x_i displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(u_i), 2\pi)$
`V_amp`	V_{amp}	F	All	Electric potential amplitude	$\lvert V \rvert$
`V_ph`	V_{ph}	F	All	Electric potential phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(V), 2\pi)$
`ui_t`	u_{it}	F	All	x_i velocity	$j\omega u_i$
`ui_t_amp`	$u_{it\mathrm{amp}}$	F	All	x_i velocity amplitude	$\omega u_{i\mathrm{amp}}$
`ui_t_ph`	$u_{it\mathrm{ph}}$	F	All	x_i velocity phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
`ui_tt`	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`ui_tt_ph`	$u_{itt\mathrm{ph}}$	F	All	x_i acceleration phase	$\mathrm{mod}(u_{i\mathrm{ph}} + 180°, 360°)$

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))^2}$
e*i*	ε_i	All	S	ε_i normal strain, global coord. system	$\frac{\partial u_i}{\partial x_i}$
exy	ε_{xy}	All	S	ε_{xy} shear strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)$
E*i*	E_i	All	S	Electric field	$-\left(\frac{\partial V}{\partial x_i}\right)$
normE	E_i	All	S	Electric field	$\sqrt{\mathbf{E}\cdot\mathbf{E}}$
e*i*l	ε_{il}	All	S	ε_{il} normal strain, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\varepsilon T_{\mathrm{coord}}$
e*ij*l	ε_{ijl}	All	S	ε_{ijl} shear strain, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\varepsilon T_{\mathrm{coord}}$
Eil	E_{il}	All	S	Electric field, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\mathbf{E}$
V*i*l	V_{il}	All	S	Electric potential gradient, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\nabla V$
e*i*_t	ε_{it}	T	S	ε_{it} normal velocity strain, global system	$\frac{\partial u_{it}}{\partial x_i}$
e*i*_t	ε_{it}	F	S	ε_{it} normal velocity strain, global system	$\frac{\partial u_i}{\partial x_i}j\omega$
exy_t	ε_{xyt}	T	S	ε_{xyt} shear velocity strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u_t}{\partial y}+\frac{\partial v_t}{\partial x}\right)$

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
exy_t	ε_{xyt}	F	S	ε_{xyt} shear velocity strain, global coord. system	$\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)j\omega$
eil_t	ε_{ilt}	F T	S	ε_{ilt} normal velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\varepsilon_t T_{\mathrm{coord}}$
exyl_t	ε_{xylt}	F T	S	ε_{xylt} shear velocity strain, user-defined coord. system	$T_{\mathrm{coord}}{}^{T}\varepsilon_t T_{\mathrm{coord}}$
cE	c_E	All	S	Stiffness matrix components	s_E^{-1} , if material is specified on strain-charge form, calculated by a special inverting-matrices element.
e	e	All	S	Piezoelectric coupling matrix if material is specified on strain-charge form	ds_E^{-1}
epsilonT	ε_T	All	S	Electric permittivity with stress field constant	$\varepsilon_0\varepsilon_{rT}$
epsilonS	ε_S	All	S	Electric permittivity with strain field constant	If material defined on stress-charge from $\varepsilon_0\varepsilon_{rS}$ If material defined on strain-charge from $\varepsilon_0\varepsilon_{rT}-d\cdot s_E^{-1}\cdot d^t$
D	D	All	S	Stiffness matrix components	For isotropic and anisotropic material
epsilon	ε_e	All	S	Electric permittivity matrix components	$\varepsilon_0\varepsilon_r$, for isotropic and anisotropic material

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
sigma	σ_e	freq	S	Electric conductivity matrix components	For isotropic and anisotropic material
s*i*	σ_i	All	S	σ_i normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}{}^T$
D*i*	D_i	All	S	Electric displacement, x_i component	If material defined in global coord. sys. $e\varepsilon + \varepsilon_S\mathbf{E}$ or $\varepsilon_e\mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{D}_1$
J*i*	J_i	T F	S	Total current density, x_i component	$J_{d,i} + J_{p,i}$ or $J_{d,i}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{J}_1$
Jd*i*	$J_{d,i}$	T	S	Displacement current density, x_i component	$\frac{\partial D_i}{\partial t}$
Jd*i*	$J_{d,i}$	F	S	Displacement current density, x_i component	$j\omega D_i$
Jp*i*	$J_{p,i}$	T F	S	Potential current density, x_i component	$\sigma_e\mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{J}_1$

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`sij`	τ_{ij}	All	S	τ_{ij} shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}^T$
`sil`	σ_i	All	S	σ_i normal stress, user-defined local coord. system	$c_E\varepsilon_1 - e^t\mathbf{E}_1$ or $D\varepsilon_1$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon_1 - e^t\mathbf{E}_1$ or $(1+j\eta)D\varepsilon_1$
`Dil`	D_{i1}	All	S	Electric displacement, x_i component, local coord. sys.	$e\varepsilon_1 + \varepsilon_S\mathbf{E}_1$ or $\varepsilon_e\mathbf{E}_1$
`Jil`	J_{i1}	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,i1} + J_{p,i1}$ or $J_{d,i1}$
`Jdil`	$J_{d,i1}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{i1}}{\partial t}$
`Jdil`	$J_{d,i1}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{i1}$
`Jpil`	$J_{p,i1}$	F	S	Potential current density, x_i component, local coord. sys.	$\sigma_e\mathbf{E}_1$
`sijl`	τ_{ij}	All	S	τ_{ij} shear stress, user-defined local coord. system	$c_E\varepsilon_1 - e^t\mathbf{E}_1$ or $D\varepsilon_1$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon_1 - e^t\mathbf{E}_1$ or $(1+j\eta)D\varepsilon_1$

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
si_t	σ_{it}	F T	S	σ_{it} time derivative of normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_t$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{\mathrm{l}t}T_{\mathrm{coord}}{}^T$
sij_t	τ_{ijt}	T	S	τ_{ijt} time derivative of shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{\mathrm{l}t}T_{\mathrm{coord}}{}^T$
sil_t	$\sigma_{i\mathrm{l}t}$	F T	S	$\sigma_{i\mathrm{l}t}$ time derivative of normal stress, user-defined local coord. system	$c_E\varepsilon_{\mathrm{l}t}$ or $D\varepsilon_{\mathrm{l}t}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_{\mathrm{l}}$ or $(1+j\eta)j\omega D\varepsilon_{\mathrm{l}}$
sijl_t	$\tau_{ij\mathrm{l}t}$	F T	S	$\tau_{ij\mathrm{l}t}$ time derivative of shear stress, user-defined local coord. system	$c_E\varepsilon_{\mathrm{l}t}$ or $D\varepsilon_{\mathrm{l}t}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_{\mathrm{l}}$ or $(1+j\eta)j\omega D\varepsilon_{\mathrm{l}}$

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
sz	σ_z	All	S	σ_z normal stress	If material defined in global coord. sys. $\sum_k (c_E)_{3k}\varepsilon_k - \sum_j e_{j3}E_j$, or $\sum_k (D)_{3k}\varepsilon_k$ With loss factor damping in frequency response analysis $\sum_k (1+j\eta)(c_E)_{3k}\varepsilon_k - \sum_j e_{j3}E_j$, or $\sum_k (1+j\eta)(D)_{3k}\varepsilon_k$ If material defined in user-def. coord. sys. $\sum_k (c_E)_{3k}(\varepsilon_1)_k - \sum_j e_{j3}(E_1)_j$, or $\sum_k (D)_{3k}(\varepsilon_1)_k$
sz_t	σ_{zt}	All	S	σ_{zt} time derivative of normal stress	If material defined in global coord. sys. $\sum_k (D)_{3k}(\varepsilon_t)_k$ (M is c_E or D) With loss factor damping in frequency response analysis $\sum_k (1+j\eta)(M)_{3k}j\omega\varepsilon_k$ (M is c_E or D) If material defined in user-def. coord. sys. $\sum_k (M)_{3k}(\varepsilon_{1t})_k$ (M is c_E or D)
s*i*	σ_i	All	S	Principal stresses, $i = 1,2,3$	Defined by elpric element
e*i*	ε_i	All	S	Principal strains, $i = 1,2,3$	Defined by elpric element

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
s*ixj*	σ_{ixj}	All	S	Principal stress directions, $i,j = 1,2,3$	Defined by elpric element
e*ixj*	ε_{ixj}	All	S	Principal strain directions, $i,j = 1,2,3$	Defined by elpric element
tresca	σ_{tresca}	All	S	Tresca stress	$\max(\max(\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert), \lvert\sigma_1 - \sigma_3\rvert)$
mises	σ_{mises}	All	S	von Mises stress	
normD	normD	All	S	Electric displacement, norm	$\sqrt{\mathbf{D}\cdot\mathbf{D}}$
Ws	W_{s}	All	S	Strain energy density	If material properties defined in global coord. sys. $\frac{\sigma\cdot\varepsilon}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\sigma\cdot\mathrm{conj}(\varepsilon))\mathrm{th}$ in frequency response analyses. If material properties defined in local user-defined coord. sys. $\frac{\sigma_l\cdot\varepsilon_l}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\sigma_l\cdot\mathrm{conj}(\varepsilon_l))\mathrm{th}$ in freq. resp.
We	W_e	All	S	Electric energy density	If material properties defined in global coord. sys. $\frac{\mathbf{E}\cdot\mathbf{D}}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\mathrm{conj}(\mathbf{E})\cdot\mathbf{D})\mathrm{th}$ in frequency response analyses. If material properties defined in local user-defined coord. sys. $\frac{\mathbf{E}_l\cdot\mathbf{D}_l}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\mathrm{conj}(\mathbf{E}_l)\cdot\mathbf{D}_l)\mathrm{th}$ in frequency response analyses.

TABLE 2-13: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Tai	Ta_i	All	B	Surface traction (force/area) in x_i direction	$\begin{bmatrix}\mathrm{Ta}_x\\ \mathrm{Ta}_y\end{bmatrix} = \begin{bmatrix}\sigma_x & \tau_{xy}\\ \tau_{xy} & \sigma_y\end{bmatrix}\begin{bmatrix}n_x\\ n_y\end{bmatrix}$
nD	nD	All	B	Surface charge density	$\mathbf{n}_{\mathrm{up}} \cdot (\mathbf{D}_{\mathrm{down}} - \mathbf{D}_{\mathrm{up}})$
nJ	nJ	F T	B	Current density outflow	$\mathbf{n} \cdot \mathbf{J}$
nJs	nJs	F	B	Source current density	Only for unsymmetric electric currents. $\mathbf{n}_{\mathrm{up}} \cdot (\mathbf{J}_{\mathrm{down}} - \mathbf{J}_{\mathrm{up}})$ or, with weak constraints, the Lagrange multiplier for V.
Fig	F_{ig}	All	All	Body load, edge load, point load, in global x_i direction	If global coordinate system $\begin{bmatrix}F_{xg}\\ F_{yg}\end{bmatrix} = \begin{bmatrix}F_x\\ F_y\end{bmatrix}$ If other coordinate system $\begin{bmatrix}F_{xg}\\ F_{yg}\end{bmatrix} = T_{\mathrm{coord}}\begin{bmatrix}F_x\\ F_y\end{bmatrix}$
smon	smon	All	S	Structural equation available	1 or 0
eson	eson	All	S	Electrical equation available	1 or 0

Piezo Axial Symmetry

A large number of variables are available for use in expressions and for postprocessing purposes. In addition to the variables listed below, almost all application-mode parameters are available as variables. Some variables change their availability with the type of analysis, as noted in the Analysis column. For frequency-response analysis a number of additional variables are available. Furthermore, the amplitudes and phases of variables such as strains and stresses are available; to access them, append `_amp` or `_ph` to the variable name. For example:

- `sr_amp` represents amplitude of the normal stress in the r direction.
- `ephi_ph` represents the phase of the normal strain in the φ direction

The exception to this scheme consists of variables defined using a nonlinear operator such as `mises`, `disp`, `Tresca`, or `s1`. The Analysis column uses the following abbreviations:

ANALYSIS	ABBREVIATION
Static	S
Frequency response	F
Time dependent	T

VARIABLES

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`uor`	uor	All	All	r displacement divided by r	uor
`uaxi`	uaxi	All	All	r displacement	$\mathrm{uor}\cdot r$
`w`	w	All	All	z displacement	w
V	V	All	All	Electric potential	V
`uort`	uor_t	T	All	r velocity divided by r	uor_t
`uaxi_t`	uaxi_t	T	All	r velocity	$\mathrm{uor}_t\cdot r$
`w_t`	w_t	T	All	z velocity	w_t
`uaxi_amp`	$\mathrm{uaxi}_{\mathrm{amp}}$	F	All	r displacement amplitude	$\lvert\mathrm{uaxi}\rvert$
`w_amp`	w_{amp}	F	All	z displacement amplitude	$\lvert w\rvert$
`uaxi_ph`	$\mathrm{uaxi}_{\mathrm{ph}}$	F	All	r displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(\mathrm{uaxi}), 2\pi)$
`w_ph`	w_{ph}	F	All	z displacement phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(w), 2\pi)$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
V_amp	V_{amp}	F	All	Electric potential amplitude	$\lvert V \rvert$
V_ph	V_{ph}	F	All	Electric potential phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(V), 2\pi)$
uaxi_t	uaxi_t	F	All	r velocity	$j\omega\,\mathrm{uaxi}$
w_t	w_t	F	All	z velocity	$j\omega w$
uaxi_t_amp	uaxi_{tamp}	F	All	r velocity amplitude	$\omega\,\mathrm{uaxi}_{\mathrm{amp}}$
w_t_amp	w_{tamp}	F	All	z velocity amplitude	$\omega\,w_{\mathrm{amp}}$
uaxi_t_ph	uaxi_{tph}	F	All	r velocity phase	$\mathrm{mod}(\mathrm{uaxi}_{\mathrm{ph}} + 90°, 360°)$
w_t_ph	w_{tph}	F	All	z velocity phase	$\mathrm{mod}(w_{\mathrm{ph}} + 90°, 360°)$
uaxi_tt	uaxi_{tt}	F	All	r acceleration	$-\omega^2\,\mathrm{uaxi}$
w_tt	w_{tt}	F	All	z acceleration	$-\omega^2 w$
uaxi_tt_amp	uaxi_{tamp}	F	All	r acceleration amplitude	$\omega^2\,\mathrm{uaxi}_{\mathrm{amp}}$
w_tt_amp	w_{tamp}	F	All	z acceleration amplitude	$\omega^2 w_{\mathrm{amp}}$
uaxi_tt_ph	uaxi_{tph}	F	All	r acceleration phase	$\mathrm{mod}(\mathrm{uaxi}_{\mathrm{ph}} + 180°, 360°)$
w_tt_ph	w_{tph}	F	All	z acceleration phase	$\mathrm{mod}(w_{\mathrm{ph}} + 180°, 360°)$
disp	disp	All	All	Total displacement	$\sqrt{\mathrm{uaxi}^2 + w^2}$
er	ε_r	All	S	ε_r normal strain, global system	$\mathrm{uor} + \frac{\partial}{\partial r}(\mathrm{uor}) \cdot r$
ez	ε_z	All	S	ε_z normal strain, global system	$\frac{\partial w}{\partial z}$
ephi	ε_φ	All	S	ε_φ normal strain	uor
erz	ε_{rz}	All	S	ε_{rz} shear strain, global coord. system	$\frac{1}{2}\left(\frac{\partial}{\partial z}(\mathrm{uor}) \cdot r + \frac{\partial w}{\partial r}\right)$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
exl, eyl	ε_{xl}, ε_{yl}	All	S	ε_{xl}, ε_{yl} normal strains, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$
exyl	ε_{xyl}	All	S	ε_{xy} shear strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon T_{\mathrm{coord}}$
er_t	ε_{rt}	T	S	ε_{rt} velocity normal strain, global system	$\mathrm{uor}_t + \frac{\partial}{\partial r}(\mathrm{uor}_t) \cdot r$
er_t	ε_{rt}	F	S	ε_{rt} velocity normal strain, global system	$j\omega\left(\mathrm{uor} + \frac{\partial}{\partial r}\mathrm{uor} \cdot r\right)$
ez_t	ε_{zt}	T	S	ε_{zt} velocity normal strain, global system	$\frac{\partial w_t}{\partial z}$
ez_t	ε_{zt}	F	S	ε_{zt} velocity normal strain, global system	$j\omega\left(\frac{\partial w}{\partial z}\right)$
ephi_t	$\varepsilon_{\varphi t}$	T	S	$\varepsilon_{\varphi t}$ velocity normal strain	uor_t
ephi_t	$\varepsilon_{\varphi t}$	F	S	$\varepsilon_{\varphi t}$ velocity normal strain	$j\omega\,\mathrm{uor}$
erz_t	ε_{rzt}	T	S	ε_{rzt} shear strain, global coord. system	$\frac{1}{2}\left(\frac{\partial}{\partial z}(\mathrm{uor}_t) \cdot r + \frac{\partial w_t}{\partial r}\right)$
erz_t	ε_{rzt}	F	S	ε_{rzt} shear strain, global coord. system	$\frac{1}{2}\left(\frac{\partial}{\partial z}(\mathrm{uor}) \cdot r + \frac{\partial w}{\partial r}\right)j\omega$
exl_t, eyl_t	ε_{xlt}, ε_{ylt}	F T	S	ε_{xlt}, ε_{ylt} velocity normal strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon_t T_{\mathrm{coord}}$
exyl_t	ε_{xylt}	F T	S	ε_{xylt} velocity shear strain, user-defined coord. system	$T_{\mathrm{coord}}{}^T \varepsilon_t T_{\mathrm{coord}}$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))}^2$
E*i*	E_i	All	S	Electric field	$-\left(\frac{\partial V}{\partial x_i}\right)$
normE	$\lvert\mathbf{E}\rvert$	All	S	Electric field	$\sqrt{\mathbf{E}\cdot\mathbf{E}}$
E*i*l	E_{il}	All	S	Electric field, user-defined coord. system	${T_{\mathrm{coord}}}^T\mathbf{E}$
V*i*l	V_{il}	All	S	Electric potential gradient, user-defined coord. system	${T_{\mathrm{coord}}}^T\nabla V$
cE	c_E	All	S	Stiffness matrix components	s_E^{-1} , if material is specified on strain-charge form, calculated by a special inverting-matrices element.
e	e	All	S	Piezoelectric coupling matrix if material is specified on strain-charge form	ds_E^{-1}
epsilonT	ε_T	All	S	Electric permittivity with stress field constant	$\varepsilon_0\varepsilon_{rT}$
epsilonS	ε_S	All	S	Electric permittivity with strain field constant	If material defined on stress-charge from $\varepsilon_0\varepsilon_{rS}$ If material defined on strain-charge from $\varepsilon_0\varepsilon_{rT}-d\cdot s_E^{-1}\cdot d^t$
D	D	All	S	Stiffness matrix components	For isotropic and anisotropic material

