AD FALCON API Manual

Footing on Soil Modeled by the Nonlinear Elastic Model

Javad Ghorbani

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1.1 Input File Name

fem_nonlinear_elastic.txt

1.2 Problem Description

This study examines the behavior of a rigid strip footing resting on a sand layer modeled using the Nonlinear Elastic Model. The analysis utilizes the **Finite Element Method (FEM)** to assess soil response and footing pressures. Particular emphasis is placed on comparing 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**: Nonlinear Elastic Model
- **Material Properties**:
  - **Initial Shear Modulus (G0)**: (125.0)$
  - **Initial Bulk Modulus (K0)**: (150.0)$
  - **Atmospheric Pressure (PATM)**: 100.0 kPa
  - **Minimum Pressure (P_min)**: 0.1 kPa *(This parameter prevents negative moduli when pressures become very low.)*
  - **Stress Tolerance (STOL)**: 1.0×10^{-5}

1.4 Initial Stress and Void Ratio Fields

Establishing proper initial stress and void ratio fields in the soil domain is critical for the accuracy of the simulation. This can be accomplished either by applying initial stresses and void ratios directly or through the application of body forces combined with predefined void ratios.

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 predefined fields) would leave unbalanced nodal forces which may lead to divergence or

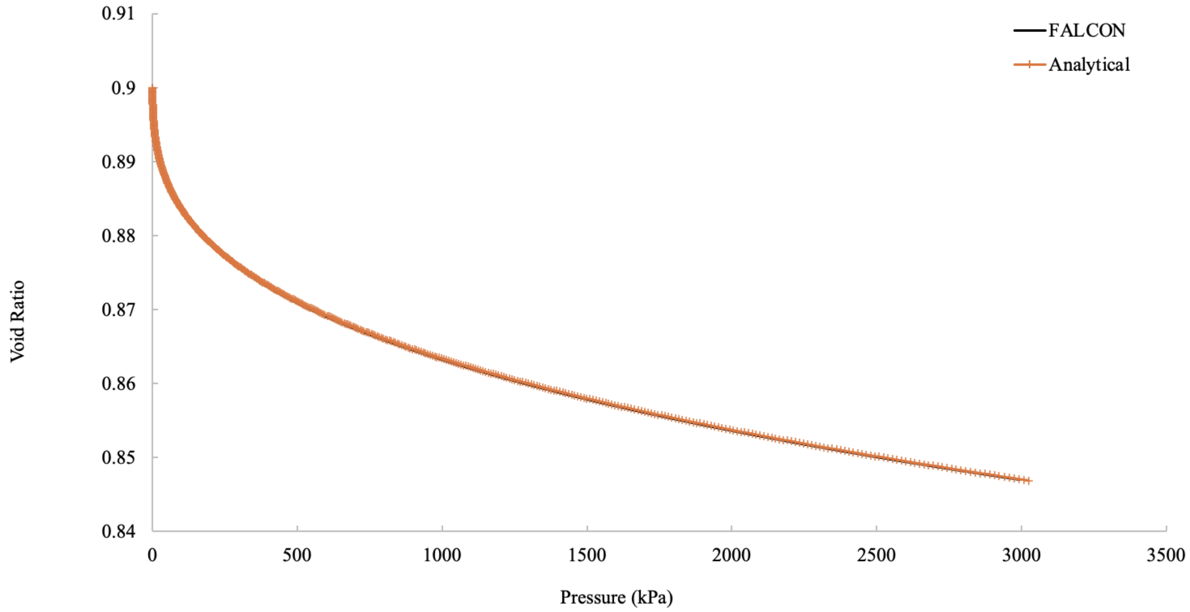

Figure 1: Void ratio vs pressure at (0,10) m

spurious displacements in later steps. For further information see Post Step Actions.

- The buoyant unit weight of the soil is set to 6 kN/m^3 to generate the initial stress distribution with the coefficient of earth pressure at rest being set to 0.5.
- The initial void ratio field must also be defined to ensure accurate simulation of soil behavior. In this example, the initial void ratio of 0.9 is assigned to the entire domain.

1.5 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.

1.6 Comparison with Closed-Form Solution

Figure 1 presents the numerical results obtained from the FEM simulations, comparing the evolution of the **void ratio** with the closed-form analytical solution provided by Ghorbani and Airey (2021).

Reference: Ghorbani, J., Airey, D.W. (2021). Modelling stress-induced anisotropy in multiphase granular soils. *Computational Mechanics*, 67, 497–521. `https://doi.org/10.1007/s00466-020-01945-8`

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

The comparison with the closed-form analytical solution confirms the model's accuracy in predicting void ratio changes under loading conditions.

