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Le Cao
University of Kentucky, le.cao_daisy@uky.edu

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Le Cao[1]

[(1)]Ph.D. Student, Department of Civil Engineering, College of Engineering, University of Kentucky, 161 Raymond Building, Lexington , KY 40506-0281, le.cao_daisy@uky.edu

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Structures designed with large degrees of static indeterminacy, may have little reserve capacity to tolerate abnormal loading conditions. Progressive failure mechanism [1] can be triggered by the loss or reduction of load-carrying capacity of a relatively small portion of the structure due to an applied abnormal load. Following the initial local damage, a propagation of disproportionate collapse could be spread. Finite element analysis of large scale structures traditionally requires a huge amount of discretization that intrinsically makes the problem become spatially multiscale, especially if the unit cell material behaves in a heterogenenous manner. Extended finite element method [2, 3] is an efficient approach in developing multiscale algorithms to obtain the equivalent material response for structural analyses. To evaluate material behavior across the scales, this study investigates in constructing the base function of a unit cell that closely relates the microscale element to the macroscopic structural element in terms of primary variables. Equation 1 gives the based function for a unit cell in 2D. Multiscale base function is adaptive to each scale in describing material mechanical property. The microscale element information can be projected to the macroscopic element through structural stiffness. Multidimensional coupling effect is considered since the multiscale base function is constructed in the vector field. The boundary condition of unit cell is discussed to obtain the solution accurately. Figure 2 shows the deformation of a heterogeneous beam with Dirichlet boundary condition and Neumann Boundary condition. The approach also enables secondary variables to be evaluated in the microscale scope from the macroscopic responses, so that the heterogeneous material strength can be evaluated, as well as the stability of macroscopic structure.

$$\begin{cases} u_{Micro} = \sum_{i=1}^{n} N_{ixx} u_{Macro} + \sum_{i=1}^{n} N_{ixy} v_{Macro} \\ v_{Micro} = \sum_{i=1}^{n} N_{iyx} u_{Macro} + \sum_{i=1}^{n} N_{iyy} v_{Macro} \end{cases} \qquad \text{Equation 1}$$

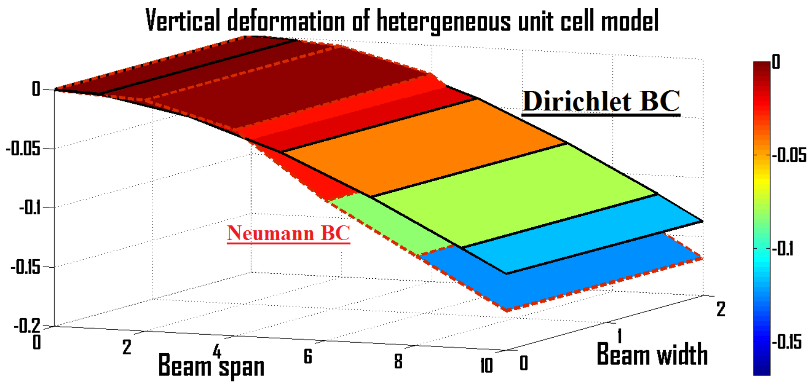

Figure 1. Heterogeneous beam deformation with Dirichlet and Neumann Boundary conditions

In the study, the unit cell model is a lattice micro-structure. Topology optimization [4] of the unit cell structure is investigated to improve structural design. Geometric nonlinearity and material inelastic behaviour are included. The optimized unit cell structure will be displayed with 3D printing models. Multiscale method enables an reduced-order modelling technique to be applied. With constraints of cross-sectional area, member stress, nodal displacement, and stability, the optimization shows that optimal critical load is substantially dependent on the structural layout, which is sensitive to dynamic loads more than static loads. Figure 2 outlines a target function with constraints. The optimal critical load value goes higher, the structural layout tends to be more spread out, with shorter member length but greater member size.

$$\min W(A) = \sum_{i=1}^{N} \rho_i A_i L_i$$

$$such\ that, \quad \sigma_{Comp} \le \sigma_i \le \sigma_{Tens}$$

$$-\delta_{required} \le \delta_i \le \delta_{required}$$

$$\sigma_i \le E \frac{A_i}{L_i}$$

$$A_i > 0$$

$$f_1 > \frac{\sqrt{\lambda_1}}{\sqrt{2\pi}}$$

$$[K]\{\Phi_1\} = \lambda_1 [m]\{\Phi_1\}$$

Figure 2. Optimization target function with constraints

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