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`epsilon`	ε_e	All	S	Electric permittivity matrix components	$\varepsilon_0\varepsilon_r$, for isotropic and anisotropic material
`sigma`	σ_e	freq	S	Electric conductivity matrix components	For isotropic and anisotropic material
`sr, sz`	σ_r, σ_z	All	S	$\sigma_{r,z}$ normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}{}^T$
`sphi`	σ_φ	All	S	σ_φ normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $c_E\varepsilon_1 - e^t\mathbf{E}_1$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`srz`	τ_{rz}	All	S	τ_{rz} shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{1t}T_{\mathrm{coord}}^T$
`si`	σ_i	All	S	σ_i normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon - e^t\mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon - e^t\mathbf{E}$ or $(1+j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}^T$
`Di`	D_i	All	S	Electric displacement, x_i component	If material defined in global coord. sys. $e\varepsilon + \varepsilon_S\mathbf{E}$ or $\varepsilon_e\mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{D}_1$
`Ji`	J_i	T F	S	Total current density, x_i component	$J_{d,i} + J_{p,i}$ or $J_{d,i}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\mathbf{J}_1$
`Jdi`	$J_{d,i}$	T	S	Displacement current density, x_i component	$\frac{\partial D_i}{\partial t}$
`Jdi`	$J_{d,i}$	F	S	Displacement current density, x_i component	$j\omega D_i$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Jp*i*	$J_{p,i}$	T F	S	Potential current density, x_i component	$\sigma_e \mathbf{E}$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}} \mathbf{J}_{\mathrm{l}}$
s*ij*	τ_{ij}	All	S	τ_{ij} shear stress, global coord. system	If material defined in global coord. sys. $c_E \varepsilon - e^t \mathbf{E}$ or $D\varepsilon$ With loss factor damping in frequency response analysis $(1 + j\eta)c_E \varepsilon - e^t \mathbf{E}$ or $(1 + j\eta)D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}} \sigma_{\mathrm{l}} T_{\mathrm{coord}}{}^T$
s*i*l	σ_i	All	S	σ_i normal stress, user-defined local coord. system	$c_E \varepsilon_{\mathrm{l}} - e^t \mathbf{E}_{\mathrm{l}}$ or $D\varepsilon_{\mathrm{l}}$ With loss factor damping in frequency response analysis $(1 + j\eta)c_E \varepsilon_{\mathrm{l}} - e^t \mathbf{E}_{\mathrm{l}}$ or $(1 + j\eta)D\varepsilon_{\mathrm{l}}$
D*i*l	$D_{i\mathrm{l}}$	All	S	Electric displacement, x_i component, local coord. sys.	$e\varepsilon_{\mathrm{l}} + \varepsilon_S \mathbf{E}_{\mathrm{l}}$ or $\varepsilon_e \mathbf{E}_{\mathrm{l}}$
J*i*l	$J_{i\mathrm{l}}$	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,i\mathrm{l}} + J_{p,i\mathrm{l}}$ or $J_{d,i\mathrm{l}}$
Jd*i*l	$J_{d,i\mathrm{l}}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{i\mathrm{l}}}{\partial t}$
Jd*i*l	$J_{d,i\mathrm{l}}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{i\mathrm{l}}$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Jpil`	$J_{p,il}$	F	S	Potential current density, x_i component, local coord. sys.	$\sigma_e \mathbf{E}_l$
`sijl`	τ_{ij}	All	S	τ_{ij} shear stress, user-defined local coord. system	$c_E\varepsilon_l - e^t\mathbf{E}_l$ or $D\varepsilon_l$ With loss factor damping in frequency response analysis $(1+j\eta)c_E\varepsilon_l - e^t\mathbf{E}_l$ or $(1+j\eta)D\varepsilon_l$
`si_t`	σ_{it}	F T	S	σ_{it} time derivative of normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_t$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}{}^T$
`sij_t`	τ_{ijt}	T	S	τ_{ijt} time derivative of shear stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}{}^T$
`sil_t`	σ_{ilt}	F T	S	σ_{ilt} time derivative of normal stress, user-defined local coord. system	$c_E\varepsilon_{lt}$ or $D\varepsilon_{lt}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_l$ or $(1+j\eta)j\omega D\varepsilon_l$

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`sijl_t`	τ_{ijlt}	F T	S	τ_{ijlt} time derivative of shear stress, user-defined local coord. system	$c_E \varepsilon_{lt}$ or $D\varepsilon_{lt}$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_l$ or $(1+j\eta)j\omega D\varepsilon_l$
`sr_t, sz_t`	σ_{rt},σ_{zt}	F T	S	σ_{rt}, σ_{zt} time derivative of normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_t$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}^T$
`sphi_t`	$\sigma_{\varphi t}$	F T	S	$\sigma_{\varphi t}$ time derivative of normal stress, global coord. system	If material defined in global coord. sys. $c_E\varepsilon_t$ or $D\varepsilon_t$ With loss factor damping in frequency response analysis $(1+j\eta)j\omega c_E\varepsilon_t$ or $(1+j\eta)j\omega D\varepsilon$ If material defined in user-def. coord. sys. $c_E\varepsilon_{lt}$
`si`	σ_i	All	S	Principal stresses, i = 1,2,3	Defined by elpric element
`ei`	ε_i	All	S	Principal strains, i = 1,2,3	Defined by elpric element
`sixj`	σ_{ixj}	All	S	Principal stress directions, i,j = 1,2,3	Defined by elpric element
`eixj`	ε_{ixj}	All	S	Principal strain directions, i,j = 1,2,3	Defined by elpric element

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
tresca	σ_{tresca}	All	S	Tresca stress	$\max(\max(\lvert\sigma_1-\sigma_2\rvert, \lvert\sigma_2-\sigma_3\rvert)), \lvert\sigma_1-\sigma_3\rvert))$
mises	σ_{mises}	All	S	von Mises stress	
normD	normD	All	S	Electric displacement, norm	$\sqrt{\mathbf{D}\cdot\mathbf{D}}$
Ws	W_{s}	All	S	Strain energy density	If material properties defined in global coord. sys. $\frac{\sigma\cdot\varepsilon}{2}$, $\frac{1}{2}\mathrm{real}(\sigma\cdot\mathrm{conj}(\varepsilon))$ in frequency response analyses. If material properties defined in local user-defined coord. sys. $\frac{\sigma_1\cdot\varepsilon_1}{2}$, $\frac{\mathrm{real}(\sigma_1\cdot\mathrm{conj}(\varepsilon_1))}{2}+\frac{\mathrm{real}(\sigma_\varphi\cdot\mathrm{conj}(\varepsilon_\varphi))}{2}$ in freq. resp.
We	W_{e}	All	S	Electric energy density	If material properties defined in global coord. sys. $\mathbf{E}\cdot\mathbf{D}/2$, $\mathrm{real}(\mathrm{conj}(\mathbf{E})\cdot\mathbf{D})/2$ in freq. resp. If material properties defined in local user-defined coord. sys. $\mathbf{E}_1\cdot\mathbf{D}_1/2$, $\mathrm{real}(\mathrm{conj}(\mathbf{E}_1)\cdot\mathbf{D}_1)/2$ in freq. resp.
Ta*i*	Ta_i	All	B	Surface traction (force/area) in x_i direction	$\begin{bmatrix}\mathrm{Ta}_r\\ \mathrm{Ta}_z\end{bmatrix}=\begin{bmatrix}\sigma_r & \tau_{rz}\\ \tau_{rz} & \sigma_z\end{bmatrix}\begin{bmatrix}n_r\\ n_z\end{bmatrix}$
nD	nD	All	B	Surface charge density	$\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{D}_{\mathrm{down}}-\mathbf{D}_{\mathrm{up}})$
smon	smon	All	S	Structural equation available	1 or 0

TABLE 2-14: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
eson	eson	All	S	Electrical equation available	1 or 0
nJ	nJ	F T	B	Current density outflow	$\mathbf{n}\cdot\mathbf{J}^{d}$
nJs	nJs	F	B	Source current density	Only for unsymmetric electric currents. $\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{J}_{\mathrm{down}}-\mathbf{J}_{\mathrm{up}})$ or, with weak constraints, the Lagrange multiplier for V.
Fig	F_{ig}	All	All	Body load, edge load, point load, in global x_i direction	If global coordinate system $\begin{bmatrix}F_{rg}\\F_{zg}\end{bmatrix} = \begin{bmatrix}F_r\\F_z\end{bmatrix}$ If other coordinate system $\begin{bmatrix}F_{xg}\\F_{zg}\end{bmatrix} = T_{\mathrm{coord}}\begin{bmatrix}F_r\\F_z\end{bmatrix}$

3

Application Mode Programming Reference

This chapter provides details about the fields in the application mode structure for the structural and piezoelectric application modes.

Application Mode Programming Reference

This reference chapter tabulates the application mode dependent fields of the application structure. For each application mode these are the following sections:

- *Dependent and independent variables*, which gives the variables in `appl.dim` and `appl.sdim`. In the GUI the dependent variables are given in the **Dependent variables** text field in the Model Navigator.
- *Application mode class and name*, which specifies which values to use in `appl.mode` and gives the default value of `appl.name`. In the user interface, you provide `appl.name` in the **Application mode name** edit field in the Model Navigator.
- *Scalar variable*, which specifies the variable in `appl.var`. The corresponding dialog box is the **Application Scalar Variables** dialog box.
- *Properties*, which specifies all fields in `appl.prop`, for example which type of analysis to perform or which elements to use. In the user interface you specify the properties in the **Application Mode Properties** dialog box.
- *Application mode parameters*, which specifies the parameters in `appl.equ`, `appl.bnd`, `appl.edg`, and `appl.pnt`. The dialog boxes corresponding to these fields are the **Subdomain Settings**, **Boundary Settings**, **Edge Settings**, and **Point Settings** dialog boxes.

In the tables below, words written in `code` format means that the structure field is given as a string (`'iso'`); the word “expression” means that the structure field or cell array component is given either as a numeric value (a floating point value, `2.0E11`) or as a string.

`fem.appl` is a cell array of structures, one for each application mode. `fem.appl{i}` refers to the application mode in question.

In the application mode parameters tables the field column means a field on a specific domain level given in the domain column. Example: field `alpha`, domain `equ`, refers to the field `fem.appl{i}.equ.alpha`, thermal expansion coefficient on subdomain level. Some fields exist in all domains, such as loads and constraints.

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
`appl.dim`	`{'u','v','w','p'}`	Dependent variable names, global displacements in x, y, z directions and pressure
`appl.sdim`	`{'x','y','z'}`	Independent variable names, space coordinates in global x, y, z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
`appl{i}.mode.class`	`SmeSolid3`	
`appl{i}.name`		`smsld`

SCALAR VARIABLE

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.var`	cell array with variable name and value	`{'freq' '100' 't_old_ini' '-1'}`	Excitation frequency for frequency response analysis and initial value for previous time step used for contact with dynamic friction.

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.prop.elemdefault`	`Lag1 | Lag2 | Lag3 | Lag4 | Lag5 | LagU2P1 | LagU3P2 | LagU4P3 | LagU5P4`	`Lag2`	Default element to use. Lagrange element of order 1–5 and mixed Lagrange element of order 2–5
`appl.prop.analysis`	`static | staticplastic | eig | time | freq | para | quasi | buckling`	`static`	Analysis to be performed, static, static elasto-plastic, eigenfrequency, time dependent, frequency response parametric, quasi-static transient, or linear buckling analysis; see note below.
`appl.prop.eigtype`	`lambda | freq | loadfactor`	`freq`	Should eigenvalues, eigenfrequencies or load factors be used
`appl.prop.largedef`	`on | off`	`off`	Include large deformation, nonlinear geometry effects.
`appl.prop.frame`	`name of the frame`	`ref`	The name of the frame where the application mode lives
`appl.prop.createframe`	`on | off`	`off`	Controls if the application mode should create a deformed frame
`appl.prop.deformframe`	`name of the deformed frame`	`deform`	The name of the by the application mode created deformed frame

APPLICATION MODE PARAMETERS

TABLE 3-1: APPLICATION MODE PARAMETERS FOR SOLID, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
matmodel	iso | ortho | aniso | plastic | hyper	iso	equ	Material model isotropic, orthotropic, anisotropic, elasto-plastic, or hyperelastic
mixedform	1 | 0	0	equ	Flag specifying whether mixed or displacement formulation should be used, 1 use mixed formulation, 0 use displacement formulation.
E	expression	2.0e11	equ	Young's modulus for isotropic material
nu	expression	0.33	equ	Poisson's ratio for isotropic material
alpha	expression	1.2e-5	equ	Thermal expansion coefficient for isotropic material
rho	expression	7850	equ	Density
Ex, Ey, Ez	expression	2.0e11	equ	Young's modulus for orthotropic material
Gxy, Gyz, Gxz	expression	7.52e10	equ	Shear modulus for orthotropic material
nuxy, nuyz, nuxz	expression	0.33	equ	Poisson's ratios for orthotropic material
alphax, alphay, alphaz	expression	1.2e-5	equ	Thermal expansion coefficients for orthotropic material
D	cell array of expressions	isotropic D matrix	equ	Elasticity 6-by-6 matrix for anisotropic material, saved in symmetric format, 21 components
alphavector	cell array of expressions	isotropic expansion	equ	Thermal expansion coefficient vector for anisotropic material
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	equ	Mass damping parameter
betadK	expression	0.001	equ	Stiffness damping parameter
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties and initial stress and strain are defined
hardeningmodel	iso | kin | ideal	iso	equ	Hardening model isotropic, kinematic or ideal-plastic
yieldtype	mises | userdef	mises	equ	Yield function, mises or user-defined
Sys	expression	2.0e8	equ	Yield stress level

