



AD FALCON API Manual

State Variables in FEM Analysis

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1 State Variables in FEM Analysis

1.1 Overview

State variables store the evolving internal state of the model during the simulation.

- **Gauss-point state:** material variables such as stress/strain, void ratio, saturation, permeability, and (when enabled) PML memory variables.
- **Nodal state:** a small subset of primary fields (notably pore pressures) is also stored in a state-variable vector at nodes and is used by features such as point/line interpolation output.

State variables are updated by the solver. UMATs should treat the provided state as read-only and return constitutive response (stress update and consistent tangent).

1.2 State-variable names accepted in input (@StateVars)

For % PointStateOutput and % LineStateOutput, the following names are currently recognized:

- **Stress:** StressXX, StressYY, StressZZ, StressZY, StressZX, StressXY
- **Strain:** StrainXX, StrainYY, StrainZZ, StrainZY, StrainZX, StrainXY
- **Incremental strain:** DStrainXX, DStrainYY, DStrainZZ, DStrainZY, DStrainZX, DStrainXY
- **Strain rate:** VelStrainXX, VelStrainYY, VelStrainZZ, VelStrainZY, VelStrainZX, VelStrainXY
- **Pressures:** PoreWaterPressure, PoreAirPressure, InitialPoreWaterPressure, InitialPoreAirPressure
- **Retention / porosity:** VoidRatio, DegreeOfSaturation, PcAlpha, SlopeR, SuctionOld, VoidRatioOld, DeltaVoidRatioOld, DeltaSuctionOld, Xi
- **Permeability:** PermW_XX, PermW_YY, PermW_ZZ, PermW_ZY, PermW_ZX, PermW_XY, PermA_XX, PermA_YY, PermA_ZZ, PermA_ZY, PermA_ZX, PermA_XY
- **Totals / damping:** TotalStressXX, TotalStressYY, TotalStressZZ, Damping

1.3 Full StateVariable enumeration (fixed ordering)

The solver uses a fixed ordering for indexing state-variable vectors. The complete list is:

```
enum StateVariable {
    StressXX,
    StressYY,
```

```
StressZZ,  
StressZY,  
StressZX,  
StressXY,  
StrainXX,  
StrainYY,  
StrainZZ,  
StrainZY,  
StrainZX,  
StrainXY,  
DStrainXX,  
DStrainYY,  
DStrainZZ,  
DStrainZY,  
DStrainZX,  
DStrainXY,  
VelStrainXX,  
VelStrainYY,  
VelStrainZZ,  
VelStrainZY,  
VelStrainZX,  
VelStrainXY,  
PoreWaterPressure,  
PoreAirPressure,  
InitialPoreWaterPressure,  
InitialPoreAirPressure,  
VoidRatio,  
DegreeOfSaturation,  
PcAlpha,  
SlopeR,  
SuctionOld,  
VoidRatioOld,  
DeltaVoidRaioOld,  
DeltaSuctionOld,  
PermW_XX,  
PermW_YY,  
PermW_ZZ,  
PermW_ZY,  
PermW_ZX,  
PermW_XY,  
PermA_XX,  
PermA_YY,  
PermA_ZZ,  
PermA_ZY,  
PermA_ZX,
```

```
    PermA_XY,  
    Xi,  
    Damping,  
    alpha_p_c,  
    delta_satOld,  
    Saturation_old,  
    TotalStressXX,  
    TotalStressYY,  
    TotalStressZZ,  
    InitialVoidRatio,  
  
    // PML (Perfectly Matched Layer) coefficients and memory variables  
    PMLSigmaX,  
    PMLKappaX,  
    PMLAlphaX,  
    PMLSigmaY,  
    PMLKappaY,  
    PMLAlphaY,  
    PMLPsiUX_X,  
    PMLPsiUY_X,  
    PMLPsiUX_Y,  
    PMLPsiUY_Y,  
    PMLSigmaZ,  
    PMLKappaZ,  
    PMLAlphaZ,  
    PMLPsiUZ_X,  
    PMLPsiUZ_Y,  
    PMLPsiUX_Z,  
    PMLPsiUY_Z,  
    PMLPsiUZ_Z,  
  
    // Coupled/Fully-coupled PML memory variables for pore pressures  
    PMLPsiPW_X,  
    PMLPsiPW_Y,  
    PMLPsiPW_Z,  
    PMLPsiPA_X,  
    PMLPsiPA_Y,  
    PMLPsiPA_Z,  
  
    NumVariables  
};
```

1.4 Variable groups (interpretation)

1.4.1 Stress and strain

- **Effective stress** is stored in StressXX, StressYY, StressZZ, StressZY, StressZX, StressXY.
- **Total strain** is stored in StrainXX, StrainYY, StrainZZ, StrainZY, StrainZX, StrainXY.
- **Incremental strain** (DStrain*) stores strain increments over the current step/increment.
- **Strain rate** (VelStrain*) stores strain-rate-like quantities used by rate-dependent/dynamic formulations.

In reduced kinematics (e.g., plane strain), the full 3D slots still exist but some components may remain unused or be constrained by the kinematic assumptions.

1.4.2 Pore pressures

- PoreWaterPressure and PoreAirPressure are the current pore pressures.
- InitialPoreWaterPressure and InitialPoreAirPressure store the initialized pore pressures.

1.4.3 Saturation, suction history, and void ratio

- VoidRatio and DegreeOfSaturation store the current porosity state.
- PcAlpha, SlopeR, alpha_p_c, SuctionOld, VoidRatioOld, DeltaVoidRaioOld, DeltaSuctionOld, delta_satOld, Saturation_old are history/memory variables used by unsaturated and hysteretic retention/permeability models.

1.4.4 Permeability

- PermW_* and PermA_* store water- and air-phase permeability tensor components (as used by the coupled flow operators).

1.4.5 Other

- Xi is an effective-stress-related coupling parameter used in unsaturated formulations.
- Damping is a damping coefficient used in dynamic analysis.
- TotalStressXX, TotalStressYY, TotalStressZZ store total normal stress components (no total shear components are stored in this vector).
- InitialVoidRatio stores the initial void ratio (copied from initial assignments where applicable).

1.4.6 PML (Perfectly Matched Layer)

When a PML region is present, additional coefficients and memory variables are stored:

- PMLSigma*, PMLKappa*, PMLAlpha*: PML profile coefficients.
- PMLPsiU*_*: CPML memory variables for displacement components.
- PMLPsiPW_*, PMLPsiPA_*: CPML memory variables for pore pressures (coupled/fully-coupled).

Outside the PML region these are typically at their defaults (e.g., $PMLKappa^* = 1$ and other PML variables near zero).

