



AD FALCON API Manual

# Nonlinear Elasticity (Pressure-Dependent)

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## Contents

<b>1</b>	<b>Nonlinear Elasticity (Pressure-Dependent)</b>	<b>3</b>
1.1	Syntax	3
1.2	Material parameters	3
1.3	Constitutive relation	4
1.3.1	Bulk Modulus	4
1.3.2	Shear Modulus	4
1.4	FALCON mini	4
1.4.1	How to run	4
1.4.2	Input syntax	4
1.4.3	Hydromechanical assumptions	6
1.4.4	Sample input	7
1.4.5	Output files and columns	7
1.5	Results	8
1.6	Applications and limitations	9
1.7	References	9

## 1 Nonlinear Elasticity (Pressure-Dependent)

This model provides pressure-dependent elastic stiffness without plastic flow. The bulk and shear moduli scale with void ratio and mean effective stress following the form used in SANISAND-type sand models (Dafalias and Manzari, 2004; Taiebat and Dafalias, 2008).

### 1.1 Syntax

This model is configured in % `Materials` as a user-defined mechanical material. Use `@UMAT:` with category `Mechanical` and pass the parameters as `name=value` pairs.

Example:

```
@UMAT: path/to/nonlinear_elastic.cpp path/to/nonlinear_elastic.hpp
Mechanical K0=400 G0=200 PATM=101325 P_min=1.0
```

See [Material Models: Syntax & Conventions](#) for shared rules.

### 1.2 Material parameters

Symbol	Keyword in input	Units	Required	Description
$K_0$	<code>K0</code>	–	✓	Bulk modulus constant in the hypoelastic law.
$G_0$	<code>G0</code>	–	✓	Shear modulus constant in the hypoelastic law.
$p_{atm}$	<code>PATM</code>	stress	✓	Atmospheric reference pressure used in normalization.
STOL	<code>STOL</code>	–	✓	Integration tolerance for substepping.
$P_{min}$	<code>P_min</code>	stress	✓	Minimum pressure threshold for numerical robustness.

## 1.3 Constitutive relation

### 1.3.1 Bulk Modulus

$$K = K_0 p_{atm} \frac{(1+e)}{e} \left( \frac{p'}{p_{atm}} \right)^{\frac{2}{3}} \quad (1)$$

### 1.3.2 Shear Modulus

$$G = G_0 p_{atm} \frac{(2.97-e)^2}{1+e} \left( \frac{p'}{p_{atm}} \right)^{\frac{1}{2}} \quad (2)$$

## 1.4 FALCON mini

The packaged mini tool id is NonlinearElastic. It lives under mini\_tools/NonlinearElastic.

### 1.4.1 How to run

Run any packaged analysis by passing its case directory:

```
falcon --mini-root /path/to/UMATLIB_FALCON/falcon_minis --mini-tool
NonlinearElastic --mini-input
/path/to/UMATLIB_FALCON/falcon_minis/NonlinearElastic/cases/drained
```

Packaged simulation families:

Packaged case	Path	Purpose
Isotropic compression	<a href="#">cases/isotropic/input.txt</a>	Isotropic compression reference path for the pressure-dependent bulk response.
Drained triaxial	<a href="#">cases/drained/input.txt</a>	Monotonic drained triaxial reference path.

### 1.4.2 Input syntax

input.txt is a simple Key = Value file, for example:

```
Mode = Drained
G0 = 125.0
K0 = 150.0
StressXX = -100.0
```

The main driver selector is Mode.

Mode value	Meaning in the standalone mini	Mechanical constraint
IsotropicCompression	Isotropic compression using the same strain increment in xx, yy, and zz.	Prescribed volumetric strain path with $q = \phi$ .
Drained	Axisymmetric drained triaxial loading.	Lateral stress is kept constant by solving the radial strain increment from the current tangent.

Mini inputs used by the packaged cases:

Material and numerical inputs:

Input key	Used by	Required / choices / defaults	Meaning
G <sub>0</sub>	all cases	Required in packaged cases	Reference shear modulus parameter of the nonlinear elastic law.
K <sub>0</sub>	all cases	Required in packaged cases	Reference bulk-modulus parameter controlling the mean-stress dependence.
PATM	all cases	Required in packaged cases	Atmospheric normalization pressure.
P_min	all cases	Optional; driver default if omitted	Lower pressure floor used in the modulus evaluation.
STOL	all cases	Optional; driver default if omitted	Integration tolerance used by the standalone driver and UMAT.

Initial-state inputs:

Input key	Used by	Required / choices / defaults	Meaning
StressXX, StressYY, StressZZ	all cases	Required in packaged cases	Initial total stress components. The packaged cases use an isotropic starting stress state.
StressZY, StressZX, StressXY	optional	Optional; default 0 if omitted	Initial shear stresses if a non-axisymmetric state is required.
VoidRatio	all cases	Required in packaged cases	Initial void ratio used in the nonlinear modulus law.

#### Loading controls:

Input key	Used by	Required / choices / defaults	Meaning
nSteps	all cases	Required in packaged cases	Number of driver increments.
dEpsIsotropic	Isotropic Compression	Required for Mode = Isotropic Compression	Isotropic strain increment applied to xx, yy, and zz.
dEpsAxial	Drained	Required for triaxial mode	Axial strain increment for the triaxial branch. Compression is negative in the packaged drivers.
OutputCSV	all cases	Optional; case-specific default if omitted	Output file name written in the case directory.

### 1.4.3 Hydromechanical assumptions

The packaged NonlinearElastic mini is purely mechanical:

- there is no plastic flow
- there is no hardening variable
- there is no suction, saturation, or retention update

- all nonlinearity comes from the stress dependence of the elastic stiffness

So this mini is useful when you want pressure-dependent stiffness without irreversible strain accumulation.

