COMSOL MULTIPHYSICS

MEMS MODULE

REFERENCE GUIDE

VERSION 3.4

COMSOL

How to contact COMSOL:

Benelux
COMSOL BV
Röntgenlaan 19
2719 DX Zoetermeer
The Netherlands
Phone: +31 (0) 79 363 4230
Fax: +31 (0) 79 361 4212
info@femlab.nl
www.femlab.nl

Denmark
COMSOL A/S
Diplomvej 376
2800 Kgs. Lyngby
Phone: +45 88 70 82 00
Fax: +45 88 70 80 90
info@comsol.dk
www.comsol.dk

Finland
COMSOL OY
Arabianranta 6
FIN-00560 Helsinki
Phone: +358 9 2510 400
Fax: +358 9 2510 4010
info@comsol.fi
www.comsol.fi

France
COMSOL France
WTC, 5 pl. Robert Schuman
F-38000 Grenoble
Phone: +33 (0)4 76 46 49 01
Fax: +33 (0)4 76 46 07 42
info@comsol.fr
www.comsol.fr

Germany
FEMLAB GmbH
Berliner Str. 4
D-37073 Göttingen
Phone: +49-551-99721-0
Fax: +49-551-99721-29
info@femlab.de
www.femlab.de

Italy
COMSOL S.r.l.
Via Vittorio Emanuele II, 22
25122 Brescia
Phone: +39-030-3793800
Fax: +39-030-3793899
info.it@comsol.com
www.it.comsol.com

Norway
COMSOL AS
Søndre gate 7
NO-7485 Trondheim
Phone: +47 73 84 24 00
Fax: +47 73 84 24 01
info@comsol.no
www.comsol.no

Sweden
COMSOL AB
Tegnérgatan 23
SE-111 40 Stockholm
Phone: +46 8 412 95 00
Fax: +46 8 412 95 10
info@comsol.se
www.comsol.se

Switzerland
FEMLAB GmbH
Technoparkstrasse 1
CH-8005 Zürich
Phone: +41 (0)44 445 2140
Fax: +41 (0)44 445 2141
info@femlab.ch
www.femlab.ch

United Kingdom
COMSOL Ltd.
UH Innovation Centre
College Lane
Hatfield
Hertfordshire AL10 9AB
Phone:+44-(0)-1707 284747
Fax: +44-(0)-1707 284746
info.uk@comsol.com
www.uk.comsol.com

United States
COMSOL, Inc.
1 New England Executive Park
Suite 350
Burlington, MA 01803
Phone: +1-781-273-3322
Fax: +1-781-273-6603

COMSOL, Inc.
10850 Wilshire Boulevard
Suite 800
Los Angeles, CA 90024
Phone: +1-310-441-4800
Fax: +1-310-441-0868

COMSOL, Inc.
744 Cowper Street
Palo Alto, CA 94301
Phone: +1-650-324-9935
Fax: +1-650-324-9936

info@comsol.com
www.comsol.com

For a complete list of international representatives, visit
www.comsol.com/contact

Company home page
www.comsol.com

COMSOL user forums
www.comsol.com/support/forums

MEMS Module Reference Guide

Version: October 2007 COMSOL 3.4

CONTENTS

Chapter 1: Introduction

Chapter 2: Application Modes Variables

Chapter 3: Application Mode Programming Reference

1

Introduction

The MEMS Module 3.4 is an optional package that extends the COMSOL Multiphysics modeling environment with customized user interfaces and functionality optimized for MEMS modeling.

The documentation set for the MEMS Module consists of the *MEMS Module User's Guide*, the *MEMS Module Model Library*, and this *MEMS Module Reference Guide*. All books are available in PDF and HTML versions from the COMSOL Help Desk. This book contains reference information about the application modes in the MEMS Module.

We hope the MEMS Module becomes a valuable tool in your modeling work, and we are convinced that the effort you put into understanding COMSOL Multiphysics will be repaid several times over. If you have any feedback on the models in this set, please let us know. Likewise, if you have any ideas for additional models that we could add to the library, we welcome your suggestions. Finally, if in your work you have developed a model you think would be a good candidate for inclusion in this model set, please let us hear about it. In any case, feel free to contact us at `info@comsol.com`.

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 MEMS 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.

Structural Mechanics 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 (`ui`) 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
`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	$\|u_i\|$
`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	$j\omega u_i$

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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	$\|p\|$
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

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`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
`sil_t, sijl_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
`Si, Sij`	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
`Sil, Sijl`	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
`Si_t, Sij_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
`Sil_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
`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	

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
evol	$\varepsilon_{\mathrm{vol}}$	All	All	volumetric strain	Defined differently for small and large deformations
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	$F^T F$
invFij	$\mathrm{inv}F_{ij}$, $i,j=1,2,3$	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 $0.5\omega\eta\mathrm{Real}(\varepsilon \cdot \mathrm{Conj}(D\varepsilon))$

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Ta*i*	Ta_i	All	B	Surface traction (force/area) in x_i-direction	Defined differently depending of large or small deformation
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*	$F_{\mathrm{t}ij}$	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_{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*	$T_{n\mathrm{p}}$	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

