



AD FALCON API Manual

# Rigid Strip Footing on Soils Modeled by the Generalized Cam-Clay (GCC) Model

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## Contents

<b>1</b>	<b>Rigid Strip Footing on Soils Modeled by the Generalized Cam-Clay (GCC) Model</b>	<b>3</b>
1.1	Problem Description	3
1.2	Input Files	3
1.3	Material Parameters	3
1.3.1	Common Parameters (Both MCC and GCC)	3
1.3.2	Model-Specific Parameters	4
1.4	Initial Assignment	4
1.5	Step 1: Geostatic Initialization via Body Force	4
1.6	Yield Surface Correction	5
1.7	Geometry and Boundary Conditions	5
1.8	Step 2: Loading (Prescribed Settlement Under the Footing)	6
1.8.1	Step definition	6
1.8.2	Restraints at Prescribed-Displacement Nodes	6
1.8.3	Prescribed Displacement (Ramp)	7
1.9	Results	7
1.10	Effect of Integration Points on the GCC Footing Response	7

# 1 Rigid Strip Footing on Soils Modeled by the Generalized Cam-Clay (GCC) Model

## 1.1 Problem Description

This study investigates the response of soil beneath a rigid strip footing using the [GCC model](#). Two series of uncoupled analyses are performed: (i) Modified Cam-Clay (MCC) with  $\alpha = 1.0$  and (ii) Generalized Cam-Clay (GCC) with  $\alpha = 0.77$ . Results from both analyses are compared with the solution reported by **Sheng et al. (2000)**, noting that the geostatic initial stress corresponds to the submerged soil density.

### Reference

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

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## 1.2 Input Files

Two input files are provided for the different model configurations:

- **MCC analysis** ( $\alpha = 1.0$ ): [fem\\_data\\_MCC\\_uncoupled.txt](#)
- **GCC analysis** ( $\alpha = 0.77$ ): [fem\\_data\\_GCC.txt](#)

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## 1.3 Material Parameters

### 1.3.1 Common Parameters (Both MCC and GCC)

- **Friction angle**  $\phi$ : 23°
- **Compressibility index**  $\lambda$ : 0.25
- **Poisson's ratio**  $\nu$ : 0.30
- **Swelling index**  $\kappa$ : 0.05
- **Default isotropic hardening**: 50 kPa (minimum isotropic hardening in the domain)
- **Critical-state specific volume**  $v_{CSL}$ : 2.60 → **Initial specific volume**  $v_N$ : 2.739
- **Overconsolidation pressure at surface**: 50 kPa

### 1.3.2 Model-Specific Parameters

- **Modified Cam-Clay (MCC):**  $\alpha = 1.0$  (circular yield surface in deviatoric plane)
- **Generalized Cam-Clay (GCC):**  $\alpha = 0.77$  (Lode-angle dependent yield surface)

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

## 1.4 Initial Assignment

Initial stresses and the initial void ratio  $e_N$  are applied to the entire domain (see [% Initial Assignments](#)).

```
% 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 1.0 H 10 values 1.0
%%%
```

## 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, turning the analysis into a purely elastic clay response during this step so the yield surface does not interfere with stress initialization.

```
% Step Definitions
@Step 1:
@@StartStep: 0
@@StepTime: 1.0
@@SolverType: Direct
@@NumberSteps: 10
@@OutputInterval: 10
@@OutputTypes: Displacement EffStress VoidRatio
@@ErrorTarget: 1.0e-1
@@UL: No
@@SimMode: Static
@@EnforceElasticFlag: All
%%%
```

Additionally, InitialVoidinBF: Yes in the body-force block forces the body-force cal-

ulation

$\gamma = (1 - n)\rho_s g$  to always use the **initial** void ratio. Because the body force is applied over multiple steps, the void ratio may otherwise evolve during loading and change the effective unit weight. This flag prevents those unintended drifts by reusing the starting void ratio every time the body force is evaluated.

```
% 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
%%%
```