1.7 Alternative Approach (Body Force → then Displacement)

1.8 Input File Name

fem_nonlinear_elastic body force

```
% Initial Assignments
@Stress: H 0 values -0.1 -0.1 -0.1 0 0 0 H 10 values 0.0 0.0 0.0 0 0 0
@Void: H 0 values 0.9 H 10 values 0.9
%%%

% Step Definitions
@Step 1:
@@SolverType: Direct
@@StartStep: 0
@@StepTime: 1.0
@@NumberSteps: 100
@@OutputInterval: 1
@@ErrorTarget: 1e-1
@@OutputTypes: Displacement EffStress  VoidRatio
@@Geostatic: No
@@UL: No
@@SimMode: Static
%%%

% Step Definitions
@Step 2:
@@StartStep: 1
@@StepTime: 1.0
@@ModernAutoInc: Yes
@@SolverType: Direct
@@MaxIterations: 100
@@OutputInterval: 1
@@InitialStepIncrement: 1e-3
@@UseModifiedNewton: No
@@OutputTypes: Displacement EffStress  VoidRatio
@@Geostatic: No
@@MinTimeStep: 1e-7
@@MaxTimeStep: 1.0e-2
@@ErrorTarget: 1.0e-3
@@UL: No
@@SimMode: Static
%%%
```

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

% Body Force
Force 0.0 -9.81 0.0
WaterContribution 0.0 0.0 0.0
AirContribution 0.0 0.0 0.0
ElementIDs All
LoadType Ramp Step 1
StartStep 1
Propagate: FinalStep 2
DisplacementReset: End of Step 1
%%%

% Restrain Dofs
Id: 1
Step: 2
776 DisY
782 DisY
808 DisY
807 DisY
817 DisY
827 DisY
825 DisY
828 DisY
837 DisY
839 DisY
841 DisY
%%%

% Prescribed Values
@PrescribedValue Displacement 1
@@DOF: DisY
@@Amplitude: -0.2
@@LoadType: Ramp
@@StartStep: 2
@@Frequency: 0.0
@@DampingFactor: 0.0
@@PhaseLag: 0.0
@@NodeIds: 776 782 808 807 817 827 825 828 837 839 841
@@Propagate: Yes
```

```
%%%
```

1.9 Detailed Analysis Procedure (what each block does)

1.9.1 1) Initial Assignments (Step 0 → pseudo-time)

- Assigns a vertical **stress profile** (`@Stress: H 0 ... H 10 ...`) and **void ratio** (`@Void: ...`) across the depth. This is to establish the correct initial stress state for pressure-dependent models, ensuring that elastic moduli are initialized consistently with in-situ pressure.

1.9.2 2) Establish Equilibrium (PostStepAction @ Step 0)

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

- Reads back the in-situ stresses defined at the end of Step 0, integrates them to **internal nodal forces** and ensure spurious motions are avoided when we turn on gravity/body force next.

1.9.3 3) Gravity / Body Force Application (StartStep 1 → Propagate to 2)

```
% Body Force
Force 0.0 -9.81 0.0
...
LoadType Ramp Step 1
StartStep 1
Propagate: FinalStep 2
DisplacementReset: End of Step 1
%%%
```

- **`Force 0.0 -9.81 0.0`** activates gravity in soild phase in the negative Y direction on **all elements**.

- **`LoadType Ramp Step 1`**: the magnitude is ramped within Step 1 (pseudo-time ramp).

- **`Propagate: FinalStep 2`** keeps the body force active through Step 2 so the in-situ weight remains during the footing loading.
- **`DisplacementReset: End of Step 1`**: clears any small accumulated displacements at the **end of Step 1**, while **retaining the stresses**. This resets the kinematic reference before applying the footing displacement—useful for cleaner settlement measurements.

Note on void ratio during gravity: While Step 1 ramps the body force, the Nonlinear Elastic model updates state variables at Gauss points based on the evolving stress state. In particular, the computed `VoidRatio` changes with the in-situ stress build-up, so the "initial" void ratio entering Step 2 is the one attained at the end of Step 1, not the originally assigned value. The `DisplacementReset` operation does not reset state variables. See State Variables.

1.10 note

Restrain DOFs (applied in Step 2): We intentionally do not restrain the footing nodes during the body-force (gravity) step so the mesh can settle and develop a realistic in-situ stress field without artificial reactions at the footing. At the start of Step 2 we then activate the vertical restraints on those nodes (DisY) and drive them with the prescribed displacement, which prevents rigid-body motion and makes the settlement boundary condition well-posed.

```
% Restrain Dofs
Id: 1
Step: 2
776 DisY
782 DisY
808 DisY
807 DisY
817 DisY
827 DisY
825 DisY
828 DisY
837 DisY
839 DisY
841 DisY
%%%
```