TABLE 2-1: SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
vslipxrj_cpi	v_{sxj}	P	B	Slip velocity vector x_j dir., contact pair i	$\frac{\mathrm{slipd}_{xrj}}{t - t_{\mathrm{old}}}$
vslip_cpi	v_s	P	B	Slip velocity magnitude, contact pair i	$\mathrm{sqrt}\left(\sum_j \mathrm{vslip}_{xrj}{}^2\right)$
mu_cpi	μ	S P	B	Frictional coefficient, contact pair i	See definition in theory section
Ttcrit_cpi	μ	P	B	Maximum friction traction, contact pair i	See definition in theory section
gap_cpi	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_cpi	contact	S P	B	In contact variable, contact pair i	Defined differently depending on the pair setting
friction_cpi	friction	S P	B	Enabling friction variable, contact pair i	contact_cpi_old

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.
`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	

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`eil, exyl`	ε_{il}, ε_{xyl}	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`	ε_{ilt}, ε_{xylt}	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`	σ_{il}, τ_{xyl}	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`	σ_{ilt}, τ_{xylt}	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_{il}, S_{xyl}	All	S	Second Piola Kirchhoff stress, user-defined coord. system	Defined differently depending of material model, and if loss factor damping is used
`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

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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	$\det F$
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	$\frac{1}{2}(I_1^2 - \mathrm{trace}(C^2))$

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
I3	I_3	All	All	Third strain invariant	${J_{el}}^2$
II1	$\bar{I}_1$	All	All	First modified strain invariant	$I_1 {J_{el}}^{-\frac{2}{3}} = I_1 {I_3}^{-\frac{1}{3}}$
II2	$\bar{I}_2$	All	All	Second modified strain invariant	$I_2 {J_{el}}^{-\frac{4}{3}} = I_1 {I_3}^{-\frac{2}{3}}$
tresca	σ_{tresca}	All	S	Tresca stress	$\max(\max\|\sigma_1 - \sigma_2\|, \|\sigma_2 - \sigma_3\|, \|\sigma_1 - \sigma_3\|))$
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*ig*	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_{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	$\mathrm{map}(x_j) + x^m_{jold}$
slip_cp*i*	slip	P	B	Slip vector magnitude reference frame, contact pair i	$\mathrm{sqrt}\left(\sum_j {\mathrm{slip}_{xj}}^2\right)$

TABLE 2-2: PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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	$\frac{\mathrm{slipd}_{xrj}}{t - t_{\mathrm{old}}}$
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	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
friction_cp*i*	friction	S P	B	Enabling friction variable, contact pair i	contact_cp*i*_old

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 (u*i*) refers to the global displacements (u, v).

TABLE 2-3: PLANE STRAIN 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_amp, v_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	$\mathrm{mod}(u_{i\mathrm{ph}} + 90°, 360°)$
u*i*_tt	u_{itt}	F	All	x_i acceleration	$-\omega^2 u_i$

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`ui_tt_amp`	$u_{itt\mathrm{amp}}$	F	All	x_i acceleration amplitude	$\omega^2 u_{i\mathrm{amp}}$
`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	$\|p\|$
`p_ph`	p_{ph}	F	All	Pressure phase	$\frac{180°}{\pi}\mathrm{mod}(\mathrm{angle}(p), 2\pi)$
`ei, exy`	ε_i, ε_{xy}	All	S	Strain, global coord. system	Engineering or Green strain depending if small or large deformation
`epi, 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	
`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, 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
`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, 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
`sil, 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

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`si_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
`sil_t, sxyl_t`	$\sigma_{il t}$, $\tau_{xyl t}$	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, 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
`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`	$S_{il t}$, $S_{xyl t}$	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, $i = 1, 2, 3$	

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
s*ixj*	σ_{ixj}	All	S	Principal stress directions, $i,j=1,2,3$	
e*ixj*	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
F*ij*	F_{ij}, $i,j=1,2,3$	All	All	Deformation gradient	$\frac{\partial \mathbf{x}}{\partial \mathbf{X}}$
c*ij*	c_{ij}, $i,j=1,2,3$	All	All	Right Cauchy-Green symmetric tensor all components are defined	$F^T F$
detF	$\mathrm{det}F$	All	All	Determinant of deformation gradient	$\mathrm{det}F$
invF*ij*	$\mathrm{inv}F_{ij}$, $i,j=1,2,3$	All	All	Inverse of deformation gradient	F^{-1} (calculated symbolically from F_{ij})
J	J	All	All	Volume ratio	$\mathrm{det}F$
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	$I_2 J_{\mathrm{el}}{}^{-\frac{4}{3}} = I_1 I_3{}^{-\frac{2}{3}}$

TABLE 2-3: PLANE STRAIN 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	
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 the force definition
F*ig*	F_{ig}	All	S	Point, Edge, Body load in global x_i-direction	Defined differently depending on the force definition
Ft*ij*	$F_{\mathrm{t}ij}$	All	B	Deformation gradient projected on the tangent plane	$\delta_{ij}+u_iTx_j$
wcn_cp*i*	w_{cn}	SP	B	Contact help variable for contact pair i	$\mathrm{nojac}(T_{np})-T_n$
wctx*j*_cp*i*	$w_{\mathrm{ct}j}$	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	$\mathrm{map}(x_j)+x^m_{j\mathrm{old}}$
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	$\sum_j \mathrm{map}(F_{tij})\mathrm{slip}_{xj}$