Because this example is **uncoupled**, the body-force term is computed using  $\gamma = (1 - n)\rho_s g$ . To reach a target **effective drained** unit weight  $\gamma$ , any initial combination of  $\rho_s$ ,  $n$ , and  $g$  that yields the desired  $\gamma$  is acceptable—their only purpose here is to establish the geostatic stress state. Consequently, the chosen  $\rho_s$  may appear non-physical; it was purposefully selected so that  $\gamma \approx 6 \text{ kN/m}^3$  in this example, rather than to represent a realistic grain density. \*\*\*

## 1.6 Yield Surface Correction

After geostatic stresses are established, the yield surface is corrected using `OverconsolidationControl`  $\neq 1$ . As detailed in the [Post-equilibrium state conditioning section](#) of the [GCC model](#), this option **fits the cap exactly through the current stress state** by solving the yield equation for the cap stress. 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 per the Cam Clay elastoplastic equation as outlined in the [GCC model documentation](#) to precisely enforce the consistency conditions.

## 1.7 Geometry and Boundary Conditions

Because this is a strip footing, a **plane-strain** formulation is used. By symmetry, only **half** the domain is modeled. Side boundaries are **laterally restrained**; the base is **vertically restrained**.

### Geometry

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

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

### 1.8.1 Step definition

```
% Step Definitions
@Step 2:
@@StartStep: 1
@@StepTime: 1.0
@@ModernAutoInc: Yes
@@SolverType: Direct
@@MaxIterations: 10
@@OutputInterval: 1
@@InitialStepIncrement: 1e-3
@@UseModifiedNewton: No
@@OutputTypes: Displacement EffStress VoidRatio
@@Geostatic: No
@@MinTimeStep: 1e-7
@@MaxTimeStep: 1.0e0
@@ErrorTarget: 1.0e-3
@@UL: No
@@SimMode: Static
%%%
```

### 1.8.2 Restraints at Prescribed-Displacement Nodes

Degrees of freedom at nodes that will receive a prescribed vertical displacement are restrained in *Y* at the beginning of Step 2:

```
% 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
%%%

