AD FALCON API Manual

Footing on Soil Modeled by the Cam Clay Elasticity Model

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1.1 Input File Name

File 1 (direct initial stress + equilibrium):
`fem_data_Clay_elasticity.txt`

File 2 (geostatic by body force + material switch using `% Step Materials`):
`fem_data_Clay_elasticity_stepmaterials.txt`

1.2 Problem Description

This study investigates the behavior of a rigid strip footing resting on a sand layer modeled using the Cam Clay Elasticity Model. The analysis evaluates soil response and footing pressures. The primary objective is to compare the evolution of the **void ratio** from FEM simulations with a closed-form analytical solution.

1.3 Model Setup

- **Footing Type**: Smooth rigid strip footing
- **Footing Width**: $B = 2$ m
- **Material Model**: Cam Clay Elasticity (UMAT)
- **Material Properties**:
  - κ: 0.02
  - ν **(Poisson's ratio)**: 0.3
  - $P_{\min}$: 0.1
  - **Solid density** ρ_s: 2.7 (for the direct-initial-stress case)

1.4 Analysis Properties (from input)

- **AnalysisType**: `PLUnCoupled`
- **Simulation Mode**: `Static`
- **SolverType**: `Direct`
- **ModernAutoInc**: `Yes`
- **StepTime**: `1.0`
- **InitialStepIncrement**: `1.0e-3`
- **MinTimeStep / MaxTimeStep**: `1.0e-7` / `1.0e0`
- **MaxIterations**: `100`
- **ErrorTarget**: `1.0e-3`
- **UseModifiedNewton**: `No`
- **UL**: `No`
- **OutputTypes**: `Displacement TotalStress VoidRatio`

1.4.1 Initialization and Actions

- Initial stress assignment at the base and a uniform initial void ratio:
  - `@Stress: H 0 values -25.8 -60.0 -25.8 0 0 0 ...`
  - `@Void: H 0 values 1.5 H 10 values 1.5`
- Post-step action to rebalance after initialization:

```
% PostStepActions
@PostStepAction  Id: 1
  Step: 0
  Type: EstablishEquilibrium
%%%
```

1.4.2 Loading

- A prescribed vertical displacement (ramp to `-0.2`) is applied to the rigid footing nodes in `DisY`:

```
@PrescribedValue Displacement 1
@@DOF: DisY
@@Amplitude: -0.2
@@LoadType: Ramp
@@StartStep: 1
@@NodeIds: 776 782 808 807 817 827 825 828 837 839 841
@@Propagate: Yes
%%%
```

1.5 Initial Stress and Void Ratio Fields

A proper definition of the initial stress and void ratio fields is essential for accurate simulation results. These fields can be established either through direct initialization or by applying body forces.

In FALCON's input language, the following block:

```
% PostStepActions
@PostStepAction  Id: 1
  Step: 0
  Type: EstablishEquilibrium
%%%
```

ensures that immediately after completing **Step 0**, subsequent steps start without any unbalanced force. Without this action, an assigned initial stress (e.g., via body forces or

