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FMulti-scale response sensitivity analysis based on direct differentiation method for concrete structures

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Abstract

As traditional composite materials, concrete and reinforced concrete (RC) have been widely used for civil and military purposes. The multi-scale response analysis of concrete structures can be implemented by coupling the finite element and discrete element methods (FEM-DEM). To study the response sensitivities, this paper presents a novel approach by extending the direct differentiation method (DDM) to coupled FEM-DEM multi-scale method. The response and response sensitivity analysis methods are implemented by coupling an existing FEM framework, OpenSees, and DEM software, Yade, based on a client-server (CS) software integration technique. An application example is used to demonstrate the multi-scale response sensitivity method presented herein.

1. Introduction

Concrete and reinforced concrete (RC), as traditional composite materials, have been widely used in structural engineering for civil and military purposes. This is partly because concrete is a versatile and cheap material, typically composed of cement, sand, aggregates (e.g., gravel, crushed stones). Specifically, RC takes advantages of each material constitutes by combining concrete's relatively low tensile strength with steel bars' higher tensile strength and ductility. A wide variety of numerical techniques have been developed for computer modeling of concrete structures. Among them, finite element method (FEM) has been widely used in modeling the mechanical behaviors of the concrete structures of real-world engineering problems. Significant research progress has evidenced that the nonlinear macroscopic responses of the structures (e.g., nonlinear force-deformation responses, strength deterioration) can be successfully simulated by using nonlinear FE models with various constitutive material models (e.g., plasticity concrete material models and damage mechanics-based models). However, the mesoscopic behaviors of concrete (e.g., the generation and propagation of micro cracks) cannot be well captured by using continuum models in FEM. Alternatively, the discrete element method (DEM) provides a practical tool to capture the mesoscopic behavior of concrete by developing appropriate meso-mechanic models at the particle level[1]. The DEM is able to model the