TABLE 3-1: APPLICATION MODE PARAMETERS FOR SOLID, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
Syfunc	expression	mises	equ	User-defined yield function
isodata	tangent | userdef	tangent	equ	Isotropic hardening specification, tangent data or user-defined function
Syhard	expression	$\frac{2 \cdot 10^{10}}{\left(1 - \frac{2 \cdot 10^{10}}{2 \cdot 10^{11}}\right)} \varepsilon_{pe}$	equ	User-defined hardening function
ETiso	expression	2.0e10	equ	Tangent modulus for isotropic hardening
ETkin	expression	2.0e10	equ	Tangent modulus for kinematic hardening
hypertype	neo_hookean | mooney_rivlin	neo_hookean	equ	Hyperelastic model
mu	expression	8e5	equ	Neo-Hookean hyperelastic material parameters, initial shear modulus
C10, C01	expression	2e5	equ	Mooney-Rivlin hyperelastic material parameters
kappa	expression	1e10	equ	Hyperelastic material parameters, initial bulk modulus
Tflag	1 | 0	0	equ	Flag specifying whether thermal expansion should be included, 1 include thermal expansion, 0 do not.
Temp	expression	0	equ	Thermal strain temperature
Tempref	expression	0	equ	Thermal strain stress free reference temperature
ini_stress	1 | 0	0	equ	Flag specifying whether initial stresses should be included, 1 include stresses, 0 do not.
ini_strain	1 | 0	0	equ	Flag specifying whether initial strains should be included, 1 include strains, 0 do not.
sxi, syi, szi	expression	0	equ	Initial normal stresses
sxyi, syzi, sxzi	expression	0	equ	Initial shear stresses
exi, eyi, ezi	expression	0	equ	Initial normal strains
exyi, eyzi, exzi	expression	0	equ	Initial shear strains

TABLE 3-1: APPLICATION MODE PARAMETERS FOR SOLID, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
constrcond	free | fixed | roller (bnd only) | displacement | sym (bnd only) | symxy (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymxy (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	equ, bnd	Type of constraint condition.
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcond	distr_force | follower_press	distr_force	bnd	Type of load
P	expression	0	bnd	Follower pressure, only used for loadcond=follower_press
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where loads are defined, not used for loadcond=follower_press
Fx, Fy, Fz	expression	0	all	Body load, face load, edge load, point load, x, y, z direction
FxPh, FyPh, FzPh	expression	0	all	Phase angle in degrees specifying the load's phases
constrtype	standard | general	standard	all	Constraint notation, for standard use Hx, Hy, Hz, Rx, Ry, Rz; for general use H and R
Hx, Hy, Hz	1 | 0	0	all	Constraint flag controlling if x,y,z direction is constrained. 1 constrained, 0 free, used with standard notation
Rx, Ry, Rz	expression	0	all	Constraint value in x, y, z direction, used with standard notation
H	cell array of expressions	{0 0 0;0 0 0;0 0 0}	all	H matrix used for general notation constraints, $Hu=R$
R	cell array of expressions	{0;0;0}	all	R vector used for general notation constraints, $Hu=R$

TABLE 3-1: APPLICATION MODE PARAMETERS FOR SOLID, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
offset	expression	0	bnd	Contact surface offset from geometric surface
pn	expression	min(1e-4*5^(auglagiter-1),0.1)E/h	bnd	Contact normal penalty factor
pt	expression	min(1e-4*5^(auglagiter-1),0.1)E/h	bnd	Contact tangential penalty factor
frictiontype	nofric | coulomb	nofric	bnd	Friction model
mustat	expression	0	bnd	Static coefficient of friction
cohe	expression	0	bnd	Cohesion sliding resistance
Ttmax	expression	Inf	bnd	Maximum tangential traction
dynfric	0 | 1	0	bnd	Should a dynamic friction model be used
mudyn	expression	0	bnd	Dynamic coefficient of friction
dcfric	expression	0	bnd	Friction decay coefficient
contacttol	auto | man	auto	bnd	Method to calculate if slave and master are incontact
mantol	expression	1e-6	bnd	Distance when slave and master are assumed to be in contact, used together with contacttol=man
searchdist	auto | man	auto	bnd	Method to calculate the distance to search for contact
mandist	expression	1e-2	bnd	Distance to search if the slave and master are in contact, used together with searchdist=man
searchmethod	fast | direct	fast	bnd	Method used when calculating if master and slave are in contact.
contact_oldi	0 | 1	0	bnd	If they where in contact in the previous time step
Tni	expression	1e6	bnd	Initial value for the contact pressure
Ttxi	expression	1e6	bnd	Initial value for the friction forces
xim_old	expression	1e6	bnd	The value of the mapped coordinates in the previous time step

Plane Stress

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'u','v','p'}	Dependent variable names, global displacements s in x, y directions and pressure
appl.sdim	{'x','y','z'}	Independent variable names, space coordinates in global x, y directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl.mode.class	SmePlaneStress	
appl.name		smps

SCALAR VARIABLE

See the solid, stress-strain application mode specification on page 101.

PROPERTIES

See the solid, stress-strain application mode specification on page 102.

APPLICATION MODE PARAMETERS

TABLE 3-2: APPLICATION MODE PARAMETERS FOR PLANE STRESS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
matmodel	iso | ortho | aniso | plastic | hyper	iso	equ	Material model isotropic, orthotropic, anisotropic, elasto-plastic, or hyperelastic
mixedform	1 | 0	0	equ	Flag specifying whether mixed or displacement formulation should be used, 1 use mixed formulation, 0 use displacement formulation.
E	expression	2.0e11	equ	Young's modulus for isotropic material
nu	expression	0.33	equ	Poisson's ratio for isotropic material
alpha	expression	1.2e-5	equ	Thermal expansion coefficient for isotropic material
rho	expression	7850	equ	Density

TABLE 3-2: APPLICATION MODE PARAMETERS FOR PLANE STRESS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
thickness	expression	0.01	equ	Thickness of the plate
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	equ	Mass damping parameter
betadK	expression	0.001	equ	Stiffness damping parameter
Ex, Ey, Ez	expression	2.0e11	equ	Young's modulus for orthotropic material
Gxy	expression	7.52e10	equ	Shear modulus for orthotropic material
nuxy, nuyz, nuxz	expression	0.33	equ	Poisson's ratios for orthotropic material
alphax, alphay, alphaz	expression	1.2e-5	equ	Thermal expansion coefficients for orthotropic material
D	cell array of expressions	isotropic D matrix	equ	Elasticity 4-by-4 matrix for anisotropic material, saved in symmetric format, 10 components
alphavector	cell array of expressions	isotropic expansion	equ	Thermal expansion coefficient vector for anisotropic material
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties and initial stress and strain are defined
hardeningmodel	iso | kin | ideal	iso	equ	Hardening model isotropic, kinematic or ideal-plastic
yieldtype	mises | userdef	mises	equ	Yield function, mises or user defined
Sys	expression	2.0e8	equ	Yield stress level
Syfunc	expression	mises	equ	User-defined yield function
isodata	tangent | userdef	tangent	equ	Isotropic hardening specification, tangent data or user-defined function
Syhard	expression	$\frac{2\cdot 10^{10}}{\left(1-\frac{2\cdot 10^{10}}{2\cdot 10^{11}}\right)}\varepsilon_{\mathrm{pe}}$	equ	User-defined hardening function
ETiso	expression	2.0e10	equ	Tangent modulus for isotropic hardening
ETkin	expression	2.0e10	equ	Tangent modulus for kinematic hardening

TABLE 3-2: APPLICATION MODE PARAMETERS FOR PLANE STRESS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
hypertype	neo_hookean | mooney_rivlin	neo_hookean	equ	Hyperelastic model
mu	expression	8e5	equ	Neo-Hookean hyperelastic material parameters, initial shear modulus
C10, C01	expression	2e5	equ	Mooney-Rivlin hyperelastic material parameters
kappa	expression	1e10	equ	Hyperelastic material parameters, initial bulk modulus
Tflag	1 | 0	0	equ	Flag specifying whether thermal expansion should be included, 1 include thermal expansion, 0 do not.
Temp	expression	0	equ	Thermal strain temperature
Tempref	expression	0	equ	Thermal strain stress free reference temperature
ini_stress	1 | 0	0	equ	Flag specifying whether initial stresses should be included, 1 include stresses, 0 do not.
ini_strain	1 | 0	0	equ	Flag specifying whether initial strains should be included, 1 include strains, 0 do not.
sxi, syi, szi	expression	0	equ	Initial normal stresses
sxyi	expression	0	equ	Initial shear stress
exi, eyi, ezi	expression	0	equ	Initial normal strains
exyi	expression	0	equ	Initial shear strain
constrcond	free | fixed | roller (bnd only) | displacement | sym (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	equ, bnd	Type of constraint condition.
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined

TABLE 3-2: APPLICATION MODE PARAMETERS FOR PLANE STRESS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
loadcond	distr_force | follower_press	distr_force	bnd	Type of load
P	expression	0	bnd	Follower pressure, only used for loadcond=follower_press
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where loads are defined, not used for loadcond=follower_press
Fx, Fy	expression	0	all	Body load, edge load, point load, x, y direction
loadtype	area | volume	area	equ	Body load definition, load/volume or load/area
loadtype	area | length	length	bnd	Edge load definition, load/length or load/area
FxPh, FyPh	expression	0	all	Phase angle in degrees specifying the load's phases
constrtype	standard | general	standard	all	Constraint notation for standard use Hx, Hy, Rx, Ry; for general use H and R
Hx, Hy	1 | 0	0	all	Constraint flag controlling if x,y direction is constrained. 1 constrained, 0 free, used with standard notation
Rx, Ry	expression	0	all	Constraint value in x, y direction, used with standard notation
H	cell array of expressions	{0 0;0 0}	all	H matrix used for general notation constraints, $Hu=R$
R	cell array of expressions	{0;0}	all	R vector used for general notation constraints, $Hu=R$
offset	expression	0	bnd	Contact surface offset from geometric surface
pn	expression	min(1e-4*5^(auglagiter-1),0.1)E/h	bnd	Contact normal penalty factor
pt	expression	min(1e-4*5^(auglagiter-1),0.1)E/h	bnd	Contact tangential penalty factor
frictiontype	nofric | coulomb	nofric	bnd	Friction model
mustat	expression	0	bnd	Static coefficient of friction

TABLE 3-2: APPLICATION MODE PARAMETERS FOR PLANE STRESS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
cohe	expression	0	bnd	Cohesion sliding resistance
Ttmax	expression	Inf	bnd	Maximum tangential traction
dynfric	0 | 1	0	bnd	Should a dynamic friction model be used
mudyn	expression	0	bnd	Dynamic coefficient of friction
dcfric	expression	0	bnd	Friction decay coefficient
contacttol	auto | man	auto	bnd	Method to calculate if slave and master are incontact
mantol	expression	1e-6	bnd	Distance when slave and master are assumed to be in contact, used together with contacttol=man
searchdist	auto | man	auto	bnd	Method to calculate the distance to search for contact
mandist	expression	1e-2	bnd	Distance to search if the slave and master are in contact, used together with searchdist=man
searchmethod	fast | direct	fast	bnd	Method used when calculating if master and slave are in contact
contact_oldi	0 | 1	0	bnd	If they where in contact in the previous time step
Tni	expression	1e6	bnd	Initial value for the contact pressure
Ttxi	expression	1e6	bnd	Initial value for the friction forces
xim_old	expression	1e6	bnd	The value of the mapped coordinates in the previous time step

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'u','v','p'}	Dependent variable names, global displacements in x,y directions and pressure
appl.sdim	{'x','y','z'}	Independent variable names, space coordinates in global x,y directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl.mode.class	SmePlaneStrain	
appl.name		smpn

SCALAR VARIABLE

See the solid, stress-strain application mode specification on page 101 for details.

PROPERTIES

See the solid, stress-strain application mode specification on page 102 for details.

APPLICATION MODE PARAMETERS

TABLE 3-3: APPLICATION MODE PARAMETERS FOR PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
matmodel	iso | ortho | aniso | plastic | hyper	iso	equ	Material model isotropic, orthotropic, anisotropic, elasto-plastic, or hyperelastic
mixedform	1 | 0	0	equ	Flag specifying whether mixed or displacement formulation should be used: 1 use mixed formulation, 0 use displacement formulation
E	expression	2.0e11	equ	Young's modulus for isotropic material
nu	expression	0.33	equ	Poisson's ratio for isotropic material
alpha	expression	1.2e-5	equ	Thermal expansion coefficient for isotropic material
rho	expression	7850	equ	Density

TABLE 3-3: APPLICATION MODE PARAMETERS FOR PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
thickness	expression	1	equ	Thickness of the plate
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	equ	Mass damping parameter
betadK	expression	0.001	equ	Stiffness damping parameter
Ex, Ey, Ez	expression	2.0e11	equ	Young's modulus for orthotropic material
Gxy	expression	7.52e10	equ	Shear modulus for orthotropic material
nuxy, nuyz, nuxz	expression	0.33	equ	Poisson's ratios for orthotropic material
alphax, alphay, alphaz	expression	1.2e-5	equ	Thermal expansion coefficients for orthotropic material
D	cell array of expressions	isotropic D matrix	equ	Elasticity 4x4 matrix for anisotropic material, saved in symmetric format, 10 components
alphavector	cell array of expressions	isotropic expansion	equ	Thermal expansion coefficient vector for anisotropic material
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties and initial stress and strain are defined
hardeningmodel	iso | kin | ideal	iso	equ	Hardening model isotropic, kinematic or ideal-plastic
yieldtype	mises | userdef	mises	equ	Yield function, mises or user defined
Sys	expression	2.0e8	equ	Yield stress level
Syfunc	expression	mises	equ	User-defined yield function
isodata	tangent | userdef	tangent	equ	Isotropic hardening specification, tangent data or user-defined function
Syhard	expression	$\frac{2\cdot 10^{10}}{\left(1-\frac{2\cdot 10^{10}}{2\cdot 10^{11}}\right)}\varepsilon_{pe}$	equ	User-defined hardening function
ETiso	expression	2.0e10	equ	Tangent modulus for isotropic hardening

TABLE 3-3: APPLICATION MODE PARAMETERS FOR PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
ETkin	expression	2.0e10	equ	Tangent modulus for kinematic hardening
hypertype	neo_hookean | mooney_rivlin	neo_hookean	equ	Hyperelastic model
mu	expression	8e5	equ	Neo-Hookean hyperelastic material parameters, initial shear modulus
C10, C01	expression	2e5	equ	Mooney-Rivlin hyperelastic material parameters
kappa	expression	1e10	equ	Hyperelastic material parameters, initial bulk modulus
Tflag	1 | 0	0	equ	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not.
Temp	expression	0	equ	Thermal strain temperature
Tempref	expression	0	equ	Thermal strain stress free reference temperature
ini_stress	1 | 0	0	equ	Flag specifying whether initial stresses should be included: 1 include stresses, 0 do not
ini_strain	1 | 0	0	equ	Flag specifying whether initial strains should be included: 1 include strains, 0 do not
sxi, syi, szi	expression	0	equ	Initial normal stresses
sxyi	expression	0	equ	Initial shear stress
exi, eyi, ezi	expression	0	equ	Initial normal strains
exyi	expression	0	equ	Initial shear strain
constrcond	free | fixed | roller (bnd only) | displacement | sym (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	equ, bnd	Type of constraint condition

TABLE 3-3: APPLICATION MODE PARAMETERS FOR PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcond	distr_force | follower_press	distr_force	bnd	Type of load
P	expression	0	bnd	Follower pressure, only used for loadcond=follower_press
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where load are defined
Fx, Fy	expression	0	all	Body load, edge load, point load, x, y direction
loadtype	area | volume	volume	equ	Body load definition, load/volume or load/area
loadtype	area | length	area	bnd	Edge load definition, load/length or load/area
FxPh, FyPh	expression	0	all	Phase angle in degrees specifying the load's phases
constrtype	standard | general	standard	all	Constraint notation: for standard use Hx, Hy, Rx, Ry; for general use H and R
Hx, Hy	1 | 0	0	all	Constraint flag controlling if x,y direction is constrained: 1 constrained, 0 free, used with standard notation
Rx, Ry	expression	0	all	Constraint value in x, y direction, used with standard notation
H	cell array of expressions	{0 0;0 0}	all	H matrix used for general notation constraints, Hu=R
R	cell array of expressions	{0;0}	all	R vector used for general notation constraints, Hu=R

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
`appl.dim`	`{'uor','w','p'}`	Dependent variable names, global displacements in r, z directions and pressure
`appl.sdim`	`{'r','phi','z'}`	Independent variable names, space coordinates in global r, φ, z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
`appl.mode.class`	`SmeAxialSolid`	
`appl.name`		`smaxi`

SCALAR VARIABLE

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.var`	cell array with variable name and value	`{'freq' '100'}`	Excitation frequency for frequency response analysis

PROPERTIES

All continuum application modes have the same application mode properties. See the solid, stress-strain application mode specification on page 102 for details.

