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DEV FALCON

AD FALCON API Manual

Rigid Strip Footing on Saturated Soils: Coupled Analysis with MCC Model

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1 Rigid Strip Footing on Saturated Soils: Coupled Analysis with MCC Model

1.1 Problem Description

This study investigates the fully coupled hydro-mechanical response of a saturated soil beneath a rigid strip footing using the MCC model. For the saturated case, two simulations are performed with identical material parameters but different characteristic loading times to demonstrate the transition from drained to undrained behavior:

- **Slow loading** ($t_{\text{load}} = 10^{15}$ s): Quasi-static loading allowing complete drainage, approaching drained conditions
- **Fast loading** ($t_{\text{load}} = 10^{5}$ s): Rapid loading with limited drainage, approaching undrained conditions

The problem uses the same geometry, boundary conditions, and material parameters as the uncoupled rigid footing analysis, allowing direct comparison between uncoupled (drained) and coupled analyses under different loading rates.

Reference

Sheng, D., Sloan, S. W., & Yu, H. S. (2000). *Aspects of finite element implementation of critical state models.* Computational Mechanics, 26, 185–196.

1.2 Input Files

Two input files are provided for the different loading rates:

- **Slow loading:** `fem_data_GCC_Sat_slow.txt` — Quasi-static loading ($t_{\text{load}} = 10^{15}$ s)
- **Fast loading:** `fem_data_GCC_Sat_fast.txt` — Rapid loading ($t_{\text{load}} = 10^{5}$ s)

1.3 Material Parameters

1.3.1 Modified Cam-Clay (MCC) Model

- **Friction angle** ϕ: 23°
- **Compressibility index** λ: 0.25
- **Poisson's ratio** ν: 0.30
- **Swelling index** κ: 0.05

- α **parameter**: 1.0 (MCC with circular yield surface)
- **Default isotropic hardening**: 50 kPa (minimum isotropic hardening in the domain)

- **Critical-state specific volume** v_{CSL}: $2.60 \rightarrow$ **Initial specific volume** v_N: 2.739

- **Overconsolidation pressure at surface**: 50 kPa

1.3.2 Hydraulic Parameters

- **Permeability (saturated)**: $k = 2.5 \times 10^{-14}$ m^2
- **Water density**: $\rho_w = 997$ kg/m^3
- **Water bulk modulus**: $K_w = 2.25 \times 10^6$ kPa
- **Water viscosity**: $\eta_w = 1.0 \times 10^{-3}$ Ns/m^2

Tolerance parameters - Stress tolerance (STOL): 1.0×10^{-6}
- **Yield surface tolerance (FTOL):** 1.0×10^{-4}
- **Loading/unloading detection tolerance (LTOL):** 1.0×10^{-6}

1.4 Initial Assignment

Initial stresses and the initial void ratio e_N are applied to the entire domain. For the coupled analysis, initial pore water pressure is also specified to establish hydrostatic conditions.

```
% Initial Assignments
@Stress: H 0 values -1e0 -1e0 -1e0 0 0 0 H 10 values -1e0 -1e0 -1e0 0 0 0
@Void: H 0 values 1.739 H 10 values 1.739
@OCR: H 0 values 0.0 H 10 values 0.0
@PoreWaterPressure: H 0 values 0.0 H 10 values 0.0
%%%
```

1.5 Step 1: Geostatic Initialization via Body Force

In Step 1, body forces are applied to establish the geostatic stress state. The flag `@@EnforceElasticFlag: All` temporarily deactivates plasticity during initialization.

```
% Step Definitions
@Step 1:
@@StartStep: 0
@@StepTime: 1.0
@@SolverType: Direct
```

```
@@NumberSteps: 10
@@OutputInterval: 10
@@OutputTypes: Displacement EffStress VoidRatio PoreWaterPressure
@@ErrorTarget: 1.0e-1
@@UL: No
@@SimMode: Static
@@EnforceElasticFlag: All
%%%
```

The body force is applied with the same parameters as the uncoupled analysis:

```
% 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
InitialVoidinBF: Yes
%%%
```

1.6 Yield Surface Correction

After geostatic stresses are established, the yield surface is corrected using `OverconsolidationControl ≠ 1`. We assumed the soil has an overconsolidation pressure of 50 kPa at the surface (`OCR = 0` and `DefIsoH = 50 kPa`), consistent with Sheng et al. (2000). The void ratio across the domain is then updated to enforce consistency conditions.