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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
Ttpx*j*_cp*i*	$T_{\mathrm{tp}j}$	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	$\dfrac{\mathrm{slipd}_{xrj}}{t - t_{\mathrm{old}}}$
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	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	$\mathrm{Geomgap}_{\mathrm{cpi}} - \mathrm{offset}_{\mathrm{cpi}} - \mathrm{map}(\mathrm{offset}_{\mathrm{cpi}})$

TABLE 2-3: PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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

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

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

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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	$\mathrm{mod}(\mathrm{uaxi}_{\mathrm{ph}} + 180°, 360°)$
w_tt_ph	$w_{t\mathrm{ph}}$	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	$\lvert p\rvert$

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

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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	$\varepsilon_{\mathrm{p}r}$, $\varepsilon_{\mathrm{p}z}$, $\varepsilon_{\mathrm{p}\varphi}$, $\varepsilon_{\mathrm{p}rz}$	S T	S	Plastic strain, global coord. system	
epe	$\varepsilon_{\mathrm{pe}}$	S T	S	Plastic strain, global coord. system	
eil, exyl	$\varepsilon_{i\mathrm{l}}$,$\varepsilon_{xy\mathrm{l}}$	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	$\varepsilon_{i\mathrm{l}t}$ $\varepsilon_{xy\mathrm{l}t}$	F T	S	Velocity strain, user-defined coord. system	${T_{\mathrm{coord}}}^T \varepsilon_t T_{\mathrm{coord}}$
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	$\sigma_{i\mathrm{l}}$, $\tau_{xy\mathrm{l}}$	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
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, 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
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*, Sxyl	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, Sxyl_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
F*ij*	F_{ij}, $i, j = 1,2,3$	All	All	Deformation gradient	$\frac{\partial \mathbf{x}}{\partial \mathbf{X}}$

TABLE 2-4: AXIAL SYMMETRY, STRESS-STRAIN 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	$F^T F$
detF	$\det F$	All	All	Determinant of deformation gradient	$\det F$
invF*ij*	$\mathrm{inv}F_{ij}$, $i, j = 1, 2, 3$	All	All	Inverse of deformation gradient	F^{-1} (calculated symbolically from F_{ij})
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
Frg, Fzg	F_{rg}, F_{zg}	All	All	Body, edge, point load in global r and z directions	Defined differently depending on force definition

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 (`u`*i*) 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 2-5: 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 2-5: 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 2-5: 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 2-5: 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 2-5: PIEZO SOLID 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. $T_{\mathrm{coord}}\mathbf{D}_l$
`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. $T_{\mathrm{coord}}\mathbf{J}_l$
`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. $T_{\mathrm{coord}}\mathbf{J}_l$
`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. $T_{\mathrm{coord}}\sigma_l T_{\mathrm{coord}}{}^T$
`sil`	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 $(1 + j\eta)D\varepsilon_l$
`Dil`	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 2-5: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`Jil`	J_{il}	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,il} + J_{p,il}$ or $J_{d,il}$
`Jdil`	$J_{d,il}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{il}}{\partial t}$
`Jdil`	$J_{d,il}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{il}$
`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. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}^T$

TABLE 2-5: PIEZO SOLID APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
`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 $(1+j\eta)j\omega D\varepsilon_l$
`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 $(1+j\eta)j\omega D\varepsilon_l$
`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
`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 2-5: 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 2-5: 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 2-6: 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 2-6: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
disp	disp	All	All	Total displacement	$\sqrt{\sum_i (\mathrm{real}(u_i))}^2$
e*i*	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	$\frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)$
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 2-6: 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 2-6: 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
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. $T_{\mathrm{coord}}\sigma_1 T_{\mathrm{coord}}^T$

TABLE 2-6: 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 2-6: PIEZO PLANE STRESS APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Jil	J_{il}	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,il} + J_{p,il}$ or $J_{d,il}$
Jdil	$J_{d,il}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{il}}{\partial t}$
Jdil	$J_{d,il}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{il}$
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. $T_{\mathrm{coord}}\sigma_{lt}T_{\mathrm{coord}}^T$

TABLE 2-6: 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 2-6: 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. $\frac{\sigma_l\cdot\varepsilon_l}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\sigma_l\cdot\mathrm{conj}(\varepsilon_l))\mathrm{th}$ 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 freqency resp. 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.
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 2-6: 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 2-7: 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 2-7: 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 2-7: 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 2-7: 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 2-7: 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. $T_{\mathrm{coord}}\sigma_{\mathrm{l}}T_{\mathrm{coord}}^T$
`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 $\varepsilon_e\mathbf{E}_{\mathrm{l}}$
`Jil`	$J_{i\mathrm{l}}$	T F	S	Total current density, x_i component, local coord. sys.	$J_{d,i\mathrm{l}} + J_{p,i\mathrm{l}}$ or $J_{d,i\mathrm{l}}$
`Jdil`	$J_{d,i\mathrm{l}}$	T	S	Displacement current density, x_i component, local coord. sys.	$\frac{\partial D_{i\mathrm{l}}}{\partial t}$
`Jdil`	$J_{d,i\mathrm{l}}$	F	S	Displacement current density, x_i component, local coord. sys.	$j\omega D_{i\mathrm{l}}$
`Jpil`	$J_{p,i\mathrm{l}}$	F	S	Potential current density, x_i component, local coord. sys.	$\sigma_e\mathbf{E}_{\mathrm{l}}$
`sijl`	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 $(1+j\eta)D\varepsilon_{\mathrm{l}}$