APPLICATION MODE PARAMETERS

TABLE 3-4: APPLICATION MODE PARAMETERS FOR AXIAL SYMMETRY, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`matmodel`	`iso` | `ortho` | `aniso` | `plastic` | `hyper`	`iso`	equ	Material model isotropic, orthotropic, anisotropic, elasto-plastic, or hyperelastic
`mixedform`	`1 | 0`	`0`	equ	Flag specifying whether mixed or displacement formulation should be used, 1 use mixed formulation, 0 use displacement formulation.
`E`	expression	`2.0e11`	equ	Young's modulus for isotropic material

TABLE 3-4: APPLICATION MODE PARAMETERS FOR AXIAL SYMMETRY, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
nu	expression	0.33	equ	Poisson's ratio for isotropic material
alpha	expression	1.2e-5	equ	Thermal expansion coefficient for isotropic material
rho	expression	7850	equ	Density
thickness	expression	1	equ	Thickness of the plate
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	equ	Mass damping parameter
betadK	expression	0.001	equ	Stiffness damping parameter
Er, Ephi, Ez	expression	2.0e11	equ	Young's modulus for orthotropic material
Grz	expression	7.52e10	equ	Shear modulus for orthotropic material
nurphi, nuphiz, nurz	expression	0.33	equ	Poisson's ratios for orthotropic material
alphar, alphaphi, alphaz	expression	1.2e-5	equ	Thermal expansion coefficients for orthotropic material
D	cell array of expressions	isotropic D matrix	equ	Elasticity 4x4 matrix for anisotropic material, saved in symmetric format, 10 components
alphavector	cell array of expressions	isotropic expansion	equ	Thermal expansion coefficient vector for anisotropic material
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties and initial stress and strain are defined
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties and initial stress and strain are defined
hardeningmodel	iso | kin | ideal	iso	equ	Hardening model isotropic, kinematic or ideal-plastic
yieldtype	mises | userdef	mises	equ	Yield function, mises or user defined
Sys	expression	2.0e8	equ	Yield stress level
Syfunc	expression	mises	equ	User-defined yield function

TABLE 3-4: APPLICATION MODE PARAMETERS FOR AXIAL SYMMETRY, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
isodata	tangent | userdef	tangent	equ	Isotropic hardening specification, tangent data or user-defined function
Syhard	expression	$\frac{2\cdot 10^{10}}{\left(1-\frac{2\cdot 10^{10}}{2\cdot 10^{11}}\right)}\varepsilon_{pe}$	equ	User-defined hardening function
ETiso	expression	2.0e10	equ	Tangent modulus for isotropic hardening
ETkin	expression	2.0e10	equ	Tangent modulus for kinematic hardening
hypertype	neo_hookean | mooney_rivlin	neo_hookean	equ	Hyperelastic model
mu	expression	8e5	equ	Neo-Hookean hyperelastic material parameters, initial shear modulus
C10, C01	expression	2e5	equ	Mooney-Rivlin hyperelastic material parameters
kappa	expression	1e10	equ	Hyperelastic material parameters, initial bulk modulus
Tflag	1 | 0	0	equ	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not
Temp	expression	0	equ	Thermal strain temperature
Tempref	expression	0	equ	Thermal strain stress free reference temperature
ini_stress	1 | 0	0	equ	Flag specifying whether initial stresses should be included: 1 include stresses, 0 do not
ini_strain	1 | 0	0	equ	Flag specifying whether initial strains should be included: 1 include strains, 0 do not
sri, sphii, szi	expression	0	equ	Initial normal stresses
srzi	expression	0	equ	Initial shear stress
eri, ephii, ezi	expression	0	equ	Initial normal strains
erzi	expression	0	equ	Initial shear strain

TABLE 3-4: APPLICATION MODE PARAMETERS FOR AXIAL SYMMETRY, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
constrcond	free | fixed | roller (bnd only) | displacement | sym (bnd only) | symrphi (bnd only) | symphiz (bnd only) | antisym (bnd only) | antisymrphi (bnd only) | antisymphiz (bnd only) | velocity (freq only) | acceleration (freq only)	free	equ, bnd	Type of constraint condition
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcond	distr_force | follower_press	distr_force	bnd	Type of load
P	expression	0	bnd	Follower pressure, only used for loadcond=follower_press
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where loads are defined
Fr, Fz	expression	0	all	Body load, edge load, point load, r, z direction
loadtype	area | volume	volume	equ	Body load definition, load/volume or load/area
loadtype	area | length	area	bnd	Edge load definition, load/length or load/area
FrPh, FzPh	expression	0	all	Phase angle in degrees specifying the load's phases
constrtype	standard | general	standard	all	Constraint notation: for standard use Hx, Hy, Rx, Ry; for general use H and R
Hr, Hz	1 | 0	0	all	Constraint flag controlling if x, y direction is constrained: 1 constrained, 0 free, used with standard notation

TABLE 3-4: APPLICATION MODE PARAMETERS FOR AXIAL SYMMETRY, STRESS-STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
Rr, Rz	expression	0	all	Constraint value in x, y direction, used with standard notation
H	cell array of expressions	{0 0;0 0}	all	H matrix used for general notation constraints, $Hu=R$
R	cell array of expressions	{0;0}	all	R vector used for general notation constraints, $Hu=R$

Mindlin Plate

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'w','thx','thy'}	Dependent variable names, global displacements in z direction and rotations about global x,y-axes
appl.sdim	{'x','y','z'}	Independent variable names, space coordinates in global x,y,z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl.mode.class	SmeMindlin	
appl.name		smdrm

SCALAR VARIABLE

See the Axial Symmetry, Stress-Strain application mode specification on page 116.

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.elemdefault`	`drmplate`	`drmplate`	Default element to be used. Mindlin plate element.
`appl.prop.analysis`	`static` | `eig` | `time` | `freq` | `para` | `quasi`	`static`	Analysis to be performed, static, eigenfrequency, timedependent, frequency response parametric, quasi-static transient.
`appl.prop.eigtype`	`lambda` | `freq`	`freq`	Should eigenvalues or eigenfrequencies be used

APPLICATION MODE PARAMETERS

TABLE 3-5: APPLICATION MODE PARAMETERS FOR MINDLIN PLATE

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`matmodel`	`iso` | `ortho` | `aniso`	`iso`	equ	Material model isotropic, orthotropic, anisotropic
`E`	expression	`2.0e11`	equ	Young's modulus for isotropic material
`Sf`	expression	`1.2`	equ	Shear factor
`nu`	expression	`0.33`	equ	Poisson's ratio for isotropic material
`alpha`	expression	`1.2e-5`	equ	Thermal expansion coefficient for isotropic material
`rho`	expression	`7850`	equ	Density
`thickness`	expression	`0.01`	equ	Thickness of the plate
`dampingtype`	`Rayleigh` | `lossfactor` | `nodamping`	`Rayleigh`	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
`alphadM`	expression	`1`	equ	Mass damping parameter
`betadK`	expression	`0.001`	equ	Stiffness damping parameter
`Ex, Ey`	expression	`2.0e11`	equ	Young's modulus for orthotropic material

TABLE 3-5: APPLICATION MODE PARAMETERS FOR MINDLIN PLATE

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
Gxy, Gyz, Gxz	expression	7.52e10	equ	Shear modulus for orthotropic material
nuxy	expression	0.33	equ	Poisson's ratio for orthotropic material
alphax, alphay	expression	1.2e-5	equ	Thermal expansion coefficients for orthotropic material
Sfyz, Sfxz	expression	1.2	equ	Shear factors for orthotropic material
Dp	cell array of expressions	isotropic Dp matrix	equ	In-plane elasticity 3-by-3 matrix for anisotropic material, saved in symmetric format, 6 components
Ds	cell array of expressions	isotropic Ds matrix	equ	Shear elasticity 2-by-2 matrix for anisotropic material, saved in symmetric format, 3 components
alphavector	cell array of expressions	isotropic expansion	equ	Thermal expansion coefficient vector for anisotropic material
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties and initial stress and strain are defined
Tflag	1 | 0	0	equ	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not
dT	expression	0	equ	Temperature difference through plate
ini_load	1 | 0	0	equ	Flag specifying whether initial loads should be included: 1 include loads, 0 do not
ini_strain	1 | 0	0	equ	Flag specifying whether initial strains should be included: 1 include strains, 0 do not
Mxpi, Mypi	expression	0	equ	Initial plate bending moments
Mxypi	expression	0	equ	Initial plate torsional moments
Qxpi, Qypi	expression	0	equ	Initial shear forces
thxyi, thyxi	expression	0	equ	Initial curvature
thyymthxxi	expression	0	equ	Initial warping
gyzi, gxzi	expression	0	equ	Initial average shear strain

TABLE 3-5: APPLICATION MODE PARAMETERS FOR MINDLIN PLATE

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where load are defined
Fz	expression	0	all	Body load, edge load, point load, z direction
Mx, My	expression	0	all	Body moment, edge moment, point moment, x, y direction
loadtype	area | volume	area	equ	Body load definition, load/volume or load/area
loadtype	area | length	length	bnd	Edge load definition, load/length or load/area
FzAmp	expression	1	all	Amplitude factor specifying the load's dependence on the excitation frequency f
FzPh	expression	0	all	Phase angle in degrees specifying the load's phase's dependence on the excitation frequency f
MxAmp, MyAmp	expression	1	all	Amplitude factor specifying the moment's dependence on the excitation frequency f
MxPh, MyPh	expression	0	all	Phase angle in degrees specifying the moment's phase's dependence on the excitation frequency f
constrtype	standard | general	standard	all	Constraint notation: for standard use Hx, Hy, Rx, Ry; for general use H and R
constrlocal type	free | simply | fixed | rotation | general	free	bnd	Local constraint condition on boundaries. Free, simply supported, fixed, rotation constrained, and general description
Hthx, Hthy	1 | 0	0	all	Constraint flag controlling if rotation about x,y-axes is constrained: 1 constrained, 0 free

TABLE 3-5: APPLICATION MODE PARAMETERS FOR MINDLIN PLATE

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
Hz	1 | 0	0	all	Constraint flag controlling if z direction displacement is constrained: 1 constrained, 0 free
Rthx, Rthy	expression	0	all	Constraint value for rotation about x, y-axes
Rz	expression	0	all	Constraint value in z direction
Rzl	expression	0	bnd	Constraint value in z direction used with simply supported in local coordinate system
Rthl	expression	0	bnd	Constraint value for tangential rotation used with rotation in local coordinate system
H	cell array of expressions	{0 0 0;0 0 0}	all	H matrix used for general notation constraints, $Hu=R$
R	cell array of expressions	{0;0;0}	all	R vector used for general notation constraints, $Hu=R$
postcontr	top | bottom | mid | other	top	all	Evaluation height for stress and strain
height	expression	0	bnd	User specified evaluation height for stress and strain, used with other

In-Plane Euler Beam

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'u','v','th'}	Dependent variable names, global displacements in x,y directions and rotation about global z-axis
appl.sdim	{'x','y','z'}	Independent variable names, space coordinates in global x,y,z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl.mode.class	SmeInPlaneEulerBeam	
appl.name		smeulip

SCALAR VARIABLE

See the Axial Symmetry, Stress-Strain application mode specification on page 116.

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.elemdefault	beam2d	beam2d	Default element to be used. In plane Euler beam element
appl.prop.analysis	static | eig | time | freq | para | quasi	static	Analysis to be performed, static, eigenfrequency, timedependent, frequency response parametric, quasi-static transient
appl.prop.eigtype	lambda | freq	freq	Should eigenvalues or eigenfrequencies be used

APPLICATION MODE PARAMETERS

TABLE 3-6: APPLICATION MODE PARAMETERS FOR IN-PLANE EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
E	expression	2.0e11	bnd	Young's modulus for isotropic material
alpha	expression	1.2e-5	bnd	Thermal expansion coefficient
rho	expression	7850	bnd	Density
A	expression	0.01	bnd	Cross section area
Iyy	expression	8.33e-6	bnd	Area moment of inertia
heightz	expression	0.1	bnd	Total section height
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	bnd	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	bnd	Mass damping parameter
betadK	expression	0.001	bnd	Stiffness damping parameter
m	expression	0	pnt	Point mass
Jz	expression	0	pnt	Mass moment of inertia about z-axis
alphadM	expression	0	pnt	Mass damping parameter for point mass and mass moment of inertia

TABLE 3-6: APPLICATION MODE PARAMETERS FOR IN-PLANE EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`Tflag`	1 | 0	0	bnd	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not
`Temp`	expression	0	bnd	Thermal strain temperature
`Tempref`	expression	0	bnd	Thermal strain stress free reference temperature
`dTz`	expression	0	bnd	Temperature difference through beam
`ini_load`	1 | 0	0	bnd	Flag specifying whether initial loads should be included: 1 include loads, 0 do not
`ini_strain`	1 | 0	0	bnd	Flag specifying whether initial strains should be included: 1 include strains, 0 do not
`Ni`	expression	0	bnd	Initial axial force
`Mzi`	expression	0	bnd	Initial bending moment
`eni`	expression	0	bnd	Initial axial strain
`thsi`	expression	0	bnd	Initial curvature
`constrcond`	`free` | `fixed` | `pinned` | `norot` | `displacement` | `sym` (bnd only) | `symyz` (bnd only) | `symxz` (bnd only) | `antisym` (bnd only) | `antisymyz` (bnd only) | `antisymxz` (bnd only) | `velocity` (freq only) | `acceleration` (freq only)	`free`	all	Type of constraint condition
`constrcoord`	`global` | `local` (bnd only) | name of user-defined coordinate system	`global`	all	Coordinate system where constraints are defined
`loadcoord`	`global` | `local` (bnd only) | name of user-defined coordinate system	`global`	all	Coordinate system where load are defined
`Fx`, `Fy`	expression	0	all	Edge load, point load, x, y directions
`Mz`	expression	0	all	Edge moment, point moment, z direction

TABLE 3-6: APPLICATION MODE PARAMETERS FOR IN-PLANE EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
FxAmp, FyAmp	expression	1	all	Amplitude factor specifying the load's dependence on the excitation frequency f
FxPh, FyPh	expression	0	all	Phase angle in degrees specifying the load's phase's dependence on the excitation frequency f
MzAmp	expression	1	all	Amplitude factor specifying the moment's dependence on the excitation frequency f
MzPh	expression	0	all	Phase angle in degrees specifying the moment's phase's dependence on the excitation frequency f
constrtype	standard | general	standard	all	Constraint notation: for standard use Hx, Hy, Hth, Rx, Ry, Rth; for general use H and R
Hth	1 | 0	0	all	Constraint flag controlling if rotation about z-axis is constrained. 1 constrained, 0 free
Hx, Hy	1 | 0	0	all	Constraint flag controlling if x, y direction displacement is constrained: 1 constrained, 0 free
Rth	expression	0	all	Constraint value for rotation about z-axis
Rx, Ry	expression	0	all	Constraint value in x, y directions
H	cell array of expressions	{0 0 0;0 0 0}	all	H matrix used for general notation constraints, $Hu=R$
R	cell array of expressions	{0;0;0}	all	R vector used for general notation constraints, $Hu=R$

3D Euler Beam

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
`appl.dim`	`{'u','v','w','thx','thy','thz'}`	Dependent variable names, global displacements in x,y,z directions and rotations about global x,y,z-axes
`appl.sdim`	`{'x','y','z'}`	Independent variable names, space coordinates in global x,y,z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
`appl.mode.class`	`Sme3DEulerBeam`	
`appl.name`		`smeul3d`

SCALAR VARIABLE

See the Axial Symmetry, Stress-Strain application mode specification on page 116.