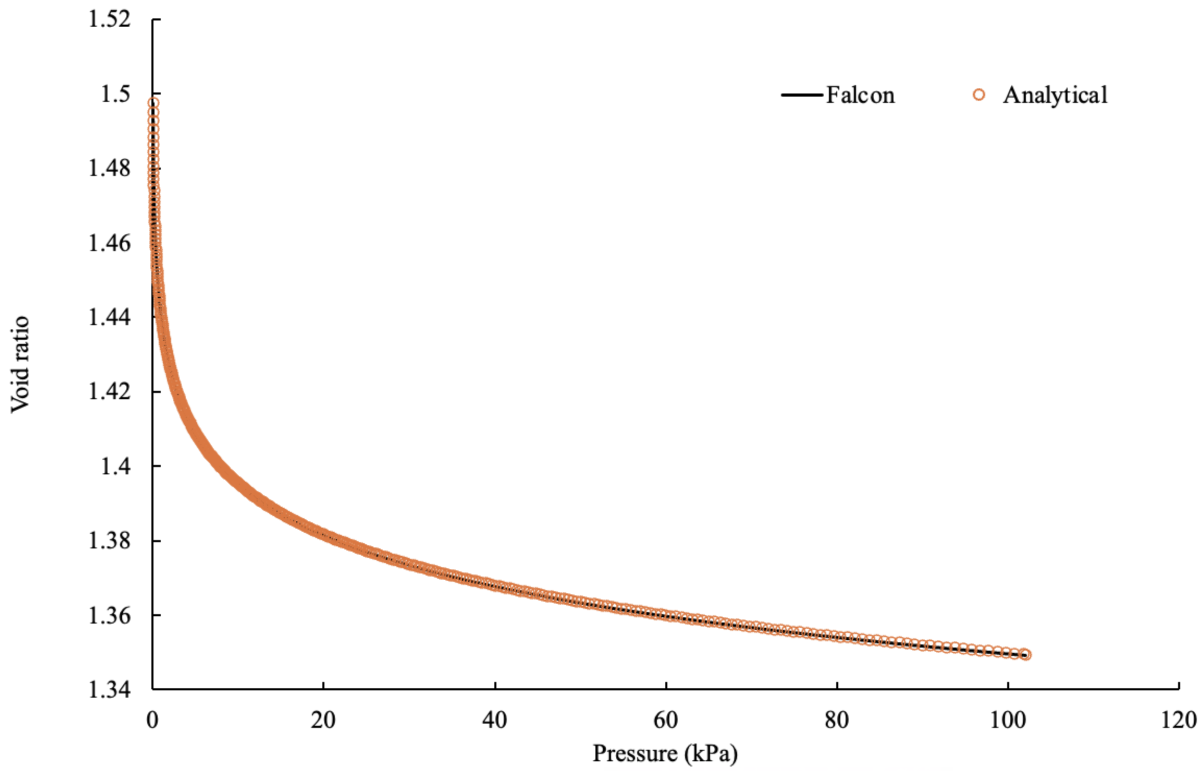

Figure 1: Void ratio vs pressure at (0,10) m

predefined fields) would leave unbalanced nodal forces which may lead to divergence or spurious displacements in later steps. For further information see Post Step Actions.

- The **initial void ratio field** is defined uniformly, with the soil possessing a value of **1.5**.
- Once the initial conditions are set, a vertical displacement of $0.1B$ is imposed on the footing to induce soil failure conditions.

1.6 Finite Element Model

- **Element Type**: 6-noded triangular elements
- **Boundary Conditions**:
  - Bottom boundary fully fixed.
  - Lateral boundaries restrained horizontally.
  - Uniform vertical displacement imposed on the footing.

1.7 Comparison with Closed-Form Solution

The numerical results obtained from FEM simulations are presented in Figure 1, comparing the evolution of the **void ratio** with the closed-form analytical solution.

Figure 1: Void ratio evolution with pressure at a depth of (0,10) m.

1.8 Alternative workflow: Step 1 geostatic (linear elastic) → Step 2 loading (Clay Elasticity UMAT)

For the same footing problem, you can also establish the initial stress state via a **geostatic body-force step** (Step 1), then apply the footing settlement in **Step 2**.

In practice, a clean way to do this in a **single run** is to define both materials in `% Materials` and then switch the soil elements at **Step 2 start** using `% Step Materials`.

- Define a `@Mech: Elastic` material for Step 1 geostatic equilibrium.
- Define the `@UMAT: ... ClayElasticityUMAT ...` material for Step 2.
- In `% Step Materials @Step 2`, assign the UMAT material ID to the target elements (often `@@Elements: All` for this example).

Why use linear elasticity (or a "less nonlinear" model) for geostatic?

