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Study on the Failure Behavior of Concrete Using Non-local Peridynamic Method

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Concrete is a complex material which is widely used in civil engineering structures. The failure process and its mechanism have been studied for a long time, but it has not been fully understood. Concrete often cracks under loading, which cause discontinuities in the displacement field. As a typical complex heterogeneous material, concrete contains many micro-cracks even before loading. The displacement field changes sharply during the cracks initiating and propagation. Therefore precise analysis of concrete is elusive. Nearly all traditional methods based on the classical theory of continuum mechanics attempt to solve the partial differential equations that include derivatives of the displacement components, but these derivatives are undefined when the displacements are discontinuous. Because of the requirements of a prior knowledge of the crack path and redefinition of the geometry and re-meshing, these theories cannot be considered as an ideal tool to the study of this problem.

To overcome the limitations of classical continuum and fracture mechanics, the peridynamic model was proposed by Silling, which can be used at different scales, from micro to macro, makes no assumption of continuous or small deformation behavior and has no requirement for the concepts of stress and strain. Peridynamic modeling of a physical structure involves simulating interacting interacting particles subjected to a “force field”, which is similar to molecular dynamics. The peridynamic method uses spatial integral equations to compute the force between interacting particles rather than solve the partial differential equations that include derivatives of the displacement components. In peridynamic model, the region is discretized into particles, which interact with each other through the prescribed pairwise function, which contains all of the constitutive information associated with the material. The maximum interaction distance between particles is called the “material horizon”, which may be considered as a material property. The particle positions are integrated in time. This is an effective method for modeling damage. The peridynamic equation of motion at a reference configuration of $\mathbf{x}$ and time t is given as

$$\rho\frac{\partial^2 u}{\partial t^2}=\int_R f(u(x',t)-u(x,t),x'-x)dV_{x'}+b(x,t) \qquad (1)$$

where u is the displacement vector field, f is a pairwise force function whose value is the force vector that the particle $\mathbf{x}'$ exerts on the particle $\mathbf{x}$. We denote the material horizon in the reference configuration by δ. When the distance between two particles is less than or equal to material horizon, they will interact with each other, otherwise, the distance exceed horizon, the interaction may vanish. In other words, the particle $\mathbf{x}$ cannot be found beyond the horizon of $\mathbf{x}'$, such that for all $\|\mathbf{x}'-\mathbf{x}\|>\delta,\ f=0$. **b** is a prescribed body-force density field and ρ is mass density in the reference configuration. For static conditions, the peridynamic equilibrium equation can be expressed as

$$\int_R f(u(x',t)-u(x,t),x'-x)dV_{x'}+b(x,t)=0 \qquad (2)$$

For simplicity, concrete is normally taken as a homogeneous material on the macroscale without considering the heterogeneity before. This is convenient for engineering applications, but cannot catch the whole process of micro-defects growing, damage accumulation, crack initiation and propagation in concrete. This paper aims to investigate the capability of peridynamic model to predict failure and damage of concrete at the bond level. Concrete material is taken as a heterogeneous material composed of three components, which is mortar matrix, aggregates, and interfaces between them. The non-local peridynamic model can evidently enhance its capacity of solving discontinuity problems, compare to the classical differential models based on continuum mechanics. The conclusion reveals the failure mechanism of concrete materials and structures, which will provide a basis of practical guidelines for the development of high performance concrete and safety evaluation of concrete structures.

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