```

### 1.8.3 Prescribed Displacement (Ramp)

A downward displacement is applied under the footing using a ramp amplitude:

```

% 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

The figure below compares the **load-deflection** response from both MCC ( $\alpha = 1.0$ ) and GCC ( $\alpha = 0.77$ ) analyses with the reference solution of **Sheng et al. (2000)**.

*Figure 1. Load-deflection comparison: MCC ( $\alpha = 1.0$ ) and GCC ( $\alpha = 0.77$ ) responses compared against Sheng et al. (2000).*

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### 1.10 Effect of Integration Points on the GCC Footing Response

To assess the influence of numerical integration order on the **load-settlement** response of the GCC footing problem, three otherwise identical uncoupled analyses were performed using six-node elements with different numbers of Gauss integration points:

- `fem_data_GCC.txt`: **N6P6** (standard integration)
- `fem_data_GCC_uncoupled_LowerordGP.txt`: **N6P3** (reduced integration)
- `fem_data_GCC_uncoupled_higherorderGP.txt`: **N6P7** (higher-order integration)

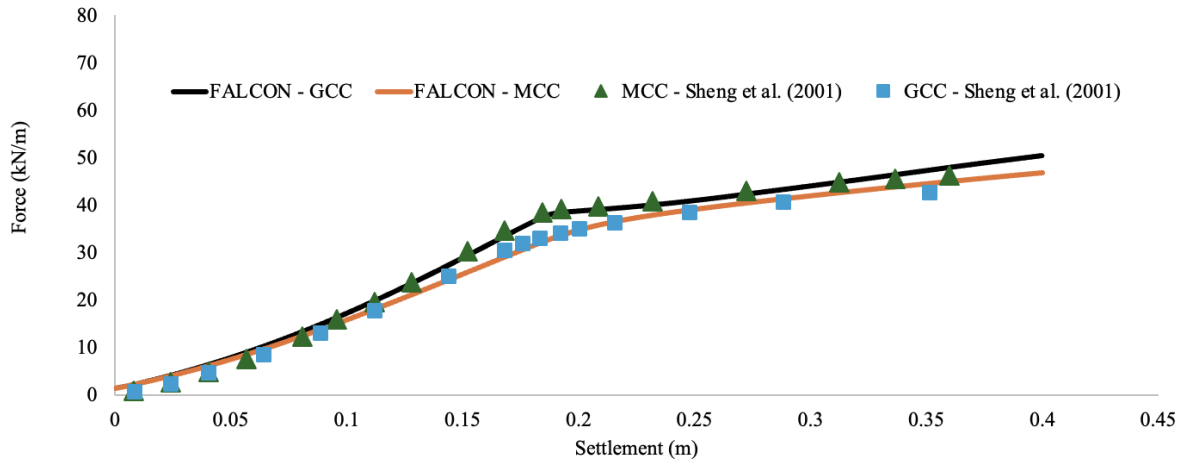


Figure 1: Load-deflection comparison between FALCON and reference

All other aspects of the problem—geometry, mesh, boundary conditions, loading, and GCC material parameters—are kept identical to the base case described above. The only difference between the three input files is the **number of Gauss integration points** used in the stress-update routine for each N6 element.

The resulting load-settlement curves are shown in Figure 2.

*Figure 2. Influence of numerical integration order on the load-settlement response for the GCC rigid footing problem.*

The three curves (N6P3, N6P6, and N6P7) are almost indistinguishable over the full loading range. This indicates that, for this footing problem and mesh density, the standard N6P6 integration already provides sufficiently accurate stress integration: both reduced (N6P3) and higher-order (N6P7) schemes lead to negligible changes in the predicted load-settlement behaviour.

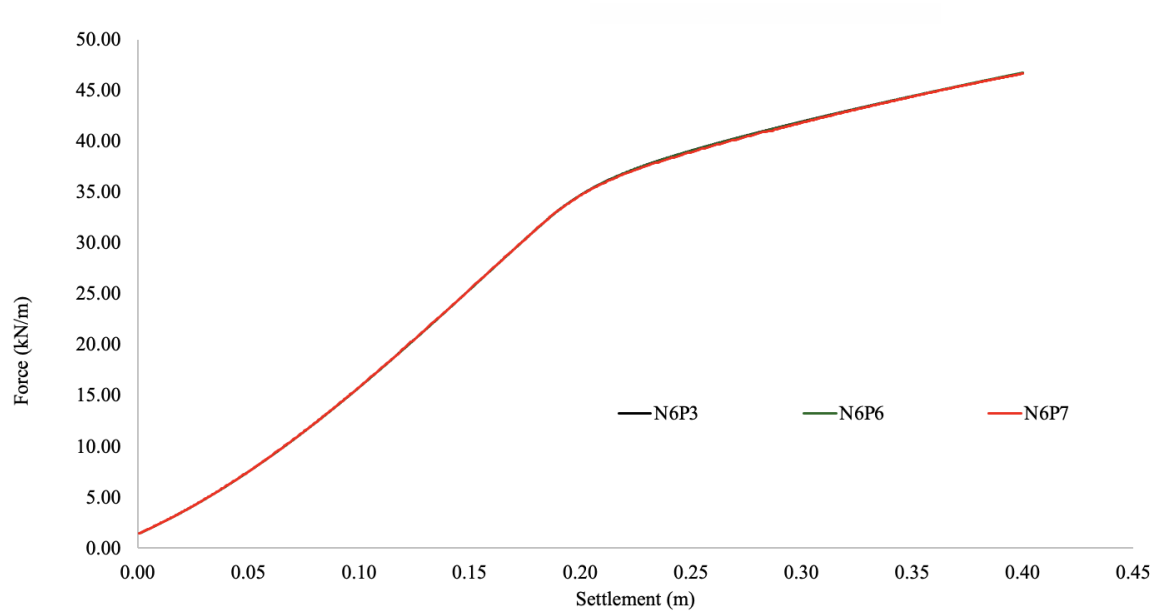


Figure 2: Load–settlement comparison for different Gauss integration orders