Spherical representative volume element for discrete mesoscale model of concrete

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Fracture in concrete occurs as a result of the interaction between aggregates and surrounding matrix. However, when modelling concrete structures, the common approach is to consider the structure as a whole and the material as homogeneous. Consequently, behavior of the structure at lower scales is not being explicitly included.

One way to capture intrinsically multiscale phenomena in models without adding insupportable computational costs is via homogenization, which allows to couple behavior between two (or even more) scales. In the case of concrete, the coupling is done between mesoscale, where fracturing occurs, and macroscale, where calculations are usually done.

The cornerstone to any homogenization scheme is a representative volume element (RVE) [1], which serves as a statistically representative sample of a material at mesoscale, attached to the integration point in the macroscopic framework and serving as a constitutive law. Loading of the macroscale structure is transferred onto the RVE via boundary conditions, which mimic the matter surrounding the RVE.

Among other options, periodic boundary conditions (PBCs) are used for the purpose most often [2], as they have been shown to not affect the RVE stiffness, contrary to other BCs [3]. PBCs presume a periodically repeating block of material, whose kinematics is restricted by the periodicity. When applied to a single RVE, it translates into constaints between nodes on opposing sides of a RVE.

Commonly, the shape of choice for a RVE is a square (2D) and a cube (3D), because they may periodically fill a space [3]. When dealing with materials experiencing strain localization and subsequent fracturing, applying PBCs to a cubical RVE is problematic. During softening, the constraint between opposing nodes introduces spurious material anisotropy and the RVE looses representability, crucial for homogenization.

To overcome the problematic aspect described above, mostly some form of a shift or a rotation have been introduced to align constraint with the desired direction of emerging crack [2]. A possible unconventional solution to the problem is offered by a shape change of the RVE [4].

By employing circular (2D) or spherical (3D) representative volume element, PBCs may still be applied, because periodic filling of a space is not in fact required in homogenization [3]. Instead, the application of PBCs assumes opposite normals to the RVE surface on opposing sides, which spherical RVE fulfills. Centrally symmetrical distribution of nodes at the surface of the RVE than allows straightforward rotation of the coordinate system. RVE of such a form is of itself immune to the shape dependency.

The present contribution aims to introduce primary results obtained with a circular RVE consisting of a lattice discrete particle model of concrete (LDPM). Firstly, the creation of a geometry and the implementation of classical PBCs is described, specifically considering discrete model. Subsequently, the performance of the circular RVE is compared with the common square RVE, with the emphasis placed on the size effect of the RVE and convergence.

References

[1] I. M. Gitman, H. Askes, L. J. Sluys, Representative volume: Existence and size determination, Eng Frac Mech 74 (2007) 2518–2534.

[2] J. Goldmann, J. Brummund, V. Ulbricht, On boundary conditions for homogenization of volume elements undergoing localization, Int J Numer Methods Eng 113 (2018) 1–21.

[3] R. Glüge, M. Weber, A. Bertram, Comparison of spherical and cubical statistical volume elements with respect to convergence, anisotropy, and localization behavior, Comput Mater Sci 63 (2012) 91–104.

[4] P. Hofman, L. Ke, F. P. van der Meer,, Circular representative volume elements for strain localization problems, Int J Numer Methods Eng 124 (2023) 784–807.