TABLE 2-7: 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 2-7: 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)
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

TABLE 2-7: PIEZO PLANE STRAIN APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
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	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. $\frac{\sigma_1\cdot\varepsilon_1}{2}\mathrm{th}$, $\frac{1}{2}\mathrm{real}(\sigma_1\cdot\mathrm{conj}(\varepsilon_1))\mathrm{th}$ 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 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 2-7: 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 2-8: 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 2-8: 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	ωw_{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 2-8: 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 2-8: 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*il*	E_{il}	All	S	Electric field, user-defined coord. system	$T_{\mathrm{coord}}{}^T\mathbf{E}$
V*il*	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 2-8: 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 2-8: 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. $T_{\mathrm{coord}}\sigma_{1t}T_{\mathrm{coord}}{}^T$
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	$j\omega D_i$

TABLE 2-8: 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 2-8: PIEZO AXIAL SYMMETRY APPLICATION MODE VARIABLES

NAME	SYMBOL	ANALYSIS	DOMAIN	DESCRIPTION	EXPRESSION
Jp*i*l	$J_{p,il}$	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. $T_{\text{coord}}\sigma_{lt}T_{\text{coord}}{}^T$
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. $T_{\text{coord}}\sigma_{lt}T_{\text{coord}}{}^T$
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 $(1+j\eta)j\omega D\varepsilon_l$

TABLE 2-8: 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. $c_E \varepsilon_{lt}$
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

TABLE 2-8: 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 2-8: 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 $\begin{bmatrix} F_{r\mathrm{g}} \\ F_{z\mathrm{g}} \end{bmatrix} = \begin{bmatrix} F_r \\ F_z \end{bmatrix}$ If other coordinate system $\begin{bmatrix} F_{x\mathrm{g}} \\ F_{z\mathrm{g}} \end{bmatrix} = T_{\mathrm{coord}}\begin{bmatrix} F_r \\ F_z \end{bmatrix}$

Film Damping Application Modes

A number of variables and physical quantities are available for postprocessing and for use in equations and boundary conditions. This chapter describes these expressions for the Film Damping application modes in 2D, 2D axisymmetric, and 3D.

The **Type** column in the following table indicates where you can use a given variable (**b** = boundary, **p/e** = point/edge):

TABLE 2-9: VARIABLES AND QUANTITIES

NAME	SYMBOL	UNIT	DESCRIPTION	TYPE	EXPRESSION/DEFAULT
pf	p_F	Pa	Dependent variable, film pressure variation	b	0
dx*i* dx dy dz	$\mathbf{d}$, dx_i	m	Components of the boundary-deformation vector	b	0
d0x*i* d0x d0y d0z	$\mathbf{d}_0$, $d_{0,\mathrm{x}i}$	m	Components of the boundary-deformation vector of the channel base	b	0
h0	h_0	m	Initial film thickness	b	10^{-5}
pA	p_A	Pa	Initial pressure	b	100
plambda0	$p_{\lambda,\,0}$	Pa	Reference pressure for λ_0	b	101325
lambda0	λ_0	m	Mean free path of gas molecules at $p_{\lambda,\,0}$	b	10^{-7}
eta	η	Pa·s	Dynamic viscosity	b	$2\cdot 10^{-5}$
alphav	α_v	1	Tangential momentum accommodation coefficient	b	1
Dh	D_h	1	Relative diffusivity	b	1
Ch	C_h	1	Relative compressibility	b	1
Yh	Y_h	m/s/Pa	Perforation admittance	b	0
dph	Δp_h	Pa	Perforation pressure difference	b	pf
dL	ΔL	m	Border elongation	p/e	$0.7\cdot 10^{-5}$
dLr	ΔL_r	1	Relative border elongation	p/e	0.7

TABLE 2-9: VARIABLES AND QUANTITIES

NAME	SYMBOL	UNIT	DESCRIPTION	TYPE	EXPRESSION/DEFAULT
pf0	$p_{F,0}$	Pa	Film pressure variation	p/e	0
Kn	Kn	1	Knudsen number	b	λ/h (time dependent) λ/h_0 (frequency response)
D	D	1	Inverse scaled Knudsen number	b	$\frac{\sqrt{\pi}}{2\mathrm{Kn}}$
Ks	Ks	1	Scaled Knudsen number	b	$\sigma_p\mathrm{Kn}$
sigmap	σ_p	1	Slip coefficient	b	Equation 6-5 in "Rarefaction and Slip Effects" on page 197 in the MEMS Module User's Guide
dn	d_n	m	Normal boundary deformation	b	$-\mathbf{n}\cdot\mathbf{d}$
d0n	$d_{0,\mathrm{n}}$	m	Normal boundary deformation of the channel base	b	$\mathbf{n}\cdot\mathbf{d}_0$
d_tx*i*	$\mathbf{d}_t$, $d_{\mathrm{t,x}i}$	m	x_i components of the tangential boundary deformation	b	$\mathbf{d}-\mathbf{n}d_n$
d0_tx*i*	$\mathbf{d}_{0,t}$, $d_{0,\mathrm{t,x}i}$	m	x_i components of the tangential boundary deformation of the channel base	b	$\mathbf{d}_0-\mathbf{n}d_{0,\mathrm{n}}$
u_tx*i*	$\mathbf{u}_t$, $u_{\mathrm{t,x}i}$	m/s	x_i components of the tangential boundary velocity		$d\mathbf{d}_t / dt$ (time dependent) $j\omega\mathbf{d}_t$ (frequensy response)
u0_tx*i*	$\mathbf{u}_{0,t}$, $u_{0,\mathrm{t,x}i}$	m/s	x_i components of the tangential boundary velocity of the channel base		$d\mathbf{d}_{0,\mathrm{t}} / dt$ (time dependent) $j\omega\mathbf{d}_{0,\mathrm{t}}$ (frequensy response)
dh	Δh	m	Film thickness variation	b	$-d_n - d_{0,\mathrm{n}}$
dht	$\frac{d(\Delta h)}{dt}$	m/s	Film thickness variation rate	b	`diff(dh,t)` (time dependent) jωdh (frequency response)
h	h	m	Film thickness	b	$h_0+\Delta h$