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.elemdefault`	`beam3D`	`beam3D`	Default element to be used. Euler 3D beam element.
`appl.prop.analysis`	`static` | `eig` | `time` | `freq` | `para` | `quasi`	`static`	Analysis to be performed, linear static, eigenfrequency, timedependent, frequency response parametric, quasi-static transient.
`appl.prop.eigtype`	`lambda` | `freq`	`freq`	Should eigenvalues or eigenfrequencies be used

APPLICATION MODE PARAMETERS

TABLE 3-7: APPLICATION MODE PARAMETERS FOR 3D EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`E`	expression	`2.0e11`	edg	Young's modulus for isotropic material
`nu`	expression	`0.33`	edg	Poisson's ratio
`alpha`	expression	`1.2e-5`	edg	Thermal expansion coefficient
`rho`	expression	`7850`	edg	Density
`A`	expression	`0.01`	edg	Cross section area
`Iyy`, `Izz`	expression	`8.33e-6`	edg	Area moment of inertia about local y- and z-axes
`heighty`, `heightz`	expression	`0.1`	edg	Total section height in local y and z direction
`localxp`, `localyp`	expression	`1`	edg	x,y-coordinate for point defining local xy-plane
`localzp`	expression	`1`	edg	z-coordinate for point defining local xy-plane
`dampingtype`	`Rayleigh` | `lossfactor` | `nodamping`	`Rayleigh`	edg	Type of damping; lossfactor can only be used for frequency reponse analysis
`alphadM`	expression	`1`	edg	Mass damping parameter
`betadK`	expression	`0.001`	edg	Stiffness damping parameter

TABLE 3-7: APPLICATION MODE PARAMETERS FOR 3D EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
m	expression	0	pnt	Point mass
Jx, Jy, Jz	expression	0	pnt	Mass moment of inertia about x, y, z-axes
alphadM	expression	0	pnt	Mass damping parameter for point mass and mass moment of inertia
masscoord	global | name of user-defined coordinate system	global	pnt	Coordinate system where mass moment of inertias are defined
Tflag	1 | 0	0	edg	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not
Temp	expression	0	edg	Thermal strain temperature
Tempref	expression	0	edg	Thermal strain stress-free reference temperature
dTy, dTz	expression	0	edg	Temperature difference through beam in local y and z direction
ini_load	1 | 0	0	edg	Flag specifying whether initial loads should be included: 1 include loads, 0 do not
ini_strain	1 | 0	0	edg	Flag specifying whether initial strains should be included: 1 include strains, 0 do not
Ni	expression	0	edg	Initial axial force
Mxli	expression	0	edg	Initial torsional moment
Myli, Mzli	expression	0	edg	Initial bending moment
eni	expression	0	edg	Initial axial strain
thxsi	expression	0	edg	Initial torsional angle derivative
thysi, thzsi	expression	0	edg	Initial curvature

TABLE 3-7: APPLICATION MODE PARAMETERS FOR 3D EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
constrcond	free | fixed | pinned | norot | displacement | sym (bnd only) | symxy (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymxy (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	all	Type of constraint condition.
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where load are defined
Fx, Fy, Fz	expression	0	all	Edge load, point load, x,y,z direction
Mx, My, Mz	expression	0	all	Edge moment, point moment, x,y,z direction
FxAmp, FyAmp, FzAmp	expression	1	all	Amplitude factor specifying the load's dependence on the excitation frequency f
FxPh, FyPh, FzPh	expression	0	all	Phase angle in degrees specifying the load's phase's dependence on the excitation frequency f
MxAmp, MyAmp, MzAmp	expression	1	all	Amplitude factor specifying the moment's dependence on the excitation frequency f
MxPh, MyPh, MzPh	expression	0	all	Phase angle in degrees specifying the moment's phase's dependence on the excitation frequency f
constrtype	standard | general	standard	all	Constraint notation: for standard use Hx, Hy, Hth, Rx, Ry, Rth; for general use H and R
Hthx, Hthy, Hthz	1 | 0	0	all	Constraint flag controlling if rotation about x,y,z-axes is constrained: 1 constrained, 0 free

TABLE 3-7: APPLICATION MODE PARAMETERS FOR 3D EULER BEAM

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
Hx, Hy, Hz	1 | 0	0	all	Constraint flag controlling if x,y,z direction displacement is constrained: 1 constrained, 0 free
Rthx, Rthy, Rthz	expression	0	all	Constraint value for rotation about x, y, z-axes
Rx, Ry, Rz	expression	0	all	Constraint value in x, y directions
H	cell array of expressions	{0 0 0 0 0 0;0 0 0 0 0}	all	H matrix used for general notation constraints, $Hu = R$
R	cell array of expressions	{0;0;0;0;0;0}	all	R vector used for general notation constraints, $Hu = R$

In-Plane Truss

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'u','v'}	Dependent variable names, global displacements in x,y directions
appl.sdim	{'x','y','z'}	Independent variable names, space coordinates in global x,y,z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl.mode.class	SmeTruss2D	
appl.name		smtr2d

SCALAR VARIABLE

See the Axial Symmetry, Stress-Strain application mode specification on page 116.

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.elemdefault	Lag1 | Lag2 | Lag3 | Lag4 | Lag5	Lag1	Default element to be used
appl.prop.analysis	static | eig | time | freq | para | quasi | buckling	static	Analysis to be performed, static, eigenfrequency, time dependent, frequency response parametric, quasi-static transient, or linear buckling analysis; see note below
appl.prop.eigtype	lambda | freq | loadfactor	freq	Should eigenvalues, eigenfrequencies or load factors be used
appl.prop.largedef	on | off	off	Include large deformation, nonlinear geometry effects

APPLICATION MODE PARAMETERS

TABLE 3-8: APPLICATION MODE PARAMETERS FOR IN-PLANE TRUSS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
E	expression	2.0e11	bnd	Young's modulus for isotropic material
alpha	expression	1.2e-5	bnd	Thermal expansion coefficient
rho	expression	7850	bnd	Density
A	expression	0.01	bnd	Cross section area
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	bnd	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	bnd	Mass damping parameter
betadK	expression	0.001	bnd	Stiffness damping parameter
m	expression	0	pnt	Point mass
alphadM	expression	0	pnt	Mass damping parameter for point mass

TABLE 3-8: APPLICATION MODE PARAMETERS FOR IN-PLANE TRUSS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
Tflag	1 | 0	0	bnd	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not
Temp	expression	0	bnd	Thermal strain temperature
Tempref	expression	0	bnd	Thermal strain stress free reference temperature
ini_stress	1 | 0	0	bnd	Flag specifying whether initial stress should be included: 1 include stresses, 0 do not
ini_strain	1 | 0	0	bnd	Flag specifying whether initial strains should be included: 1 include strains, 0 do not
sni	expression	0	bnd	Initial axial stress
eni	expression	0	bnd	Initial axial strain
straight	1 | 0	1	bnd	Flag specifying whether constrains should be added to enforce boundary to be straight: 1 enforce boundary, 0 do not
constrcond	free | pinned | roller (bnd only) | displacement | sym (bnd only) | symxy (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymxy (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	bnd/ edg, pnt	Type of constraint condition
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where load are defined
Fx, Fy, Fz	expression	0	all	Edge load, point load, x, y, z direction
FxAmp, FyAmp, FzAmp	expression	1	all	Amplitude factor specifying the load's dependence on the excitation frequency f

TABLE 3-8: APPLICATION MODE PARAMETERS FOR IN-PLANE TRUSS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
FxPh, FyPh, FzPh	expression	0	all	Phase angle in degrees specifying the load's phase's dependence on the excitation frequency f
constrtype	standard | general	standard	all	Constraint notation: standard use Hx, Hy, Hz Rx, Ry, Rz; general use H and R
Hx, Hy, Hz	1 | 0	0	all	Constraint flag controlling if x, y, z direction displacement is constrained: 1 constrained, 0 free
Rx, Ry, Rz	expression	0	all	Constraint value in x, y, z directions
H	cell array of expressions	{0 0;0 0}	all	H matrix used for general notation constraints, $Hu=R$
R	cell array of expressions	{0;0}	all	R vector used for general notation constraints, $Hu=R$

3D Truss

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'u','v','w'}	Dependent variable names, global displacements in x, y, z directions
appl.sdim	{'x','y','z'}	Independent variable names, space coordinates in global x, y, z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl.mode.class	SmeTruss3D	
appl.name		smtr3d

SCALAR VARIABLE

See the Axial Symmetry, Stress-Strain application mode specification on page 116.

PROPERTIES

Same as In-Plane Truss application mode.

APPLICATION MODE PARAMETERS

Same as for In-Plane Truss application mode but three instead of two space variables, resulting in three load components and three constraints.

Shell

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
`appl.dim`	`{'u','v','w','thx','thy','thz'}`	Dependent variable names, global displacements in x, y, z directions and rotations about global x, y, z-axes
`appl.sdim`	`{'x','y','z'}`	Independent variable names, space coordinates in global x, y, z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
`appl.mode.class`	`SmeShell`	
`appl.name`		`shell`

SCALAR VARIABLE

See the Axial Symmetry, Stress-Strain application mode specification on page 116.

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.elemdefault	shell	shell	Default element to use. Shell element
appl.prop.analysis	static | eig | time | freq | para | quasi	static	Analysis to perform: static, eigenfrequency, timedependent, frequency response parametric, quasi-static transient
appl.prop.eigtype	lambda | freq	freq	Should eigenvalues or eigenfrequencies be used

APPLICATION MODE PARAMETERS

TABLE 3-9: APPLICATION MODE PARAMETERS FOR SHELLS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
E	expression	2.0e11	bnd	Young's modulus for isotropic material
nu	expression	0.33	bnd	Poisson's ratio
alpha	expression	1.2e-5	bnd	Thermal expansion coefficient for isotropic material
rho	expression	7850	bnd	Density
Sf	expression	1.2	bnd	Shear factor
thickness	expression	0.01	bnd	Thickness of the shell
Tflag	1 | 0	0	bnd	Flag specifying whether thermal expansion should be included: 1 include thermal expansion, 0 do not.
Temp	expression	0	bnd	Thermal strain temperature
Tempref	expression	0	bnd	Thermal strain stress free reference temperature
dT	expression	0	bnd	Temperature difference through shell in local z direction
xlocalx, xlocaly, xlocalz	expression	t1x, t1y, t1z	bnd	x,y,z-components for projection vector defining local x-axis

TABLE 3-9: APPLICATION MODE PARAMETERS FOR SHELLS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
nsidex, nsidey, nsidez	expression	x+nx, y+ny, z+nz	bnd	*x*, *y*, *z*-coordinates for point defining side of shell with positive *z*
dampingtype	Rayleigh | lossfactor | nodamping	Rayleigh	bnd	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	1	bnd	Mass damping parameter
betadK	expression	0.001	bnd	Stiffness damping parameter
constrcond	free | fixed | pinned | norot | displacement | sym (bnd only) | symxy (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymxy (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	bnd, edg	Type of constraint condition.
constrcoord	global | post (bnd only) | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcoord	global | post (bnd only) | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where load are defined
loadtype	area | volume	area	bnd	Body load definition, load/volume or load/area
loadtype	area | length	length	edg	Body load, edge load definition, load/length or load/area
Fx, Fy, Fz	expression	0	all	Body load, edge load, point load, *x*, *y*, *z* directions
Mx, My, Mz	expression	0	all	Body load, edge moment, point moment, *x*, *y*, *z* directions
FxAmp, FyAmp, FzAmp	expression	1	all	Amplitude factor specifying the load's dependence on the excitation frequency *f*

TABLE 3-9: APPLICATION MODE PARAMETERS FOR SHELLS

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
FxPh, FyPh, FzPh	expression	0	all	Phase angle in degrees specifying the load's phase's dependence on the excitation frequency f
MxAmp, MyAmp, MzAmp	expression	1	all	Amplitude factor specifying the moment's dependence on the excitation frequency f
MxPh, MyPh, MzPh	expression	0	all	Phase angle in degrees specifying the moment's phase's dependence on the excitation frequency f
constrtype	standard | general	standard	all	Constraint notation: for standard use Hx, Hy, Hth, Rx, Ry, Rth; for general use H and R
Hthx, Hthy, Hthz	1 | 0	0	all	Constraint flag controlling if rotation about x,y,z-axes is constrained: 1 constrained, 0 free
Hx, Hy, Hz	1 | 0	0	all	Constraint flag controlling if x,y,z direction displacement is constrained: 1 constrained, 0 free
Rthx, Rthy, Rthz	expression	0	all	Constraint value for rotation about x, y, z-axes
Rx, Ry, Rz	expression	0	all	Constraint value in x, y directions
H	cell array of expressions	{0 0 0 0 0 0;0 0 0 0 0 0}	all	H matrix used for general notation constraints, $Hu = R$
R	cell array of expressions	{0;0;0;0;0;0}	all	R vector used for general notation constraints, $Hu = R$
postcontr	top | bottom | mid | other	top	all	Evaluation height for stress and strain
height	expression	0	bnd	User specified evaluation height for stress and strain, used with other

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
`appl.dim`	`{'u','v','w','V'}`	Dependent variable names, global displacements in x, y, z directions and electric potential
`appl.sdim`	`{'x','y','z'}`	Independent variable names, space coordinates in global x, y, z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
`appl{i}.mode.class`	`PiezoSolid3`	
`appl{i}.name`		`smpz3d`

SCALAR VARIABLE

FIELD	DEFAULT	DESCRIPTION
`appl.var.freq`	`1e6`	Excitation frequency for frequency response analysis
`appl.var.epsilon0`	`8.854187817e-12`	Permittivity of vacuum

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.elemdefault`	`Lag1` | `Lag2` | `Lag3` | `Lag4` | `Lag5`	`Lag2`	Default element to use: Lagrange element of order 1–5
`appl.prop.analysis`	`static` | `eig` | `time` | `freq`	`static`	Analysis to perform: linear static, eigenfrequency, timedependent, and frequency response.

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.prop.eigtype	lambda | freq	freq	Should eigenvalues or eigenfrequencies be used
appl.prop.esform	symmetric_es | unsymmetric_es | unsymmetric_ec	unsymmetric_ec	Defines the form of the electrostatic part of the equation

APPLICATION MODE PARAMETERS

TABLE 3-10: APPLICATION MODE PARAMETERS FOR PIEZO SOLID

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
materialmodel	piezoelectric | aniso | iso	piezoelectric	equ	Defines the material model for each subdomain
constform	strain | stress	strain	equ	Form for the constitutive relation, strain-charge, stress-charge, for piezoelectric material
structuralon	1 | 0	1	equ	Defines wheter structural part of the equation is active. For iso and aniso materials.
electricalon	1 | 0	0	equ	Defines wheter electrical part of the equation is active. For iso and aniso materials.
rho	expression	7850	equ	Density
rhov	expression	0	equ	Space charge density
sE	cell array of expressions	Piezo material (PZT-5H)	equ	Compliance matrix 6-by-6 matrix, used for strain-charge form, saved in symmetric format, 21 components
cE	cell array of expressions	Piezo material (PZT-5H)	equ	Elasticity matrix 6-by-6 matrix, used for stress-charge form, saved in symmetric format, 21 components
d	cell array of expressions	Piezo material (PZT-5H)	equ	Piezoelectric coupling matrix for strain-charge form 3-by-6 matrix
e	cell array of expressions	Piezo material (PZT-5H)	equ	Piezoelectric coupling matrix for stress-charge form 3-by-6 matrix
epsilonrT	cell array of expressions	Piezo material (PZT-5H)	equ	Relative electric permittivity matrix 3-by-3 matrix, used for strain-charge form, saved in symmetric format, 6 components

TABLE 3-10: APPLICATION MODE PARAMETERS FOR PIEZO SOLID

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
epsilonrS	cell array of expressions	Piezo material (PZT-5H)	equ	Relative electric permittivity matrix 3-by-3 matrix, used for stress-charge form, saved in symmetric format, 6 components
D	cell array of expressions	Elasticity matrix of PZT-5H	equ	Elasticity 6-by-6 matrix for anisotropic material, saved in symmetric format, 21 components
E	expression	2.0e11	equ	Young's modulus for isotropic material
nu	expression	0.33	equ	Poisson's ratio for isotropic material
epsilonr	expression	1	equ	Relative permittivity for isotropic material
epsilonrtensor	cell array of expressions	Isotropic relative permittivity 1	equ	Relative electric permittivity for anisotropic material, 3-by-3 matrix, saved in symmetric format, 6 components
sigma	expression	5.99e7	equ	Electrical conductivity for isotropic material
sigmatensor	cell array of expressions	Isotropic conductivity 5.99e7	equ	Electrical conductivity for anisotropic material, 3-by-3 matrix, saved in symmetric format, 6 components
dampingtype	Rayleigh | lossfactor | nodamping | equiviscous	nodamping	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	0	equ	Mass damping parameter
betadK	expression	0	equ	Stiffness damping parameter
eta	expression	0	equ	Loss factor can only be used for frequency response damping
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties are defined
rhos	expression	0	bnd	Surface charge density
D0	cell array of expressions	0	bnd	Electric displacement
V0	expression	0	bnd	Electric potential
J0	cell array of expressions	0	bnd	Electric current density
Jn	expression	0	bnd	Inward electric current density

TABLE 3-10: APPLICATION MODE PARAMETERS FOR PIEZO SOLID

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
electrictype	V0 | cont | D | V | r | nD0 | J | nJ | nJ0 | dnJ | fp	V0 or cont	bnd	The type of electric boundary condition. Available conditions depend on the esform property
constrcond	free | fixed | roller (bnd only) | displacement | sym (bnd only) | symxy (bnd only) | symyz (bnd only) | symxz (bnd only) | antisym (bnd only) | antisymxy (bnd only) | antisymyz (bnd only) | antisymxz (bnd only) | velocity (freq only) | acceleration (freq only)	free	equ, bnd	Type of constraint condition
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where loads are defined
Fx, Fy, Fz	expression	0	all	Body load, face load, edge load, point load, x, y, z directions
Hx, Hy, Hz	1 | 0	0	all	Constraint flag controlling if x,y,z direction is constrained: 1 constrained, 0 free
Rx, Ry, Rz	expression	0	all	Constraint value in x, y, z direction
HV0	1 | 0	0	edg | pnt	Constraint flag controlling if potential is constrained: 1 constrained, 0 free
V0	expression	0	edg | pnt	Electric potential
Ql	expression	0	edg	Line charge
Q0	expression	0	pnt	Point charge
Q0	expression	0	bnd	Total charge on the floating potential boundary
I0	expression	0	bnd	Total inward current through the floating potential boundary
index	expression	0	bnd	Grouping index for floating potential

Piezo Plane Stress and Piezo Plane Strain

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
`appl.dim`	`{'u','v','V'}`	Dependent variable names, global displacements in x, y directions and electric potential
`appl.sdim`	`{'x','y','z'}`	Independent variable names, space coordinates in global x, y, z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
`appl{i}.mode.class`	`PiezoPlaneStress` `PiezoPlaneStrain`	
`appl{i}.name`		`smpps, smppn`

SCALAR VARIABLE

FIELD	DEFAULT	DESCRIPTION
`appl.var.freq`	`1e6`	Excitation frequency for frequency response analysis
`appl.var.epsilon0`	`8.854187817e-12`	Permittivity of vacuum

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
`appl.elemdefault`	`Lag1` | `Lag2` | `Lag3` | `Lag4` | `Lag5`	`Lag2`	Default element to use: Lagrange element of order 1–5
`appl.prop.analysis`	`static` | `eig` | `time` | `freq`	`static`	Analysis to perform: linear static, eigenfrequency, timedependent, and frequency response.