- A geostatic step is primarily a way to establish a stress field and reach equilibrium; if a highly nonlinear/plastic model is used during the gravity ramp it can yield and accumulate irreversible strains before the actual loading step, which makes the later response harder to interpret.
- A simple elastic model is often more robust for convergence in the equilibrium step (fewer path-dependent internal variables evolving during the ramp), while still producing the intended stress distribution once equilibrium is reached.

In `fem_data_Clay_elasticity_stepmaterials.txt`, the solid density `@PhaseChar: Solid rhos` is intentionally set to `0.7645` so that the gravity-driven geostatic stress level matches the direct-initial-stress setup (i.e., the same stress field is generated without prescribing stresses explicitly). This keeps the Step 2 response comparable between the two approaches.

Both workflows are intended to produce the same **void ratio–pressure** response governed by the Clay Elasticity law; any remaining differences are typically due to solver tolerances and how the initial equilibrium is established.

1.9 Direct vs geostatic-switch comparison

Both input files include a `% PointStateOutput` at `(x,y)=(0.0, 9.999)` to record `Stress YY` and `VoidRatio`, allowing a direct comparison of the void-ratio response beneath the footing centerline.

The slight difference between the curves is due to a mild change in void ratio during the body-force (gravity) application step. This can be reduced by choosing a higher elastic modulus for the geostatic elasticity model, which minimizes volumetric strain during the gravity ramp.

Figure 2: Void ratio vs vertical stress (`-StressYY`) at `(x,y)=(0.0, 9.999)` (just below the footing centerline), comparing the direct-initial-stress case vs the geostatic + step-material switch case.

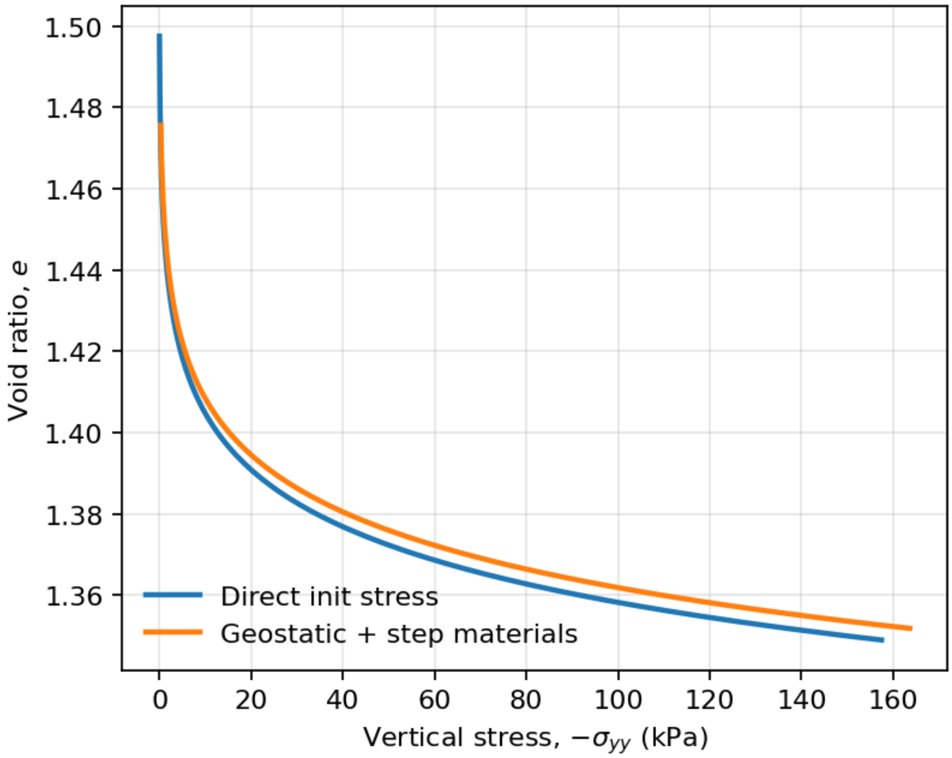

Figure 2: Direct vs step-materials comparison