#### 1.4.4 Sample input

**Drained triaxial example** Path: [mini\\_tools/NonlinearElastic/cases/drained/input.txt](#)

```
Mode = Drained
G0 = 125.0
K0 = 150.0
PATM = 100.0
P_min = 0.1
nSteps = 200
dEpsAxial = -1.0e-4
OutputCSV = stress_results.csv
StressXX = -100.0
StressYY = -100.0
StressZZ = -100.0
VoidRatio = 0.8941
```

This is the monotonic drained reference path. It is the simplest packaged case for seeing how the elastic tangent stiffens with confinement while the driver enforces constant radial stress.

**Isotropic compression example** Path: [mini\\_tools/NonlinearElastic/cases/isotropic/input.txt](#)

This packaged case isolates the isotropic pressure-dependent elastic response with  $q = 0$  throughout.

#### 1.4.5 Output files and columns

The isotropic case writes `results.csv`. The drained case writes `stress_results.csv`.

Output file	Produced by	Main use
<code>results.csv</code>	isotropic compression	Isotropic stress-strain history.
<code>stress_results.csv</code>	drained triaxial	Main triaxial history file.

Primary output columns:

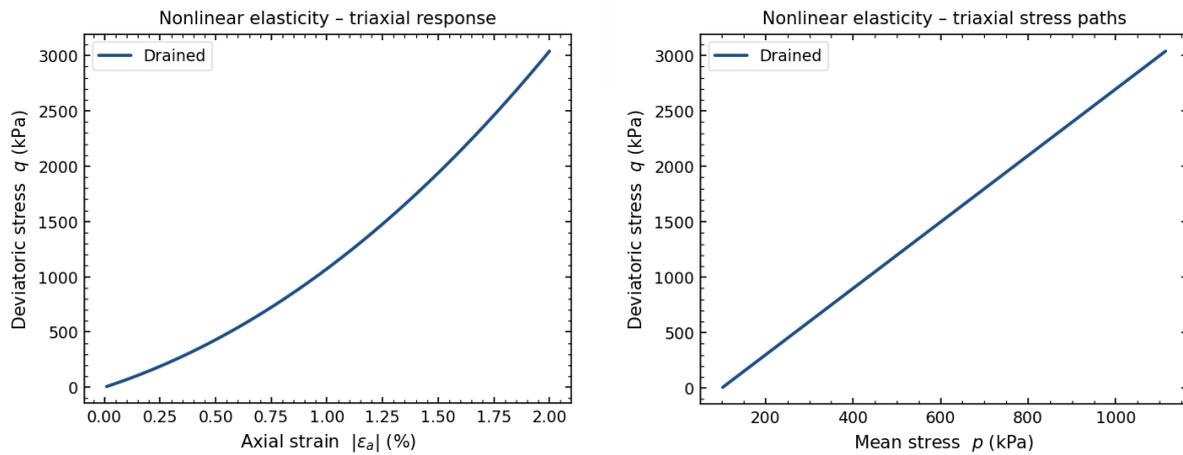
Output column	Meaning
step, mode	Driver bookkeeping.
exx, eyy, ezz, epsv	Strain components and volumetric strain.
sxx, syy, szz, q, p	Stress components and stress invariants.
void_ratio	Void ratio carried by the standalone driver.

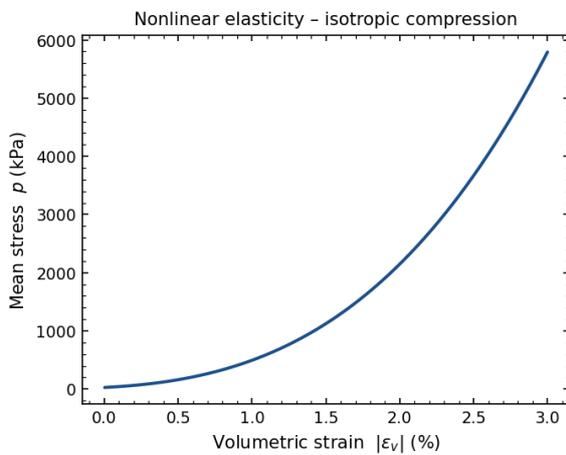
When reading the packaged outputs, inspect q and p first, then epsv and void\_ratio to see how the elastic volume change develops under the chosen loading path.

The plots in the next section are generated from these packaged case CSVs.

### 1.5 Results

The plots below are produced directly from the bundled FALCON mini case inputs under mini\_tools/NonlinearElastic/cases. The packaged examples all use the same nonlinear elastic parameter set so the influence of the loading path is easy to read.





Bundled cases [cases/drained/input.txt](#) and [cases/isotropic/input.txt](#). Top-left:  $q$ - $v$  response for drained triaxial loading. Top-right: the corresponding  $p$ - $q$  drained stress path. Bottom-left: mean stress versus volumetric strain under isotropic compression, showing the pressure-dependent bulk stiffness of the model.

## 1.6 Applications and limitations

- Best suited to problems where stress-dependent stiffness is important but irreversible plastic deformation is not required.
- Can be used as the mechanical law in uncoupled, coupled, or fully coupled analyses when the rest of the material definition is supplied separately.
- It does not generate plastic strains, hardening, softening, suction-dependent yield behavior, or cyclic mobility effects.

## 1.7 References

1. Dafalias, Y. F., and Manzari, M. T. (2004). Simple plasticity sand model accounting for fabric change effects. *Journal of Engineering Mechanics*, 130(6), 622-634.
2. Taiebat, M., and Dafalias, Y. F. (2008). SANISAND: Simple anisotropic sand plasticity model. *International Journal for Numerical and Analytical Methods in Geomechanics*, 32(8), 915-948.