AD FALCON API Manual

Constitutive Models Overview

Javad Ghorbani

March 26, 2026

Contents

1 Constitutive Models Overview

This page covers the mechanical constitutive models available in FALCON: where the constitutive law sits in the material definition, what it does in different analysis types, and how to navigate to the model-specific pages.

1.1 What the constitutive model does

In FALCON, the constitutive model is the mechanical law attached to a material through `@UMAT:` (a user material routine). It provides the stress update, tangent stiffness, and any internal state evolution required by the selected soil or rock model.

At a minimum, the constitutive model controls:

- the elastic stress-strain response
- yielding and plastic flow, if the model is inelastic
- hardening, softening, fabric, anisotropy, or bonding effects, if present
- any custom state variables that must be stored for restart or output

For all analysis types, the constitutive law is the core mechanical part of the material definition.

1.2 Where it appears in the input file

Constitutive models are defined in the `% Materials` section using `@UMAT:` with category `Mechanical`.

Example (illustrative; required parameters and custom variables are model-specific):

```
% Materials
MySoil
@UMAT: path/to/YourModelUMAT.cpp path/to/YourModelUMAT.hpp Mechanical
ParamA=... ParamB=... CustomVariable=Var1,Var2
%%%
```

`CustomVariable=` declares which **custom state variables** (history variables) the UMAT should read and/or update so they are available for output and preserved across steps and restarts. Many advanced models require specific `CustomVariable=` entries; others do not use custom variables. See UMAT development for details.

FALCON accepts the same `@UMAT:` loading styles documented in Material Models: Syntax & Conventions. In practice, the mechanical model may be provided as:

- source files such as `path/to/Model.cpp path/to/Model.hpp`
- a compiled dynamic library / shared object, when your workflow uses a prebuilt UMAT
- other supported UMAT loading forms already used in your FALCON installation

General syntax rules, path conventions, and `CustomVariable=` usage are documented in Material Models: Syntax & Conventions.

1.3 Role in different analysis types

The constitutive law is always required, but additional material components are needed as the analysis becomes more strongly coupled. The exact set depends on your chosen formulation and options (for example, saturated vs unsaturated, whether air is modeled, and which effective-stress model is selected).

Analysis type	Mechanical model via `@UMAT:`	Additional material models typically required
Uncoupled (solid-only)	required	Solid phase properties as required by the analysis setup (for example, density for dynamics)
Coupled (solid + water, saturated)	required	Liquid phase properties and permeability
Fully coupled (solid + water + air, variably saturated)	required	Liquid and gas phase properties, SWRC, effective-stress model, and permeability

Read the constitutive model page together with:

- phaseproperties.md
- effective stress
- SWRC
- permeability
- analysis formulations and sign conventions

for coupled and fully coupled formulations.

1.4 Common conventions across constitutive pages

The following conventions apply across all constitutive model pages:

- FALCON mechanical models are configured by `name=value` pairs on the `@UMAT:` line.
- Many advanced models require `CustomVariable=` declarations so internal variables are preserved between steps.
- Angles are given in degrees (°) unless a model page explicitly states otherwise.
- Unit consistency is the user's responsibility. Unless a parameter name explicitly encodes units (for example, `*_kPa`), the UMATs are written in a unit-consistent form and expect

a single consistent unit system across geometry, stress/pressure, density, time, and permeability.
- Sign conventions can differ across references. In FALCON, stresses are stored in a tension-positive tensor convention (so compressive normal stresses are negative), while pore pressures are positive in compression; see analysis formulations and sign conventions.
- Some model pages present equations using compression-positive geotechnical invariants (for example, writing mean pressure as `p = -σ_m`) for readability. This does not change FALCON's sign conventions: stresses and strains are negative in compression, while pore-water and pore-air pressures are positive in compression. Always follow the variable definitions given on the specific model page.
- In fully coupled analyses, the mechanical UMAT is used together with an effective-stress model and an SWRC. Some mechanical models include explicit suction/saturation dependence, while others are saturated-only and should be treated as such even if they can be run numerically in a variably saturated analysis.
- Standalone single-point drivers are packaged as FALCON minis for model exploration and verification.

1.5 Documented constitutive models

The model names below are manual labels. In input files you reference a particular UMAT implementation using the `@UMAT:` directive documented on each model page.

Model	Manual page	Typical material class	Main features
Linear Elasticity (isotropic)	elasticity.md	General elastic solid	Constant isotropic elasticity
Orthotropic Elasticity	orthotropic.md	Layered or direction-dependent materials	Orthotropic elastic stiffness
Nonlinear Elastic	nonlinearelastic.md	Stress-dependent elastic soils	Pressure-dependent elastic stiffness without plastic flow
Mohr-Coulomb	mohr.md	Frictional soils and general geotechnical strength checks	Rounded Mohr-Coulomb plasticity with optional unsaturated effective-stress coupling
Hoek-Brown	hoekbrownmodel.md	Rock and rock masses	Hoek-Brown strength surface with dilation option

