ESPFEM2D Documentation

1. Introduction

The Smoothed Particle Finite Element Method (SPFEM) has gained popularity as one of the effective numerical methods for modelling geotechnical problems involving large deformations. To advance the research and application of SPFEM in geotechnical engineering, we present ESPFEM2D, a two-dimensional SPFEM open-source solver developed using MATLAB. ESPFEM2D discretizes the problem domain into computable particle clouds and generates the finite element mesh using Delaunay triangulation and the alpha-shape technique to resolve mesh distortion issues. Additionally, it incorporates a node integration technique based on strain smoothing, effectively eliminating defects associated with the state variable mapping after remeshing. Furthermore, the solver adopts a simple yet robust approach to prevent instability arising from under-integration using only nodal values. The Drucker-Prager model is adopted to describe the soil's constitutive behavior as a demonstration.

2. MATLAB implementation of the open-source solver ESPFEM2D

The ESPFEM2D open-source solver is developed based on MATLAB. As the main program of ESPFEM2D, "SPFEM.m" controls and runs all functions under the open-source solver of ESPFEM2D. In ESPFEM2D, all these steps are implemented in the form of MATLAB functions except that the MATLAB script named "SPFEM.m" is used as the main program. All the MATLAB codes are summarized in Table 1.

Table 1 Summary of MATLAB codes

File name	Stage	Functionality
SPFEM.m	main program	the main program of ESPFEM2D
input_data.m	pre-processing	Example input
ex_bar_gravity_vibration.m	pre-processing	Example input
ex_non_cohesive_soil_stage1.m	pre-processing	Example input
ex_non_cohesive_soil_stage2.m	pre-processing	Example input
ex_cohesive_soil_stage1.m	pre-processing	Example input
ex_cohesive_soil_stage2.m	pre-processing	Example input
ex_slope_stage1.m	pre-processing	Example input
ex_slope_stage2.m	pre-processing	Example input
initializing.m	Computational step 1	Prepare for the calculation process of ESPFEM2D

File name	Stage	Functionality
mesh_alpha_shape.m	Computational step 1	Identify the computational domain boundary using the α-shape technique
mesh_remesh.m	Computational step 2	Reconstruct the finite element mesh
mesh_quality.m	Computational step 2	Get mesh quality
mesh_get_related_element_node.m	Computational step 3	Get related particle and element information
element_data_prepare.m	Computational step 3	Get element information
node_data_prepare.m	Computational step 3	Get particle information
mesh_lap_smoothing.m	Computational step 4	Calculate the smooth strain of the particles
constitutive_model.m	Computational step 5	Select constitutive model
mat_model_elas.m	Computational step 5	Elasticity constitutive model
mat_model_DP.m	Computational step 5	Drucker-Prager constitutive model

File name	Stage	Functionality
DP_implicit.m	Computational step 5	Update nodal stresses through Drucker-Prager constitutive model integration
force_int.m	Computational step 6	Calculate the nodal internal forces
update_half_velocity.m	Computational step 7	Prepare for the leapfrog time integration
force_hourglass.m	Computational step 7	Calculate hourglass control forces
time_integration.m	Computational step 7	Perform time integration
contact_wall.m	Computational step 7	Treatment of rigid boundary contact
output_vtk.m	Post-processing	Output the mesh results
save_monitor_data.m	Post-processing	Output the monitor results