1.7 Geometry and Boundary Conditions

The geometry is identical to the uncoupled analysis:

Geometry - **Half-width of footing:** $B_a/2 = 1$ (m)
- **Soil domain:** 10×10 (m)

Mechanical Boundary Conditions - Side boundaries: **laterally restrained** (roller supports)
- Base: **vertically restrained** (fixed in Y direction)

Hydraulic Boundary Conditions - Top surface: **drained** (zero pore pressure) - Side boundaries and base: **impermeable** (zero flux)

1.8 Step 2: Loading (Prescribed Settlement Under the Footing)

1.8.1 Loading Scenarios

Two loading scenarios are simulated to examine the effect of loading rate:

Case 1: Slow Loading (Quasi-Static, Drained Response)

- **Characteristic loading time**: $t_{\text{load}} = 10^{15}$ s
- **Loading rate**: Quasi-static loading allowing nearly complete drainage
- **Expected behavior**: Response approaches the drained solution from uncoupled analysis

Case 2: Fast Loading (Partially Drained Response)

- **Characteristic loading time**: $t_{\text{load}} = 10^{5}$ s
- **Loading rate**: Rapid loading with limited drainage
- **Expected behavior**: Stiffer initial response due to transient effects, lower ultimate bearing capacity compared to drained case

1.8.2 Step Definition

```
% Step Definitions
@Step 2:
@@StartStep: 1
@@StepTime: 1.0e15  # Use 1.0e15 for slow loading or 1.0e5 for fast loading
@@ModernAutoInc: Yes
@@SolverType: Direct
@@MaxIterations: 10
@@OutputInterval: 100
@@InitialStepIncrement: 1e-3
@@UseModifiedNewton: No
@@OutputTypes: Displacement EffStress VoidRatio PoreWaterPressure
@@Geostatic: No
@@MinTimeStep: 1e-7
@@MaxTimeStep: 1.0e0
@@ErrorTarget: 1.0e-3
@@UL: No
@@SimMode: Static
%%%
```

1.8.3 Prescribed Displacement

The same downward displacement of -0.4 m is applied under the footing:

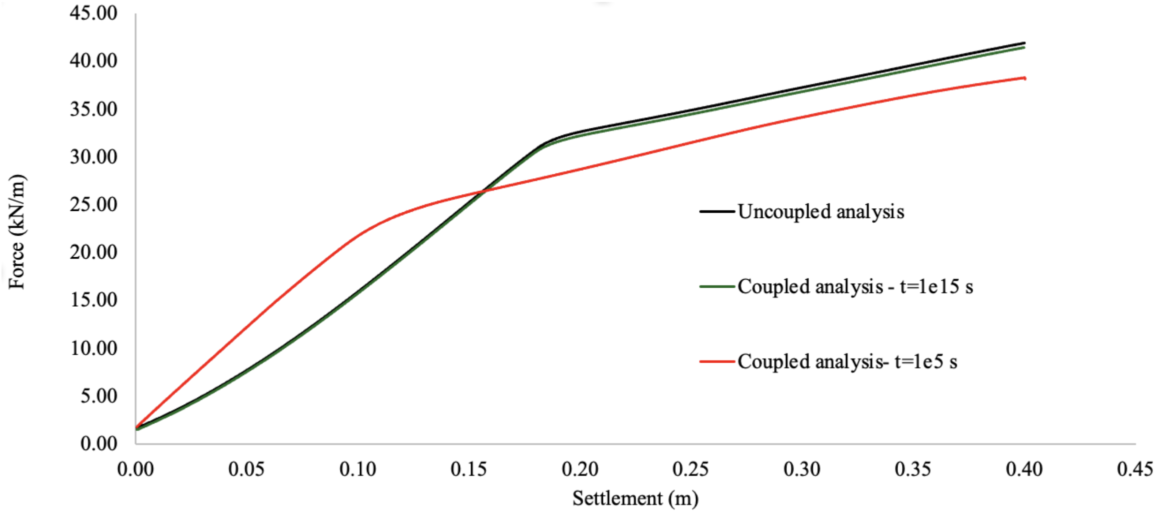

Figure 1: Load–deflection comparison for different loading rates

```
% Prescribed Values
@PrescribedValue Displacement 1
@@DOF: DisY
@@Amplitude: -0.4
@@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 Results

1.9.1 Load–Deflection Response

The figure below compares the **load–deflection** response for three cases: 1. **Uncoupled analysis** (drained, from rigidfootinggcc.md) 2. **Slow loading** ($t_{load} = 10^{15}$ s) — coupled analysis 3. **Fast loading** ($t_{load} = 10^{5}$ s) — coupled analysis

Figure 1. Load–deflection comparison: effect of loading rate on bearing capacity. The slow loading case ($t_{load} = 10^{15}$ s) closely matches the uncoupled drained solution, while fast loading ($t_{load} = 10^{5}$ s) exhibits a stiffer initial response but lower ultimate bearing capacity.