TABLE 2-9: VARIABLES AND QUANTITIES

NAME	SYMBOL	UNIT	DESCRIPTION	TYPE	EXPRESSION/DEFAULT
lambda	λ	m	Gas molecules mean free path	b	$\lambda_0 p_{\lambda,0}/(p_a + p_f)$ (time dependent) $\lambda_0 p_{\lambda,0}/p_a$ (frequency response
Qch	Q_{ch}		Relative flow rate function	b	Different expressions according to equations Equation 6-6 – Equation 6-9 in “Rarefaction and Slip Effects” on page 197 in the MEMS Module User’s Guide
pf_amp	$p_{F,amp}$		Pressure variation amplitude, in Freq	b	abs(pf)
pf_ph	$p_{F,ph}$		Pressure variation phase, in Freq	b	180/pi*mod(angle(pf),2*pi)
F_x*i*	$\mathbf{F}$, F_{xi}		x_i components of the film load	b	$\mathbf{F}_n$ for squeezed film $\mathbf{F}_n + \mathbf{F}_t$ otherwise
F_nx*i*	$\mathbf{F}_n$, $F_{n,xi}$		x_i components of the normal film load	b	$-\mathbf{n}p_f$
F_tx*i*	$\mathbf{F}_t$, $F_{t,xi}$		x_i components of the tangential film load	b	$-\eta\frac{\mathbf{u}_t - \mathbf{u}_{0,t}}{h} - \frac{h}{2}\nabla_t p_f$ for No slip Relative flow rate function, $-\eta\frac{\mathbf{u}_t - \mathbf{u}_{0,t}}{h} - \frac{h}{2}\nabla_t p_f$ otherwise

Electrostatic Fields

A number of variables and physical quantities are available for postprocessing and for use in equations and boundary conditions. They are all given in the following tables.

Conductive Media DC Application Mode

The fundamental fields that can be derived from the electric potential are available for postprocessing and for use in equations and boundary conditions.

APPLICATION MODE SUBDOMAIN VARIABLES

The subdomain variables for Conductive Media DC are given the table below.

TABLE 2-10: APPLICATION MODE SUBDOMAIN VARIABLES, CONDUCTIVE MEDIA DC

NAME	DESCRIPTION	EXPRESSION
V	electric potential	V
sigma	electric conductivity	σ
sigma*ij*	electric conductivity, $x_i x_j$ component	σ_{ij}
Qj	current source	Q_j
d	thickness	d
Je*i*	external current density, x_i component	J_i^e
normJe	external current density, norm	$\sqrt{\mathbf{J}^e \cdot \mathbf{J}^e}$
Ji*i*	potential current density, x_i component	$\sigma_{ij} E_j$
normJi	potential current density, norm	$\sqrt{\mathbf{J}^i \cdot \mathbf{J}^i}$
J*i*	total current density, x_i component	$J_i^e + J_i^i$
normJ	total current density, norm	$\sqrt{\mathbf{J} \cdot \mathbf{J}}$
E*i*	electric field, x_i component	$-\frac{\partial V}{\partial x_i}$
normE	electric field, norm	$\sqrt{\mathbf{E} \cdot \mathbf{E}}$
Q	resistive heating	$\mathbf{J} \cdot \mathbf{E}$

APPLICATION BOUNDARY VARIABLES

The boundary variables for Conductive Media DC are given in the table below.

TABLE 2-11: APPLICATION MODE BOUNDARY VARIABLES, CONDUCTIVE MEDIA DC

NAME	DESCRIPTION	EXPRESSION
tE*i*	tangential electric field, x_i component	$-\mathbf{t}_i \cdot \nabla_t V$
normtE	tangential electric field, norm	$\sqrt{t\mathbf{E} \cdot t\mathbf{E}}$
nJ	current density outflow	$\mathbf{n} \cdot \mathbf{J}$
nJs	source current density	$\mathbf{n}_{\mathrm{up}} \cdot (\mathbf{J}_{\mathrm{down}} - \mathbf{J}_{\mathrm{up}})$
Js*i*	surface current density, x_i component	$d\sigma tE_i$
normJs	surface current density, norm	$\sqrt{\mathbf{J}_s \cdot \mathbf{J}_s}$
sigmabnd	electric conductivity on boundary	σ_{bnd}
Qs	surface resistive heating	$\mathbf{J}_s \cdot t\mathbf{E}$
Qjl	line current source	Q_{jl}
Qj0	point current source	Q_{j0}

APPLICATION POINT VARIABLES

The point variable for the Conductive Media DC application mode appears in the following table.

