



AD FALCON API Manual

# Anisotropic Permeability Model

Javad Ghorbani

March 26, 2026

## Contents

|          |                                                        |          |
|----------|--------------------------------------------------------|----------|
| <b>1</b> | <b>Anisotropic Permeability Model</b>                  | <b>3</b> |
| 1.1      | Syntax                                                 | 3        |
| 1.2      | Mathematical Formulation                               | 3        |
| 1.2.1    | Interaction with Relative Permeability Models          | 3        |
| 1.2.2    | For Coupled Analyses (Water Only)                      | 3        |
| 1.2.3    | For Fully Coupled Analyses (Water and Air)             | 4        |
| 1.3      | Parameter Specification                                | 4        |
| 1.3.1    | Isotropic Case                                         | 4        |
| 1.3.2    | Transversely Isotropic Case                            | 4        |
| 1.3.3    | Fully Anisotropic Case                                 | 4        |
| 1.4      | Optional Specification                                 | 5        |
| 1.5      | Material Requirements                                  | 5        |
| 1.6      | Examples                                               | 5        |
| 1.6.1    | Example 1: Transversely Isotropic (Layered Soil)       | 5        |
| 1.6.2    | Example 2: Fully Coupled with Anisotropic Permeability | 5        |
| 1.7      | Physical Interpretation                                | 6        |
| 1.8      | Dimensional Consistency                                | 6        |
| 1.9      | Related Documentation                                  | 6        |

## 1 Anisotropic Permeability Model

The Anisotropic Permeability model allows specification of a full permeability tensor to account for directional variations in soil permeability. This is essential for modeling soils with layered structures, preferential flow paths, or other anisotropic characteristics.

### 1.1 Syntax

```
@AnisotropicPerm: <XX> <YY> <ZZ> <XY> <ZX> <ZY>
```

**Format:** Six permeability coefficients representing the full permeability tensor: - XX, YY, ZZ: Diagonal components (principal directions) - XY, ZX, ZY: Off-diagonal components (shear terms)

### 1.2 Mathematical Formulation

The anisotropic permeability tensor,  $\mathbf{k}$ , is a symmetric 3×3 tensor:

$$\mathbf{k} = \begin{bmatrix} k_{xx} & k_{xy} & k_{xz} \\ k_{yx} & k_{yy} & k_{yz} \\ k_{zx} & k_{zy} & k_{zz} \end{bmatrix}$$

where  $k_{xy} = k_{yx}$ ,  $k_{xz} = k_{zx}$ , and  $k_{yz} = k_{zy}$  due to symmetry.

#### 1.2.1 Interaction with Relative Permeability Models

The anisotropic permeability model works in conjunction with isotropic permeability models specified via @Perm:. The final permeability tensor components are computed as:

$$k_{ij}^{final} = k_{ij}^{aniso} \times k_r(S_e, e) \times k_{sat} / \mu$$

where: -  $k_{ij}^{aniso}$ : Anisotropic scaling factor from @AnisotropicPerm: -  $k_r(S_e, e)$ : Relative permeability from the @Perm: model (depends on effective saturation  $S_e$  and void ratio  $e$ ). The void ratio effect is incorporated into  $k_r$  through the void ratio correction factor  $k_c$  when applicable (see [Void Ratio Affected Constant Permeability](#), [van Genuchten Permeability](#), and [Brooks-Corey Permeability](#)) -  $k_{sat}$ : Saturated permeability from the @Perm: model (constant, not affected by void ratio) -  $\mu$ : Fluid viscosity (water viscosity for liquid, gas viscosity for air)

#### 1.2.2 For Coupled Analyses (Water Only)

In coupled analyses, only water permeability is computed:

$$k_{w,ij} = k_{ij}^{aniso} \times k_{rw}(S_e, e) \times k_{sat} / \mu_w$$

where  $k_{rw}$  is the relative permeability for water from the @Perm: model, and  $S_e = 1.0$  (fully saturated).

### 1.2.3 For Fully Coupled Analyses (Water and Air)

In fully coupled analyses, both water and air permeabilities are computed:

#### Water permeability:

$$k_{w,ij} = k_{ij}^{aniso} \times k_{rw}(S_e, e) \times k_{sat}/\mu_w$$

#### Air permeability:

$$k_{a,ij} = k_{ij}^{aniso} \times k_{rg}(S_e, e) \times k_{sat}/\mu_g$$

where: -  $k_{rw}$ : Relative permeability for water from the @Perm: model -  $k_{rg}$ : Relative permeability for gas from the @Perm: model -  $S_e$ : Effective saturation (computed from SWRC model) -  $\mu_w$ : Water viscosity -  $\mu_g$ : Gas viscosity

## 1.3 Parameter Specification

### 1.3.1 Isotropic Case

For isotropic permeability, use equal diagonal values and zero off-diagonal terms:

```
@AnisotropicPerm: 1.0 1.0 1.0 0.0 0.0 0.0
```

This is equivalent to not specifying @AnisotropicPerm: at all (the code defaults to isotropic behavior).