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.prop.eigtype	lambda | freq	freq	Should eigenvalues or eigenfrequencies be used
appl.prop.esform	symmetric_es | unsymmetric_es | unsymmetric_ec	unsymmetric_ec	Defines the form of the electrostatic part of the equation

APPLICATION MODE PARAMETERS

TABLE 3-11: APPLICATION MODE PARAMETERS FOR PIEZO PLANE STRESS AND PIEZO PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
materialmodel	piezoelectric | aniso | iso	piezoelectric	equ	Defines the material model for each subdomain
constform	strain | stress	strain	equ	Form for the constitutive relation, strain-charge, stress-charge, for piezoelectric material
structuralon	1 | 0	1	equ	Defines wheter structural part of the equation is active. For iso and aniso materials.
electricalon	1 | 0	0	equ	Defines wheter electrical part of the equation is active. For iso and aniso materials.
rho	expression	7850	equ	Density
rhov	expression	0	equ	Space charge density
sE	cell array of expressions	Piezo material (PZT-5H)	equ	Compliance matrix 6-by-6 matrix, used for strain-charge form, saved in symmetric format, 21 components
cE	cell array of expressions	Piezo material (PZT-5H)	equ	Elasticity matrix 6-by-6 matrix, used for stress-charge form, saved in symmetric format, 21 components
d	cell array of expressions	Piezo material (PZT-5H)	equ	Piezoelectric coupling matrix for strain-charge form 3-by-6 matrix
e	cell array of expressions	Piezo material (PZT-5H)	equ	Piezoelectric coupling matrix for stress-charge form 3-by-6 matrix
epsilonrT	cell array of expressions	Piezo material (PZT-5H)	equ	Relative electric permittivity matrix 3-by-3 matrix, used for strain-charge form, saved in symmetric format, 6 components

TABLE 3-11: APPLICATION MODE PARAMETERS FOR PIEZO PLANE STRESS AND PIEZO PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
epsilonrS	cell array of expressions	Piezo material (PZT-5H)	equ	Relative electric permittivity matrix 3-by-3 matrix, used for stress-charge form, saved in symmetric format, 6 components
D	cell array of expressions	Elasticity matrix of PZT-5H	equ	Elasticity 6-by-6 matrix for anisotropic material, saved in symmetric format, 21 components
E	expression	2.0e11	equ	Young's modulus for isotropic material
nu	expression	0.33	equ	Poisson's ratio for isotropic material
epsilonr	expression	1	equ	Relative permittivity for isotropic material
epsilonrtensor	cell array of expressions	Isotropic relative permittivity 1	equ	Relative electric permittivity for anisotropic material, 3-by-3 matrix, saved in symmetric format, 6 components
sigma	expression	5.99e7	equ	Electrical conductivity for isotropic material
sigmatensor	cell array of expressions	Isotropic conductivity 5.99e7	equ	Electrical conductivity for anisotropic material, 3-by-3 matrix, saved in symmetric format, 6 components
dampingtype	Rayleigh | lossfactor | nodamping | equiviscous	nodamping	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	0	equ	Mass damping parameter
betadK	expression	0	equ	Stiffness damping parameter
eta	expression	0	equ	Loss factor can only be used for frequency response damping
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties are defined
materialori	xy|yx|zx|yx|zy| xz	xz	equ	Material orientation. how the 3D material properties is oriented relative the 2D analysis plane
thickness	expression	1	equ	Thickness of the material
rhos	expression	0	bnd	Surface charge density
D0	cell array of expressions	0	bnd	Electric displacement

TABLE 3-11: APPLICATION MODE PARAMETERS FOR PIEZO PLANE STRESS AND PIEZO PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`V0`	expression	0	bnd	Electric potential
`J0`	cell array of expressions	0	bnd	Electric current density
`Jn`	expression	0	bnd	Inward electric current density
`electrictype`	`V0` | `cont` | `D` | `V` | `r` | `nD0` | `J` | `nJ` | `nJ0` | `dnJ` | `fp`	`V0` or `cont`	bnd	The type of electric boundary condition. Available conditions depend on the esform property
`constrcond`	`free` | `fixed` | `roller` (bnd only) | `displacement` | `sym` (bnd only) | `symyz` (bnd only) | `symxz` (bnd only) | `antisym` (bnd only) | `antisymyz` (bnd only) | `antisymxz` (bnd only) | `velocity` (freq only) | `acceleration` (freq only)	`free`	equ, bnd	Type of constraint condition.
`constrcoord`	`global` | `local` (bnd only) | name of user-defined coordinate system	`global`	all	Coordinate system where constraints are defined
`loadcoord`	`global` | `local` (bnd only) | name of user-defined coordinate system	`global`	all	Coordinate system where loads are defined
`Fx, Fy`	expression	0	all	Body load, face load, edge load, point load, x, y directions
`Hx, Hy`	1 | 0	0	all	Constraint flag controlling if x,y direction is constrained: 1 constrained, 0 free
`Rx, Ry`	expression	0	all	Constraint value in x, y direction
`HV0`	1 | 0	0	pnt	Constraint flag controlling if potential is constrained: 1 constrained, 0 free
`V0`	`expression`	0	pnt	Electric potential
`Q0`	expression	0	`pnt`	Point charge
`Q0`	expression	0	bnd	Total charge on the floating potential boundary

TABLE 3-11: APPLICATION MODE PARAMETERS FOR PIEZO PLANE STRESS AND PIEZO PLANE STRAIN

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`I0`	expression	0	bnd	Total inward current through the floating potential boundary
`index`	expression	0	bnd	Grouping index for floating potential

Piezo Axial Symmetry

DEPENDENT AND INDEPENDENT VARIABLES

FIELD	DEFAULT	DESCRIPTION
appl.dim	{'uor','w','V'}	Dependent variable names, global displacements in r, z directions and electric potential. uor is the radial displacement divided by the radius
appl.sdim	{'r','phi','z'}	Independent variable names, space coordinates in global r, φ , z directions

APPLICATION MODE CLASS AND NAME

FIELD	VALUE	DEFAULT
appl{i}.mode.class	PiezoAxialSymmetry	
appl{i}.name		smpaxi

SCALAR VARIABLE

FIELD	DEFAULT	DESCRIPTION
appl.var.freq	1e6	Excitation frequency for frequency response analysis
appl.var.epsilon0	8.854187817e-12	Permittivity of vacuum

PROPERTIES

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.elemdefault	Lag1 | Lag2 | Lag3 | Lag4 | Lag5	Lag2	Default element to use: Lagrange element of order 1–5
appl.prop.analysis	static | eig | time | freq	static	Analysis to performe: linear static, eigenfrequency, timedependent, and frequency response

FIELD	VALUE	DEFAULT	DESCRIPTION
appl.prop.eigtype	lambda | freq	freq	Should eigenvalues or eigenfrequencies be used
appl.prop.esform	symmetric_es | unsymmetric_es | unsymmetric_ec	unsymmetric_ec	Defines the form of the electrostatic part of the equation

APPLICATION MODE PARAMETERS

TABLE 3-12: APPLICATION MODE PARAMETERS FOR PIEZO AXIAL SYMMETRY

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
materialmodel	piezoelectric | aniso | iso	piezoelectric	equ	Defines the material model: piezoelectric, isotropic, anisotropic
constform	strain | stress	strain	equ	Form for the constitutive relation, strain-charge, stress-charge, for piezoelectric material
structuralon	1 | 0	1	equ	Defines wheter structural part of the equation is active. For isotropic and anisotropic materials.
electricalon	1 | 0	0	equ	Defines wheter electrical part of the equation is active. For isotropic and anisotropic materials.
rho	expression	7850	equ	Density
rhov	expression	0	equ	Space charge density
sE	cell array of expressions	Piezo material (PZT-5H)	equ	Compliance matrix 6-by-6 matrix, used for strain-charge form, saved in symmetric format, 21 components
cE	cell array of expressions	Piezo material (PZT-5H)	equ	Elasticity matrix 6-by-6 matrix, used for stress-charge form, saved in symmetric format, 21 components
d	cell array of expressions	Piezo material (PZT-5H)	equ	Piezoelectric coupling matrix for strain-charge form 3-by-6 matrix
e	cell array of expressions	Piezo material (PZT-5H)	equ	Piezoelectric coupling matrix for stress-charge form 3-by-6 matrix
epsilonrT	cell array of expressions	Piezo material (PZT-5H)	equ	Relative electric permittivity matrix 3-by-3 matrix, used for strain-charge form, saved in symmetric format, 6 components

TABLE 3-12: APPLICATION MODE PARAMETERS FOR PIEZO AXIAL SYMMETRY

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
epsilonrS	cell array of expressions	Piezo material (PZT-5H)	equ	Relative electric permittivity matrix 3-by-3 matrix, used for stress-charge form, saved in symmetric format, 6 components
D	cell array of expressions	Elasticity matrix of PZT-5H	equ	Elasticity 6-by-6 matrix for anisotropic material, saved in symmetric format, 21 components
E	expression	2.0e11	equ	Young's modulus for isotropic material
nu	expression	0.33	equ	Poisson's ratio for isotropic material
epsilonr	expression	1	equ	Relative permittivity for isotropic material
epsilonrtensor	cell array of expressions	Isotropic relative permittivity 1	equ	Relative electric permittivity for anisotropic material, 3-by-3 matrix, saved in symmetric format, 6 components
sigma	expression	5.99e7	equ	Electrical conductivity for isotropic material
sigmatensor	cell array of expressions	Isotropic conductivity 5.99e7	equ	Electrical conductivity for anisotropic material, 3-by-3 matrix, saved in symmetric format, 6 components
dampingtype	Rayleigh | lossfactor | nodamping | equiviscous	nodamping	equ	Type of damping; lossfactor can only be used for frequency reponse analysis
alphadM	expression	0	equ	Mass damping parameter
betadK	expression	0	equ	Stiffness damping parameter
eta	expression	0	equ	Loss factor can only be used for frequency response damping
matcoord	global | name of user-defined coordinate system	global	equ	Coordinate system where the material properties are defined
materialori	xy | yx | zx | yx | zy | xz	xz	equ	Material orientation. how the 3D material properties is oriented relative the 2D analysis plane
rhos	expression	0	bnd	Surface charge density
D0	cell array of expressions	0	bnd	Electric displacement
V0	expression	0	bnd	Electric potential

TABLE 3-12: APPLICATION MODE PARAMETERS FOR PIEZO AXIAL SYMMETRY

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
J0	cell array of expressions	0	bnd	Electric current density
Jn	expression	0	bnd	Inward electric current density
electrictype	V0 | cont | D | V | r | nD0 | J | nJ | nJ0 | dnJ | fp	V0 or cont	bnd	The type of electric boundary condition. Available conditions depend on the esform property
constrcond	free | fixed | roller (bnd only) | displacement | sym (bnd only) | symrphi (bnd only) | symphiz (bnd only) | antisym (bnd only) | antisymrphi (bnd only) | antisymphiz (bnd only) | velocity (freq only) | acceleration (freq only)	free	equ, bnd	Type of constraint condition.
constrcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where constraints are defined
loadcoord	global | local (bnd only) | name of user-defined coordinate system	global	all	Coordinate system where loads are defined
Fr, Fz	expression	0	all	Body load, face load, edge load, point load, *r*, *z* directions
Hr, Hz	1 | 0	0	all	Constraint flag controlling if *r*, *z* direction is constrained: 1 constrained, 0 free
Rr, Rz	expression	0	all	Constraint value in *r*, *z* direction
HV0	1 | 0	0	pnt	Constraint flag controlling if potential is constrained: 1 constrained, 0 free
V0	expression	0	pnt	Electric potential
Q0	expression	0	pnt	Point charge
Q0	expression	0	bnd	Total charge on the floating potential boundary

TABLE 3-12: APPLICATION MODE PARAMETERS FOR PIEZO AXIAL SYMMETRY

FIELD	VALUE	DEFAULT	DOMAIN	DESCRIPTION
`I0`	expression	0	bnd	Total inward current through the floating potential boundary
`index`	expression	0	bnd	Grouping index for floating potential

4

Function Reference

Summary of Commands

Commands Grouped by Function

Shape Function Classes

FUNCTION	PURPOSE
`shbar`	Bar element shape function object. Can be used to model bars in 1D, 2D, and 3D.
`shdrm`	Mindlin plate shape function object. Used to model Mindlin plates in 2D.
`sheulb3d`	3D Euler beam shape function object. Used to model 3D Euler beams.
`sheulbps`	2D in plane Euler beam shape function object. Used to model 2D Euler beams.

Purpose

Create an nD bar shape function object.

Syntax

```
obj = shbar(dispnames)
obj = shbar(dispvarnames,dispdofnames)
obj = shbar(dispvarnames,dispdofnames,tangdername)
obj = shbar(...)
```

Description

`obj = shbar(dispnames)` The bar shape function object is used to implement nD bar elements. The cell array `dispnames` contains variable names for the displacements and the displacements degrees of freedom.

`obj = shbar(dispvarnames,dispdofnames)` The cell arrays `dispvarnames` and dispdofnames contain the displacement variable names and the displacement degrees of freedom names, respectively.

`obj = shbar(dispvarnames,dispdofnames,tangdername)` The variable `tangdofnames` additionally contains the variable name of the tangential derivative of the axial displacement.

`obj = shbar(...)` Alternate syntax based on property/values. The following property values are allowed:

TABLE 4-1: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`dispnames`	cell array of string of length sdim		Default for displacement variable names and degree of freedom variable names
`dispvarnames`	cell array of string of length sdim	`dispnames`	Displacement variable names
`dispdofnames`	cell array of string of length sdim	`dispnames`	Degree of freedom variable names
`tangdername`	string	See below	Tangential derivative of the axial displacement

The property names cannot be abbreviated and must be written in lower case.

Node points: The end points of the bar element.

Degrees of freedom names: The variables in `dispdofnames`.

The option to manually define different degrees of freedom names and variables makes it possible to couple a bar to a solid using the degrees of freedom without having the same variables.

Degrees of freedom: The global displacements at both endpoints of the bar element.

Variables:

- The variables names in the cell array dispvarnames, signifying the displacements.
- [dispvarnames{:} 'ts'] defined on edges, meaning the tangential derivative of the axial displacement. the variable name can also be explicitly given using the property `tangdername`.