TABLE 2-12: APPLICATION MODE POINT VARIABLES, CONDUCTIVE MEDIA DC

NAME	TYPE	DESCRIPTION	EXPRESSION
Qj0	P	Point current source	Q_{j0}

The Electrostatics Application Mode

The fundamental fields that can be derived from the electric potential are available for postprocessing and for use in equations and boundary conditions.

APPLICATION MODE SCALAR VARIABLES

The application-specific scalar variable in this mode is given in the following table.

TABLE 2-13: APPLICATION MODE SCALAR VARIABLES, ELECTROSTATICS,

NAME	DESCRIPTION	EXPRESSION
epsilon0	permittivity of vacuum	ε_0

APPLICATION MODE SUBDOMAIN VARIABLES

The subdomain variables for Electrostatics are given the table below.

TABLE 2-14: APPLICATION MODE SUBDOMAIN VARIABLES, ELECTROSTATICS,

NAME	CONSTITUTIVE RELATION	DESCRIPTION	EXPRESSION
V		electric potential	V
epsilonr	epsr, Dr	relative permittivity	ε_{r}
epsilonr	P	relative permittivity	1
epsilonr*ij*	epsr, Dr	relative permittivity, $x_i x_j$ component	$\varepsilon_{\mathrm{r}ij}$
epsilonr*ij*	P	relative permittivity, $x_i x_j$ component	1
epsilon		permittivity	$\varepsilon_0\varepsilon_{\mathrm{r}}$
epsilon*ij*		permittivity, $x_i x_j$ component	$\varepsilon_0\varepsilon_{\mathrm{r}ij}$
P*i*	P	electric polarization, x_i component	P_i
P*i*	epsr, Dr	electric polarization, x_i component	$D_i - \varepsilon_0 E_i$
normP		electric polarization, norm	$\sqrt{\mathbf{P}\cdot\mathbf{P}}$
Dr*i*	epsr	remanent displacement, x_i component	0
Dr*i*	P	remanent displacement, x_i component	P_i
Dr*i*	Dr	remanent displacement, x_i component	$D_{\mathrm{r}i}$
normDr		remanent displacement, norm	$\sqrt{\mathbf{D}_{\mathrm{r}}\cdot\mathbf{D}_{\mathrm{r}}}$
rho		space charge density	ρ
E*i*		electric field, x_i component	$-\frac{\partial V}{\partial x_i}$
normE		electric field, norm	$\sqrt{\mathbf{E}\cdot\mathbf{E}}$
D*i*	epsr	electric displacement, x_i component	$\varepsilon_0\varepsilon_{\mathrm{r}ij}E_j$
D*i*	P	electric displacement, x_i component	$\varepsilon_0 E_i + P_i$
D*i*	Dr	electric displacement, x_i component	$\varepsilon_0\varepsilon_{\mathrm{r}ij}E_j + D_{\mathrm{r}i}$
normD		electric displacement, norm	$\sqrt{\mathbf{D}\cdot\mathbf{D}}$
We		electric energy density	$\frac{\mathbf{E}\cdot\mathbf{D}}{2}$

APPLICATION BOUNDARY VARIABLES

The boundary variables for Electrostatics are given in the table below.

TABLE 2-15: APPLICATION MODE BOUNDARY VARIABLES, ELECTROSTATICS,

NAME	DESCRIPTION	EXPRESSION
nD	surface charge density	$\mathbf{n}_{\mathrm{up}}\cdot(\mathbf{D}_{\mathrm{down}}-\mathbf{D}_{\mathrm{up}})$
epsilonbnd	relative permittivity on boundary	$\varepsilon_{\mathrm{bnd}}$
unT*i*	Maxwell surface stress tensor, x_i component, up side of boundary	$-\frac{1}{2}(\mathbf{E}_{\mathrm{up}}\cdot\mathbf{D}_{\mathrm{up}})n_{i\mathrm{down}} + (\mathbf{n}_{\mathrm{down}}\cdot\mathbf{D}_{\mathrm{up}})E_{i\mathrm{up}}$
dnT*i*	Maxwell surface stress tensor, x_i component, down side of boundary	$-\frac{1}{2}(\mathbf{E}_{\mathrm{down}}\cdot\mathbf{D}_{\mathrm{down}})n_{i\mathrm{up}} + (\mathbf{n}_{\mathrm{up}}\cdot\mathbf{D}_{\mathrm{down}})E_{i\mathrm{down}}$
unTE*i*	electric Maxwell surface stress tensor, x_i component, up side of boundary	$-\frac{1}{2}(\mathbf{E}_{\mathrm{up}}\cdot\mathbf{D}_{\mathrm{up}})n_{i\mathrm{down}} + (\mathbf{n}_{\mathrm{down}}\cdot\mathbf{D}_{\mathrm{up}})E_{i\mathrm{up}}$
dnTE*i*	electric Maxwell surface stress tensor, x_i component, down side of boundary	$-\frac{1}{2}(\mathbf{E}_{\mathrm{down}}\cdot\mathbf{D}_{\mathrm{down}})n_{i\mathrm{up}} + (\mathbf{n}_{\mathrm{up}}\cdot\mathbf{D}_{\mathrm{down}})E_{i\mathrm{down}}$