Model	Manual page	Typical material class	Main features
Mohr Hardening	mohrhardening.md	Frictional materials with peak/residual strength evolution	Rounded Mohr model with hardening-softening laws
Generalized Cam-Clay (GCC)	gccmodel.md	Unsaturated critical-state soils	Suction-dependent Cam-Clay formulation
CASM	casmmodel.md	Clay-sand unified critical-state response	Unified clay and sand model with elliptic surface
MIT-S1	mits1model.md	Unified effective-stress soil model for clays and sands	Critical-state model with bounding-surface plasticity and evolving anisotropy
SANICLAY	saniclaymodel.md	Anisotropic saturated clays	SANICLAY-family anisotropic critical-state clay plasticity
SSLSM / Subloading	sslsmmodel.md	Overconsolidated soils; structured soils (via RS)	Subloading-surface plasticity with superloading and structure effects
SANISAND-type (`sanisand_type`)	sanisandmodel.md	Sands under monotonic and cyclic loading	Bounding-surface sand model with fabric evolution
NorSand	norsandmodel.md	State-parameter sands	Image-stress hardening and state-parameter framework
Multi-Yield (Elgamal)	elgamalmodel.md	Cyclic mobility / liquefaction-oriented sand response	Pressure-dependent multi-yield model with strain-space cyclic mobility mechanism

1.6 Analysis scope and material class

The table below is a practical guide to which models are mainly elastic, which are intended for sand, clay, or rock, and which models are documented for variably saturated (unsaturated) analyses. Here, `Coupled / fully coupled mechanical use` means the model can act as the mechanical part of that analysis when the required hydraulic, phase, SWRC, and effective-stress components are also defined. `Available for unsaturated analyses` means the model can be used in a variably saturated analysis; depending on the model, suction/saturation effects may enter through the selected effective-stress model, through explicit suction-dependent constitutive terms, or both.

Model	Typical material class	Uncoupled	Coupled / fully coupled mechanical use	Available for unsaturated analyses	Typical use
Linear Elasticity	General elastic solids	Yes	Yes	No	Baseline elastic benchmarks
Orthotropic Elasticity	Layered / anisotropic elastic media	Yes	Yes	No	Direction-dependent elastic response
Nonlinear Elastic	Stress-dependent elastic soils	Yes	Yes	Yes (via effective stress)	Pressure-dependent stiffness without plastic flow (suction effects enter via effective stress, not via this UMAT)

Model	Typical material class	Uncoupled	Coupled / fully coupled mechanical use	Available for unsaturated analyses	Typical use
Mohr-Coulomb	General frictional soils	Yes	Yes	Yes	General geotechnical strength problems, including suction-strength effects when configured
Hoek-Brown	Rock and rock mass	Yes	Yes	No	Rock-mass strength and dilation
Mohr Hardening	Frictional soils / rockfill	Yes	Yes	No	Peak-residual frictional evolution (saturated formulation)
GCC	Unsaturated fine-grained soils	Yes	Yes	Yes	Suction-dependent critical-state response

Model	Typical material class	Uncoupled	Coupled / fully coupled mechanical use	Available for unsaturated analyses	Typical use
CASM	Critical-state soils	Yes	Yes	No	Unified clay-sand effective-stress response (saturated formulation)
MIT-S1	Unified effective-stress soils	Yes	Yes	No	Unified clay-sand effective-stress behavior with anisotropy (saturated formulation)
SANICLAY	Clays	Yes	Yes	No	Anisotropic clay response (saturated formulation)

Model	Typical material class	Uncoupled	Coupled / fully coupled mechanical use	Available for unsaturated analyses	Typical use
SSLSM / Subloading	Overconsolidated soils; structured soils (via RS)	Yes	Yes	No	Subloading-surface response with structure effects (saturated formulation)
SANISAND-type (`sanisand_type`)	Sands	Yes	Yes	Yes	Advanced monotonic and cyclic sand plasticity (optional unsaturation coupling)
NorSand	Sands	Yes	Yes	No	State-parameter sand behavior (saturated formulation)

Model	Typical material class	Uncoupled	Coupled / fully coupled mechanical use	Available for unsaturated analyses	Typical use
Multi-Yield (Elgamal)	Medium-dense sands under cyclic mobility	Yes	Yes	No	Cyclic mobility and liquefaction-oriented response (saturated formulation)

Loading-path suitability (for example, monotonic versus cyclic, drained versus undrained, and triaxial versus simple-shear style paths) is model-specific and is documented on each model page. Many model pages also include a packaged FALCON mini with bundled verification cases that illustrate the typical response under those paths.

1.7 FALCON minis and constitutive pages

Most constitutive models have a corresponding mini under `mini_tools/`. These standalone single-point drivers package the live UMAT with case-based input files and are useful for:

- checking a constitutive response without building a full FEM model
- reproducing standard triaxial, simple-shear, cyclic, or isotropic paths
- low-cost calibration and parameter-sensitivity studies at the single-point level

The constitutive page remains the primary source for equations, parameter definitions, and citations.

1.8 Related pages

- materialmodels-syntax.md
- phaseproperties.md
- permintro.md
- swrcintro.md
- gk2024.md