The global space coordinates are expressed as linear (affine) functions in the local coordinates.

Compatibility

The FEMLAB 2.3 syntax is obsolete but still supported:

```
obj = shbar3d(uname, vname, wname)
obj = shbar3d(uname, vname, wname, udof, vdof, wdof)
```

Purpose

Create a discrete Reissner-Mindlin triangular plate bending shape function object

Syntax

```
obj = shdrm(dispname,rxname,ryname)
obj = shdrm(dispname,rxname,ryname,applname)
obj = shdrm(...)
```

Description

`obj = shdrm(dispname,rxname,ryname,applname)` The DRM shape function object is used to implement discrete Reissner-Mindlin plate elements. The variable `dispname` denotes the displacement perpendicular to the plate (global z direction). The variables `rxname` and `ryname` denote the rotations around the global x and y-axis.

`obj = shdrm(...)` Alternate syntax based on property/values. The following property values are allowed:

TABLE 4-2: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`dispname`	string		Displacement
`rotnames`	cell array of two strings		Variable names of rotations
`shearnames`	cell array of two strings	`{gxz gyz}`	Shear strain components variable names
`tangrotname`	string	`thn`	Degree of freedom name
`rot`	`axis` | `gradient`	axis	Rotation style

The property names cannot be abbreviated and must be written in lower case.

In the following when the symbols are not provided as property names, let `extraname = ['_' applname]` if `applname` is given, otherwise `''`, **`rotnames = {rxname, ryname}`**, `shearnames = ['g' indepname 'z' extraname]`, and `tangrotname = ['thn' extraname]`.

Depending on the settings of `rot`, rotations can be with respect to the coordinate axes (default) or be like gradient components.

The DRM element is a triangular element of order 1 in displacements, partly of order 2 in rotations (rotations around element 1D edges vary linearly), and partly of order 1 in shears (shear components along element 1D edges are constant).

Node points: Node points are second order Lagrange points. The element shape is computed from the corner points only.

Degrees of freedom names:

`dispname` meaning the displacement perpendicular to the plane of the element. And the variables in `rotnames` are the rotations.

`tangrotname` at each 1D edge midpoint, meaning rotation around axis perpendicular to side (with a direction convention).

Degrees of freedom:

The displacement perpendicular to the plane at each corner point. Rotation in each corner point. Rotation normal to the edge at each 1D edge midpoint.

Variables:

- `dispname` meaning the displacement perpendicular to the plane of the element (global z direction).
- The elements of rotnames are the rotations.
- `[rname indepname]`, where rname is a rotation, meaning the first space derivative of rotations defined for `edim==2`.
- `shearnames` meaning shear strain components, defined for `edim==2`.

Purpose

Create an Euler 3D beam shape function object.

Syntax

```
obj = sheulb3d(uname, vname, wname, thxname, thyname, thzname,
  point)
obj = sheulb3d(uname, vname, wname, thxname, thyname, thzname,
  point, udof, vdof, wdof, thxdof, thydof, thzdof)
obj = sheulb3d(uname, vname, wname, thxname, thyname, thzname)
obj = sheulb3d(uname, vname, wname, thxname, thyname, thzname,
  udof, vdof, wdof, thxdof, thydof, thzdof)
obj = sheulb3d(...)
```

Description

The Euler 3D beam shape function object is used to implement Euler beam elements in 3D. The beams local coordinate system is defined by the direction of the edge=local *x*-axis and the coordinates of a point defining the local *xy*-plane.

`obj = sheulb3d(uname, vname, wname, thxname, thyname, thzname, point)` or `obj = sheulb3d(uname, vname, wname, thxname, thyname, thzname, point, udof, vdof, wdof, thxdof, thydof, thzdof)` The variables `uname`, `vname`, and `wname` denote the components of the displacement of the beam in the global coordinate system. The variables `thxname`, `thyname`, and `thzname` denote the rotation angles around the global coordinate axes. `point` is a vector with global coordinates for the point that defines the local *xy*-plane. `point` can be omitted and then defaults to `[1,1,0]`. The normal components of the displacements in the local *xy*- and *xz*-plane are assumed to vary as Hermitian cubic polynomials of the arclength along the beam. The displacement in the local *x* direction (edge direction) and rotation about the local *x*-axis are assumed to vary linearly along the beam.

`obj = sheulb3d(...)` Alternate syntax based on property/values. The following property values are allowed:

TABLE 4-3: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`dispnames`	cell array of three strings		Displacement variable names and degrees of freedom names default
`dispvarnames`	cell array of three strings	`dispnames`	Displacement variable names
`dispdofnames`	cell array of three strings	`dispnames`	Displacement degrees of freedom names
`localdispvarnames`	cell array of three strings	`[dispvarnames[i] + 'l']`, i=1-3	Displacement degrees of freedom names

TABLE 4-3: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`rotnames`	cell array of three strings		Rotation variable name and degrees of freedom names default
`rotvarnames`	cell array of three strings	`rotnames`	Rotation variable names
`rotdofnames`	cell array of three strings	`rotnames`	Rotation degrees of freedom names
`localrotvarnames`	cell array of three strings	`[rotvarnames(i) + 'l']`, i=1-3	Local rotation variable name
`tangdisptangdername`	string	`[dispvarnames(1)+dispvarnames(2)+dispvarnames(3)+'ts']`	Name of tangential derivative of the axial displacement
`tangrottangdername`	string	`[rotvarnames(1) + 's']`	Name of tangential derivative of rotations
`normrottangdernames`	cell array of two strings	`[rotvarnames(i) + 's']`, i=2-3	Name of tangential derivative of the rotation around the local *y*- and *z*-axis
`normrottangder2names`	cell array of two strings	`[rotvarnames(i) + 'ss']`, i=2-3	Name of second tangential derivative of the rotation around the local *y*- and *z*-axis
`point`	cell array of three strings	{1 1 0}	

The property names cannot be abbreviated and must be written in lower case.

The arguments `uname`, `vname`, and wname are equivalent with the property `dispnames` if there are seven inputs, and `dispvarnames` if there are thirteen inputs. The arguments `thxname`, `thyname`, and `thzname` is equivalent with the property `rotnames` if there are seven inputs, and **`rotvarnames`** if there are thirteen input. If there are thirteen inputs, `udof`, `vdof`, `wdof` are equivalent with the property `vardofnames` and `thxdof`, `thydof`, and `thzdof` is equivalent with the property `rotdofnames`.

Node points: The end points of the beam element.

Degrees of freedom names:

The strings `uname`, `vname`, `wname`, `thxname`, `thyname`, and `thzname` if six or seven inputs or as provided with the properties `dispvarnames` and `rotvarnames`.

The strings `udof`, `vdof`, `wdof`, `thxdof`, `thydof`, and `thzdof` if twelve or thirteen inputs or as provided with the properties `dispdofnames` and `rotdofnames`.

The option to manually define different degrees of freedom names and variables makes it possible to couple a beam to a solid using the degrees of freedom without having the same variables.

Degrees of freedom:

The global displacements and rotations at each endpoint of the beam element.

Variables:

- `uname` defined on edges and points, meaning the x component of the global displacement.
- `vname` defined on edges and points, meaning the y component of the global displacement.
- `wname` defined on edges and points, meaning the z component of the global displacement.
- `thxname` defined on edges and points, meaning the rotation around the global x-axis.
- `thyname` defined on edges and points, meaning the rotation around the global y-axis.
- `thzname` defined on edges and points`,` meaning the rotation around the global z-axis.
- `[uname 'l']` defined on edges, meaning the x component of the local displacement.
- `[vname 'l']` defined on edges, meaning the y component of the local displacement.
- `[wname 'l']` defined on edges, meaning the z component of the local displacement.
- `[thxname 'l']` defined on edges, meaning the rotation around the local x-axis.
- `[thyname 'l']` defined on edges, meaning the rotation around the local y-axis.
- `[thzname 'l']` defined on edges, meaning the rotation around the local z-axis.
- `[uname vname wname 'ts']` or the property `tangdisptangdername` defined on edges, meaning the tangential derivative of the axial displacement.

- `[thxname 's']` or the property `tangrottangdername` defined on edges, meaning the tangential derivative of the rotation around the local x-axis.
- `[thyname 's']` or the first element of the property `rottangdername` defined on edges, meaning the tangential derivative of the rotation around the local y-axis.
- `[thzname 's']` or the second element of the property `rottangdername` defined on edges, meaning the tangential derivative of the rotation around the local z-axis.
- `[thyname 'ss']` or the first element of the property `normrottangder2names` defined on edges, meaning the second tangential derivative of the rotation around the local y-axis.
- `[thzname 'ss']` or the second element of the property `normrottangder2names` defined on edges, meaning the second tangential derivative of the rotation around the local z-axis.

The global space coordinates are expressed as linear (affine) functions in the local coordinates.

Compatibility

The FEMLAB 2.3 default mechanism for handling the local coordinate system if the point vector for node 1 is close to parallel with the edge has been removed, instead an error is reported.

Purpose

Create a beam shape function object.

Syntax

```
obj = sheulbps(uname, vname, rotname)
obj = sheulbps(uname, vname, rotname, udof, vdof, rotdof)
obj = sheulbps(...)
```

Description

`obj = sheulbps(uname, vname, rotname)` or `obj = sheulbps(uname, vname, rotname, udof, vdof, rotdof)` The beam shape function object is used to implement in-plane Euler beam elements in 2D. The variables `uname` and `vname` denote the components of the displacement of the beam in the plane. The variable `rotname` denotes the rotation angle of the beam. The normal components of the displacements are assumed to vary as Hermitian cubic polynomials in the arclength along the beam. The displacement in the local *x* direction (edge direction) is assumed to vary linearly along the beam.

`obj = sheulbps(...)` Alternate syntax based on property/values. The following property values are allowed:

TABLE 4-4: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`dispnames`	cell array of two strings		Displacement variable names and degrees of freedom names default
`dispvarnames`	cell array of two strings	`dispnames`	Displacement variable names
`dispdofnames`	cell array of two strings	`dispnames`	Displacement degrees of freedom names
`rotname`	string		Rotation variable name and degrees of freedom name default
`rotvarname`	string	`rotname`	Rotation variable name
`rotdofname`	string	`rotname`	Rotation degrees of freedom name
`disptangdername`	string	`[dispvarnames(1)+dispvarnames(2)+'ts']`	Name of tangential derivative of displacement
`rottangdername`	string	`[rotvarname+'s']`	Name of tangential derivative of rotation
`rottangder2name`	string	`[rotvarname+'ss']`	Name of tangential second derivative of rotation

The property names cannot be abbreviated and must be written in lower case.

The arguments `uname` and `vname` are equivalent with the property `dispnames` if there are three inputs, and `dispvarnames` if there are six inputs. The argument `rotname` is equivalent with the property `rotname` if there are three inputs, and rotvarnames if there are six input. If there are six inputs, `udof`, `vdof` are equivalent to the property `vardofnames` and `rotdof` is equivalent to the property `rotdofnames`.

Node points: The end points of the beam.

Degrees of freedom names:

The strings `uname`, `vname`, and `rotname` at each endpoint if 3 input arguments.

The strings udof, `vdof`, and `rotdof` at each endpoint if 6 input arguments.

The option to manually define different degrees of freedom names and variables makes it possible to couple a beam to a membrane using the degrees of freedom without having the same variables.

Degrees of freedom:

The global displacement in x and y direction and the rotation angle about the global z-axis.

Variables:

- `uname` defined on boundaries and points, meaning the x component of the displacement.
- `vname` defined on boundaries and points, meaning the y component of the displacement.
- `rotname` defined on boundaries and points, meaning the rotation angle of the beam.
- `[uname vname 'ts']` or the property `disptangdername` defined on boundaries, meaning the tangential derivative of the axial displacement.
- `[rotname 's']` or the property `rottangdername` defined on boundaries, meaning the tangential derivative of the rotation.
- `[rotname 'ss']` or the property `rottangder2name` defined on boundaries, meaning the second tangential derivative of the rotation.

The global space coordinates are expressed as linear (affine) functions in the local coordinates.

5

Fatigue Function Reference

This chapter describes the fatigue analysis functions included in the Structural Mechanics Module.

Summary of Commands

Commands Grouped by Function

Fatigue Analysis Main Functions

FUNCTION	PURPOSE
`fatiguedamage`	High cycle fatigue analysis with proportional loading and non-constant loading using Palmgren-Miner accumulated damage rule together with rainflow count.
`hcfmultiax`	High cycle fatigue analysis with non-proportional loading using critical plane method.
`lcfmultiaxlin`	Low cycle fatigue analysis with non-proportional loading based on a linear elastic analysis.
`lcfmultiaxpla`	Low cycle fatigue analysis with non-proportional loading based on a full elasto-plastic analysis.

Utility Functions

FUNCTION	PURPOSE
`circumcircle`	Calculates the minimal enclosing circles of 2D point sets. Used to find maximum shear stress in Findleys method used in `hcfmultiax`.
`rainflow`	Performs a rainflow count on a load data resulting in a count matrix. Used to get input data to Palmgren-Miner accumulated damage rule used in `fatiguedamage`.
`sn2cycles`	Compute number of cycles to fatigue, given one or two SN-curves where the stress amplitude is given as a function of number of cycles.
`swt2cycles`	Compute number of cycles to fatigue given SWT parameter values and SWT model parameters.
`elastic2plastic`	Compute principal stress and strain from a linear-elastic analysis using a Ramberg-Osgood elasto-plastic material law model.
`matlibfatigue`	Extracts fatigue data from Material Library and creates an S-N function.

Purpose Calculates the minimal enclosing circles of 2D point sets.

Syntax

```
[x y r] = circumcircle(coord)
```

Description `[x y r] = circumcircle(coord)` returns n-vectors of x-coordinates, y-coordinates, and radii given the coordinate matrix `coord` with dimensions 2-by-`n`-by-`m`. Each of the `n` cases consists of `m` points; `coord(1, :, :)` and `coord(2, :, :)` contain x- and y-coordinates respectively.

Examples

```
coord = rand(2, 1, 10);
[x y r] = circumcircle(coord);
clf
plot(coord(1, :), coord(2, :), '*')
hold on
v = 2*pi*0.01*(0:100);
plot(x+r*cos(v), y+r*sin(v))
axis equal
```

See Also `hcfmultiax`

Purpose

Compute principal stress and strain from a linear-elastic analysis using a Ramberg-Osgood elasto-plastic material law model.

Syntax

```
[spric1, epric1] = elastic2plastic(spric, 'params', para)
```

Description

```
[spric1, epric1] = elastic2plastic(spric, 'params', para)
```

Calculates the major principal strain `epric1` and corresponding principal stress `spric1` from principal stresses `spric` from a linear-elastic analysis. Input are the principal stresses `spric` and the Ramberg-Osgood material law parameters given in the struct para. `spric1` and `epric1` are vectors of size `nloc`, where `nloc` are the number of locations where we like to compute the strains and stresses. `spric` are the principal stress with size 3 x `nloc` ordered s1, s2, s3. The principal stresses from the linear-elastic analysis are transformed to plastic stresses and strains using an approximative method assuming a Ramberg-Osgood material law and was developed by Hoffman-Seeger.

`elastic2plastic` accepts the following property/value pairs:

TABLE 5-1: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`elplmethod`	string	`'hoffman_seeger'`	What method should be used to calculate the plastic strains from linear elastic stresses.
`params`	struct containing the Ramberg-Osgood parameters, E, K, nu, and n stored as double in para.E, para.K, para.nu, and para.n.		Ramberg-Osgood material law parameters

Examples

Used in `lcfmultiaxlin`.

See Also

`lcfmultiaxlin`

Purpose

Compute fatigue usage factor for proportional loading with non-constant amplitude using Palmgren-Miner accumulation.

Syntax

```
damtot = fatiguedamage('amprange', amprange, ...)
[damtot, damdistr] = fatiguedamage('amprange', amprange, ...)
```

Description

```
damtot = fatiguedamage('amprange', amprange, 'meanrange',...
  meanrange, 'count', count, 'fatiguelim', fatiguelim,...
  'sncurve', {'SN_func'})
```

Calculates the total accumulated damage `damtot` from the loading history specified in `count`, `amprange`, and `meanrange`, and the material fatigue data specified through `fatiguelim` and the S-N function `'SN_func'`.

```
[damtot, damdistr] = fatiguedamage('amprange', amprange,...
  'meanrange', meanrange, 'count', count, 'fatiguelim',...
  fatiguelim, 'sncurve', {'sn_func'})
```

Calculates also the damage distribution matrix `damdistr` of the same size as the `count` matrix.