APPLICATION EDGE VARIABLES

The edge variable for Electrostatics appears in the following table:

TABLE 2-16: APPLICATION MODE EDGE VARIABLES, ELECTROSTATICS,

NAME	DESCRIPTION	EXPRESSION
Ql	line charge density	Q_{l}

APPLICATION POINT VARIABLES

The point variable for Electrostatics appears in the following table:

TABLE 2-17: APPLICATION MODE POINT VARIABLES, ELECTROSTATICS,

NAME	DESCRIPTION	EXPRESSION
Q0	charge	Q_0

Microfluidics Application Modes

Application Modes for Laminar Flow

A number of variables and physical quantities are available for postprocessing and for use in equations and boundary conditions. The **Type** column in the following table indicates where you can use a given variable:

- P = points
- B = boundaries
- S = subdomains
- V = vector expressions

Many of the boundary variables belong to certain boundary condition and thus are available only on certain boundaries. The table points out these cases with the following code: lf—laminar inflow/outflow boundary condition; eo—electroosmotic velocity boundary condition; and sv—slip velocity boundary condition.

Most labels for postprocessing variables are followed by the code given to the respective application mode. For example, in any of the microfluidics application modes the modulus of the velocity, denoted `U`, becomes `U_mmglf`. Even so, the name `mmglf` can change (for example, to `mmglf2`) if the model includes multiple microfluidics application modes or if you have renamed the application mode. Always check the label of the appropriate variables before using them in equation-based modeling.

The following table reviews the application modes variables:

TABLE 2-18: APPLICATION MODES FOR LAMINAR FLOW—AVAILABLE APPLICATION MODE VARIABLES

LABEL	TYPE	DESCRIPTION	EXPRESSION
u, v, w	B/S/V	Dependent variable, x_i velocity (u_i)	u, v, w
p	P/B/S	Dependent variable, pressure	p
rho	S	Density	ρ
eta	S	Dynamic viscosity	η
kappadv	S	Dilatational viscosity	κ
thickness	S	Thickness of the channel	Thickness (2D)

TABLE 2-18: APPLICATION MODES FOR LAMINAR FLOW—AVAILABLE APPLICATION MODE VARIABLES

LABEL	TYPE	DESCRIPTION	EXPRESSION
epsilonr	S	Relative permittivity of the fluid	ε_r
meanfrp	S	Mean free path of the gas molecules	λ
F_*xi*	S	Volume force	$\mathbf{F}$
u0, v0, w0	B	Components of the fluid's boundary velocity	$\mathbf{u}_0$
p0	B/P	Pressure	p_0
f0	B	Normal stress	f_0
Fbnd*xi*	B/V	Boundary stress	$\mathbf{F}_{bnd}$
U0in	B	Normal inflow velocity	U_0
U0out	B	Normal outflow velocity	V_0
uvw_	B	Tangential wall velocity	U_w
uw, vw, ww	B	Wall velocity components	u_w, v_w, w_w,
U	B/S	Velocity field	$\|\mathbf{u}\|$
V	S	Vorticity (in 2D, 2D-axi)	$\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}$ (2D), $\frac{\partial u}{\partial z}-\frac{\partial v}{\partial r}$ (2D-axi)
V_*xi*	S	Vorticity (in 3D)	$\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z}, \frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}, \frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}$ (u, v, w components)
divU	S	Divergence of velocity field	$\nabla \cdot \mathbf{u}$
K_*xi*	B	Viscous force per area	$\sum_j n_j\left[\eta\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-(2\eta/3-\kappa)(\nabla\cdot\mathbf{u})\delta_{ij}\right]$ (Non-Isothermal Flow and Non-Isothermal Stokes Flow)
K_*xi*	B	Viscous force per area	$\sum_j n_j\left[\eta\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]$ (Incompressible Navier-Stokes and Stokes Flow)

TABLE 2-18: APPLICATION MODES FOR LAMINAR FLOW—AVAILABLE APPLICATION MODE VARIABLES

LABEL	TYPE	DESCRIPTION	EXPRESSION
T_*xi*	B	Total force per area	$\sum_j n_j\left[-p\delta_{ij}+\eta\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-(2\eta/3-\kappa)(\nabla\cdot\mathbf{u})\delta_{ij}\right]$ (Non-Isothermal Flow and Non-Isothermal Stokes Flow)
T_*xi*	B	Total force per area	$\sum_j n_j\left[-p\delta_{ij}+\eta\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]$ (Incompressible Navier-Stokes and Stokes Flow)
cellRe	S	Cell Reynolds number	$\frac{\rho\lvert\mathbf{u}\rvert h}{\eta}$
res_*xi*	S	Equation residual	$\rho\mathbf{u}\cdot\nabla\mathbf{u}+\nabla p-\mathbf{F}-$ $\nabla\cdot[\eta(\nabla\mathbf{u}+(\nabla\mathbf{u})^T)-(2\eta/3-\kappa)(\nabla\cdot\mathbf{u})\mathbf{I}]$
res_sc_*xi*	S	Shock-capturing residual	$\rho\mathbf{u}\cdot\nabla\mathbf{u}+\nabla p-\mathbf{F}$
beta_*xi*	S	Convective field	ρu_i (2D, 3D), $r\rho u_i$ (2D-axi)
Dm	S	Mean-diffusion coefficient	η (2D, 3D), $r\eta$ (2D-axi)
da	S	Total time-scale factor	ρ (2D, 3D), $r\rho$ (2D-axi)
taum	S	GLS time scale	$\min\left(\frac{\Delta t}{\rho},\frac{0.5h}{\max\left(\rho\lvert\mathbf{u}\rvert,\frac{6\eta}{h}\right)}\right)$
tauc	S	GLS time scale	$0.5\lvert\mathbf{u}\rvert h\min\left(1,\frac{\rho\lvert\mathbf{u}\rvert h}{\eta}\right)$
Pinl	P	Dependent variable, pressure at the end of entrance or exit channel	p_{entr} or p_{exit} (lf)
Pinl	B	Pressure at the end of entrance or exit channel	p_{entr} or p_{exit}, from weak form point equation (lf)
U0	B	Average velocity through laminar inflow inlet	U_0 (lf)
V0	B	Volume flow through the laminar inflow inlet	V_0 (lf)