### 1.3.2 Transversely Isotropic Case

For transversely isotropic materials (e.g., horizontally layered soils), use:

```
@AnisotropicPerm: 1.0 1.0 0.1 0.0 0.0 0.0
```

This represents: - Horizontal permeability:  $k_{xx} = k_{yy} = 1.0$  (reference) - Vertical permeability:  $k_{zz} = 0.1$  (10% of horizontal) - No cross-coupling:  $k_{xy} = k_{zx} = k_{zy} = 0.0$

### 1.3.3 Fully Anisotropic Case

For fully anisotropic materials, specify all six components:

```
@AnisotropicPerm: 1.0 0.5 0.2 0.1 0.05 0.02
```

This represents a general anisotropic permeability tensor with: - Principal components:  $k_{xx} = 1.0$ ,  $k_{yy} = 0.5$ ,  $k_{zz} = 0.2$  - Off-diagonal components:  $k_{xy} = 0.1$ ,  $k_{zx} = 0.05$ ,  $k_{zy} = 0.02$

## 1.4 Optional Specification

**Important:** The @AnisotropicPerm: directive is **optional**. When not specified: - The code defaults to isotropic permeability behavior - All permeability tensor components use the same value from the @Perm: model - The permeability tensor becomes:  $k_{ij} = k_r(S_e, e) \times k_{sat} / \mu$  for  $i = j$ , and  $k_{ij} = 0$  for  $i \neq j$

## 1.5 Material Requirements

- **Coupled analyses (\*Coupled):** Requires @Perm: directive. Anisotropic permeability is optional.
- **Fully coupled analyses (\*FullyCoupled):** Requires @Perm: and @SWRC: directives. Anisotropic permeability is optional.

## 1.6 Examples

### 1.6.1 Example 1: Transversely Isotropic (Layered Soil)

```
% Materials
LayeredClay
@UMAT:/path/to/GCCUMAT.cpp /path/to/GCCUMAT.hpp Mechanical lambda=0.2
kappa=0.05 M=1.25
@Perm: VanGenuchten m 0.98 k_sat 1e-10
@AnisotropicPerm: 1.0 1.0 0.1 0.0 0.0 0.0
@PhaseChar: Solid rhos 2.7
@PhaseChar: Liquid rhow 0.997 K_l 2.25e6 l_viscosity 1e-6
%%%
```

Horizontal permeability is 10 times larger than vertical permeability.

### 1.6.2 Example 2: Fully Coupled with Anisotropic Permeability

```
% Materials
AnisotropicSoil
@UMAT:/path/to/GCCUMAT.cpp /path/to/GCCUMAT.hpp Mechanical lambda=0.2
kappa=0.05 M=1.25
@SWRC: Hysteretic alpha_1 0.5 n 1.4 m 0.5 omega_prime 0.1 alpha_2 0.2 bd
0.05 bw 0.05 SW_max 0.45 SW_min 0.05 b_s_c 0.01
@EffectiveStress: GhorbaniKodikara Beta1 0.55 Beta2 0.25
@Perm: BrooksCorey lambda 1.5 k_sat 1e-12
@AnisotropicPerm: 1.0 0.8 0.3 0.0 0.0 0.0
@PhaseChar: Solid rhos 2.7
@PhaseChar: Liquid rhow 0.997 K_l 2.25e6 l_viscosity 1e-6
```

```
@PhaseChar: Gas rhog 1.1e-3 k_g 1.01e2 g_viscosity 1.8e-5
%%%
```

Both water and air permeabilities will be anisotropic, with the same directional scaling factors applied to both phases.

## 1.7 Physical Interpretation

- **Diagonal components:**  $k_{xx}$ ,  $k_{yy}$ ,  $k_{zz}$  represent permeability in the X, Y, and Z directions
- **Off-diagonal components:**  $k_{xy}$ ,  $k_{zx}$ ,  $k_{zy}$  represent coupling between directions

For most geotechnical applications, off-diagonal terms are zero when the coordinate system aligns with the principal directions of anisotropy.

## 1.8 Dimensional Consistency

All anisotropic permeability coefficients are **dimensionless scaling factors**. The actual permeability values have dimensions  $L^2$  (length squared), but the anisotropic coefficients multiply the base permeability from the @Perm: model, which already has the correct dimensions.

The final permeability tensor components have dimensions  $L^2/(M \cdot T)$  when divided by viscosity, or  $L/T$  when expressed as hydraulic conductivity, where: - **L**: length - **M**: mass - **T**: time

## 1.9 Related Documentation

- [Permeability Overview](#) - General permeability models
- [Constant Permeability](#) - Isotropic constant permeability
- [Void Ratio Affected Constant Permeability](#) - Void ratio effects
- [van Genuchten Permeability](#) - Van Genuchten relative permeability
- [Brooks-Corey Permeability](#) - Brooks-Corey relative permeability
- [Materials](#) - General material property definitions