The minimum compulsory input to `fatiguedamage` are the following property/value pairs

TABLE 5-2: MINIMUM COMPULSORY PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DESCRIPTION
`amprange`	double array [minstress maxstress]	The range of the stress amplitude.
`meanrange`	double array [minstress maxstress]	The range of the mean stress.
`count`	double array `namp` x `nmean`	Array with stress values counted in bins of equal size `namp` x `nmean` with the stress ranges specified through `amprange` and `meanrange`

TABLE 5-2: MINIMUM COMPULSORY PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DESCRIPTION
`fatiguelim`	double array of the same size as the number of S-N curves.	Fatigue limit (below which no number of damage occurs) for the corresponding S-N curve
`sncurve`	cell array of strings	Names of functions giving stress amplitude as function of cycles to cracking for a specific R-value

The property names cannot be abbreviated.

In addition to the compulsory property pairs given above `fatiguedamage` accepts the following optional property/value pairs:

TABLE 5-3: OPTIONAL PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`nrepeat`	double	1	Number of occurances of the `count` matrix during total life.
`rvalue`	double array of the same size as the number of sn-curves	[-1]	R-values for the different sn-curves. $R = \frac{\mathrm{mean} - \mathrm{ampl}}{\mathrm{mean} + \mathrm{ampl}}$ R=-1 corresponds to alternating loading R=0 corresponds to pulse loading
`method`	`'none'` | `'goodman'` | `'gerber'`	`'none'`	Name of mean correction method only used if a single sn-curve is given
`params`	struct containing method parameters. For `goodman` and `gerber` `para.ultstress`		Method specific parameters. Ultimate stress for the `goodman` and `gerber` method

The property names cannot be abbreviated.

Examples

See script `frame_with_cutout_fatigue.m` for model `frame_with_cutout` in the Fatigue Lab model library.

See Also

`hcfmultiax`, `rainflow`, `lcfmultiaxpla`, `lcfmultiaxlin`, `sn2cyles`

Purpose

Compute fatigue usage factor for high cycle multi axial fatigue with non-proportional loading.

Syntax

```
fus = hcfmultiax(sigma, 'params', para)
[fus, sigmamax, deltatau] = hcfmultiax(sigma, 'params', para)
[fus, sigmamax, deltatau, maxind, stresshis] = hcfmultiax(sigma,...
  'params', para)
```

Description

`fus = hcfmultiax(sigma, 'params', para)` calculates the fatigue usage factor `fus` for the critical plane from the stress tensor `sigma` and the fatigue model parameters given in the structure `para`. `fus` is a vector of size `nloc`, where `nloc` is the number of locations for the computation of the fatigue usage factor. `sigma` is the stress tensor with size `6 x nloc x nblc`, ordered xx, yy, zz, xy, yz, xz, where `nblc` is the number of basic load cases.

`[fus, sigmamax, deltatau] = hcfmultiax(sigma, 'params', para)` also calculates the maximum normal stress `sigmamax` and the shear stress amplitude `deltatau` on the critical plane.

`[fus, sigmamax, deltatau, maxind, stresshis] = hcfmultiax(sigma, 'params', para)` also calculates the index `maxind` to the location with the highest fatigue usage factor together with the stress history `stresshis` at this location.

`hcfmultiax` accepts the following property/value pairs:

TABLE 5-4: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`method`	string `'findley'`	`'findley'`	Method to be used for fatigue usage factor calculation.
`params`	struct with fields containing method parameters, for `findley` and `normal_stress` (see table below)		Method specific parameters
`lccomb`	matrix of size `nlcc` x `nblc` where `nlcc` is the number of load case combinations	`{eye(nblc, nblc)}`	Matrix containing the load case combinations of the basic load cases, used to obtain stresses from the basic load cases for the fatigue calculations. `lccomb(i,j)` = weight factor for basic load case `j` in load case combination `i`.

TABLE 5-4: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`anglestep`	double	`{10}`	Step size in degrees used in search for critical planes
`opt`	`{'quick'} | 'full'`	`'quick'`	Method used in calculating the shear stress range.

The property names cannot be abbreviated.

TABLE 5-5: FIELDS IN THE STRUCT FOR THE PROPERTY PARAMS

FIELD	VALUE	EQUATION NAME	DESCRIPTION
`f`	double	f	Material parameter for the Findley fatigue criteria
`k`	double	k	Material parameter for the Findley fatigue criteria
`fatlim`	double		Fatigue stress limit used in the normal stress fatigue criteria
`ultstress`	double		Ultimate stress used in the normal stress fatigue criteria
`yield`	double		Yield stress used in the normal stress fatigue criteria

Examples

See script `shaft_with_fillet.m` for the model `shaft_with_fillet` in the *Structural Mechanics Module Model Library*.

See Also

`fatiguedamage`, `circumcircle`, `sn2cycles`, `rainflow`, `lcfmultiaxpla`, `lcfmultiaxlin`

Purpose

Compute number of cycles to fatigue for low cycle multiaxial fatigue with non-proportional loading based on a linear elastic analysis.

Syntax

```
ncycle = lcfmultiaxlin(spric, 'params', para)
```

Description

```
ncycle = lcfmultiaxlin(spric, 'params', para)
```

Calculates the number of cycles (`ncycle`) to fatigue. Input are the principal stresses `spric` from a linear elastic analysis and the Ramberg-Osgood and fatigue model parameters given in the struct `para`. `ncycle` is a vector of size `nloc`, where `nloc` are the number of locations where we like to compute the number of cycles to fatigue. `spric` are the principal stress with size 3 x `nloc`, ordered s1, s2, s3. The principal stresses from the linear-elastic analysis are transformed to plastic stresses and strains using an approximative method assuming a Ramberg-Osgood material law and was developed by Hoffman-Seeger.

`lcfmultiaxlin` accepts the following property/value pairs:

TABLE 5-6: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`method`	string	`'swt'`	What method should be used to calculate the number of cycles to fatigue.
`elplmethod`	string	`'hoffman_seeger'`	What method should be used to calculate the plastic strains from linear elastic stresses.
`params`	struct with fields containing method parameters, for `swt` and Ramberg-Osgood material law parameters (see table below)		Method specific parameters

The property names cannot be abbreviated.

TABLE 5-7: FIELDS IN THE STRUCT FOR THE PROPERTY PARAMS

FIELD	VALUE	EQUATION NAME	DESCRIPTION
`epsf`	double	ε_f'	Fatigue ductility coefficient
`c`	double	c	Fatigue ductility exponent
`sigmaf`	double	σ_f'	Fatigue strength coefficient
`b`	double	b	Fatigue strength exponent
`E`	double	E	Young's modulus
`K`	double	K	Ramberg-Osgood material law parameter
`n`	double	n	Ramberg-Osgood material law parameter

Examples

See script `cylinder_hole_linear_fatigue.m` for the model `cylinder_hole` in the Fatigue Lab model library.

See Also

`hcfmultiax`, `fatiguedamage`, `swt2cycles`, `lcfmultiaxpla`

Purpose

Compute number of cycles to fatigue for low cycle multiaxial fatigue with non-proportional loading from an elasto-plastic analysis.

Syntax

```
ncycle = lcfmultiaxpla(stress, strain, 'params', para)
[ncycle, sigmamax, maxdeltaeps, swt] = lcfmultiaxpla(stress,...
  strain, 'params', para)
```

Description

```
ncycle = lcfmultiaxpla(stress, strain, 'params', para)
```

Calculates the number of cycles (`ncycle`) to fatigue for the critical plane. Input are the stress tensor `stress` and the strain tensor `strain` from an elasto-plastic analysis and the fatigue model parameters given in the struct `para`. `ncycle` is a vector of size `nloc`, where `nloc` is the number of locations where you want to compute the number of cycles to fatigue. `stress` and `strain` are the stress and strain tensors with size 6-by-`nloc`-by-`np`, ordered *xx*, *yy*, *zz*, xy, *yz*, *xz*, where `np` is the number of saved load steps in the elasto-plastic analysis.

```
[ncycle, sigmamax, maxdeltaeps, swt] = lcfmultiaxpla(stress,...
  strain, 'params', para)
```

Calculates also the maximum normal stress `sigmamax`, the maximum strain amplitude or strain amplitude maximizing the stress times strain product `maxdeltaeps` depending of the selected critical plane method, and the SWT (Smith-Watson-Topper) parameter.

`lcfmultiaxpla` accepts the following property/value pairs:

TABLE 5-8: VALID PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`method`	string	`'swt'`	What method should be used to calculate the number of cycles to fatigue.
`critplane`	`'strain'` | `'damage'`	`'strain'`	Option determining what method to use when calculating the critical plane to determine the damage parameter, `strain` meaning plane of maximum strain range and `damage` meaning plane with maximum damage parameter
`params`	struct with fields containing method parameters, for `swt` (see table below)		Method specific parameters
`anglestep`	double	`{10}`	Step size in search for critical planes, degrees

The property names cannot be abbreviated.

TABLE 5-9: FIELDS IN THE STRUCT FOR THE PROPERTY PARAMS

FIELD	VALUE	EQUATION NAME	DESCRIPTION
`epsf`	double	ε_f'	Fatigue ductility coefficient
`c`	double	c	Fatigue ductility exponent
`sigmaf`	double	σ_f'	Fatigue strength coefficient
`b`	double	b	Fatigue strength exponent
`E`	double	E	Youngs modulus

Examples

See script `cylinder_hole_plastic_fatigue.m` for the model `cylinder_hole` in the Fatigue Lab model library.

See Also `hcfmultiax`, `fatiguedamage`, `swt2cycles`, `lcfmultiaxlin`

matlibfatigue

Purpose

Extracts fatigue data from the Material Library and returns it in form of an S-N function to be used in `fatiguedamage` for instance.

Syntax

```
found = matlibfatigue('material', matname,'phase', phase, 'ori',
  ori, 'funcname', funcname, 'rvalue', r)
```

Description

```
  matlibfatigue('material', matname, 'phase', phase...
    'ori', ori, 'function', funcname, 'rvalue', r)
```

Locates S-N curves in Material Library for the material `matname` with the phase `phase` and orientation `ori`. Returns true if an S-N curve was found and false if it couldn't be found. The function itself is written to the file `funcname`. The S-N curve is transformed (In Material Library the S-N curves are stored as maximum stress as a function of number of cycles to fatigue.) to return stress amplitude as a function of number of cycles to fatigue. To do this an R value need to specified. The S-N values outside the definition interval are extrapolated to have the same value as the value at the end of the interval.

Note: You need COMSOL Multiphysics Material Library in order to extract fatigue data using this function. Smoothing is not supported through the script interface.

The name of the material, the phase/condition, and the orientation/condition need to be specified exactly as they are spelled out in the COMSOL Multiphysics Material Library. The easiest way to find the names is to use COMSOL Multiphysics and open the **Materials/Coefficients Library** dialog box from the options menu.

The minimum compulsory input to `matlibfatigue` are the following property/value pairs

TABLE 5-10: MINIMUM COMPULSORY PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DESCRIPTION
`material`	string	Name of the material
`funcname`	string	Name of file/function where the S-N function will be defined
`phase`	string	Phase/condition for the material
`ori`	string	Orientation/condition for the material with the specified phase/condition

The property names cannot be abbreviated.

In addition to the compulsory property pairs given above `matlibfatigue` accepts the following optional property/value pair:

TABLE 5-11: OPTIONAL PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`rvalue`	double	-1	R-value for the S-N-curve. $R = \frac{\text{mean} - \text{ampl}}{\text{mean} + \text{ampl}}$ R=-1 corresponds to alternating loading R=0 corresponds to pulse loading

The property names cannot be abbreviated.

Examples

See script `extractSNCurvesFromMatlib.m used in` model `frame_with_cutout` in the Fatigue Lab model library.

See Also

`fatiguedamage, extractSnCurvesFromMatlib`

Purpose Rainflow counting of load data

Syntax `[rangerange meanrange count] = rainfow(load, nrange, nmean)`

Description `[rangerange meanrange count] = rainfow(load, nrange, nmean)` performs rainflow counting of the loadvector `load`. Ranges `rangerange` and `meanrange` for ranges and mean values of load cycles are returned, as well as a `count` matrix with discretized occurrence counts for (range,mean) pairs. `count` has size `nrange`-by-`nmean`.

Examples

```
t = 1:1e3;
r = rand(2, length(t));
load = t.^0.25.*(1+1*r(1, :))+(1+t.^0.2.*(1+3*r(2, :))).*...
mod(t, 2);
nrange = 20;
nmean = 15;
[rr mr c] = rainflow(load, nrange, nmean);
r = rr(1)+sort([(0:(nrange-1))+0.01 (1:nrange)-0.01])*...
diff(rr)/nrange;
m = mr(1)+sort([(0:(nmean-1))+0.01  (1:nmean)-0.01])*...
diff(mr)/nmean;
[R M] = meshgrid(m, r);
surf(R, M, c(floor(0.5*(2:(2*nrange+1))),
floor(0.5*(2:(2*nmean+1)))))
title('Cycle count as a function of (range, mean)')
```

See Also `fatiguedamage`

Purpose

Compute number of cycles to fatigue, given one or two SN-curves where the stress amplitude is given as a function of the number of cycles.

Syntax

```
n = sn2cycles('amp', amp, 'mean', mean, ...
              'fatiguelim', fatiguelim, 'sncurve', {'sn_func'})
```

Description

```
n = sn2cycles('amp', amp, 'mean', mean, ...
              'fatiguelim', fatiguelim, 'sncurve', {'SN_func'})
```

Calculates the number of cycles to fatigue from the stress amplitude `amp`, the mean stress `mean`, and the material fatigue data specified through `fatiguelim` and the SN-function `'SN_func'`.

The minimum compulsory input to `sn2cycles` are the following property/value pairs:

TABLE 5-12: MINIMUM COMPULSORY PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DESCRIPTION
`amp`	double	Stress amplitude.
`mean`	double	Mean stress
`fatiguelim`	double array of the same size as the number of S-N curves.	Fatigue limit (below which no damage occurs) for the corresponding S-N curve
`sncurve`	cell array of strings	Names of functions giving stress amplitude as function of cycles to cracking for a specific r-value. If two or more curves are specified they must be given in ascending r-value order

In addition to the compulsory property pairs given above `sn2cycles` accepts the following optional property/value pairs:

TABLE 5-13: OPTIONAL PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DEFAULT	DESCRIPTION
`rvalue`	double array of the same size as the number of sn-curves	[-1]	R-values for the different sn-curves. $R = \frac{\mathrm{mean} - \mathrm{ampl}}{\mathrm{mean} + \mathrm{ampl}}$ R=-1 corresponding to alternating loading R=0 corresponding to pulse loading
`method`	`'none'` | `'goodman'` | `'gerber'`	`'none'`	Name of mean correction method only used if a single sn-curve is given
`params`	struct containing method parameters. For `goodman` and `gerber` `para.ultstress`		Method specific parameters. Ultimate stress for the `goodman` and `gerber` method

The property names cannot be abbreviated.

Examples

Used in `fatiguedamage.m`

See Also

`fatiguedamage`

Purpose Compute number of cycles to fatigue given SWT parameter values and SWT model parameters.

Syntax

```
ncycles = swt2cycles(swtvalues, 'params', para)
```

Description

```
ncycles = swt2cycles(swtvalues, 'PARAMS', PARA)
```

Calculates the number of cycles (`ncycles`) to fatigue. Inputs are the SWT parameter values `swtvalues`, a vector of size `nloc` and the SWT fatigue model parameters given in the struct `para`. `ncycles` has the same size (`nloc`) as `swtvalues`, that is, the number of locations where you want to compute the number of cycles to fatigue.

`swt2cycles` accepts the following property/value pairs:

TABLE 5-14: PROPERTY/VALUE PAIRS

PROPERTY	VALUE	DESCRIPTION
`params`	struct with fields containing swt parameters (see table below)	SWT model parameters

The property names cannot be abbreviated.

TABLE 5-15: FIELDS IN THE STRUCT FOR THE PROPERTY PARAMS

FIELD	VALUE	EQUATION NAME	DESCRIPTION
`epsf`	double	ε_f'	Fatigue ductility coefficient
`c`	double	c	Fatigue ductility exponent
`sigmaf`	double	σ_f'	Fatigue strength coefficient
`b`	double	b	Fatigue strength exponent
`E`	double	E	Young's modulus

Examples Used in `lcfmultiaxlin.m` and `lcfmultiaxlin.m`

See Also `lcfmultiaxlin`, `lcfmultiaxlin`, `sn2cycles`

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