TABLE 2-18: APPLICATION MODES FOR LAMINAR FLOW—AVAILABLE APPLICATION MODE VARIABLES

LABEL	TYPE	DESCRIPTION	EXPRESSION
Lentr	B	Length of the entrance channel	$\mathrm{L_{entr}}$ (lf)
Lexit	B	Length of the exit channel	$\mathrm{L_{exit}}$ (lf)
p0_entr	B	Pressure at the end of the entrance channel	$\mathrm{p_{0,entr}}$ (lf)
p0_exit	B	Pressure at the end of the exit channel	$\mathrm{p_{0,exit}}$ (lf)
lm*xi*	B/V	Lagrange multiplier corresponding to viscous boundary force	From weak form boundary equation (eo,sv)
N*xi*	B/V	Boundary normal vector component	$\mathrm{n}x_{i\_}$ (eo,sv)
mueo	B	Electroosmotic mobility	μ_{eo}
zeta	B	Zeta potential of the boundary	ζ
E_*xi*	B/V	Electric field in the fluid	Ex_i (eo)
ET_*xi*	B/V	Tangential component of the electric field	$Ex_i - Nx_i\sum_j Ex_jNx_j$ (eo)
*ui*w0	B/V	Wall velocity	$u_{i\ \mathrm{wall}}$ (sv)
Ls	B	Slip length	L_s (sv)
alphav	B	Momentum accommodation coefficient	α_{v} (sv)
T	B	Temperature of the fluid	T (sv)
sigmat	B	Thermal slip coefficient	σ_T (sv)
TT*xi*	B/V	Tangential component of the temperature gradient	$Tx_i - Nx_i\sum_j Nx_jTx_j$ (sv)
*ui*wT	B/V	Tangential wall velocity	$u_{i,\ \mathrm{wall}} - Nx_i\sum_j Nx_ju_{j,\ \mathrm{wall}}$ (sv)

The Level Set Two Phase Flow Application Mode

The Level Set Two Phase Flow application mode contains all the variables for the Application Modes for Laminar Flow (Table 2-18 on page 74). In addition it has the following variables:

TABLE 2-19: LEVEL SET TWO-PHASE FLOW—AVAILABLE APPLICATION MODE VARIABLES

LABEL	TYPE	DESCRIPTION	EXPRESSION
phi	S	Dependent variable, the level set variable	ϕ
delta_	S	Dirac delta function	$6\|\nabla\phi\|\|\phi(1-\phi)\|$
gamma_	S	Reinitialization parameter	γ
u_	S	Fluid velocity	$\mathbf{u}$
gradphi_	S	Gradient of phi	$\nabla\phi$
norm_	S	interface normal	$\mathbf{n}_{\mathrm{interface}} = \frac{\nabla\phi}{\|\nabla\phi\|}$
kappa_	S	Mean curvature	$(-\nabla\cdot\mathbf{n}_{\mathrm{interface}})(\phi>0)(\phi<0.9)$
Vf1_	S	Volume fraction of fluid 1	$1-\phi$
Vf2_	S	Volume fraction of fluid 2	ϕ
`hmaxi_`	B	Maximum mesh size in subdomain i	
hmax_	B/P	Maximum mesh size	

3

Application Mode Programming Reference

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

Structural Mechanics Application Modes

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	$\frac{2 \cdot 10^{10}}{\left(1 - \frac{2 \cdot 10^{10}}{2 \cdot 10^{11}}\right)} \varepsilon_{\mathrm{pe}}$	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
`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 81.

PROPERTIES

See the solid, stress-strain application mode specification on page 82.

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	$\frac{2 \cdot 10^{10}}{\left(1 - \frac{2 \cdot 10^{10}}{2 \cdot 10^{11}}\right)} \varepsilon_{pe}$	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

Plane Strain

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 81 for details.

PROPERTIES

See the solid, stress-strain application mode specification on page 82 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

Axial Symmetry, Stress-Strain

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 82 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, $Hu=R$

Piezo Solid

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 3-5: 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 3-5: 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 3-5: 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 3-6: 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 3-6: 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 3-6: 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 3-6: 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 3-7: 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 3-7: 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 3-7: 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 3-7: 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

INDEX