A coupled BEM-FEM aproach for nonlinear electro-elastostatics of CNT-based MEMS structures

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Numerical simulation of electrostatic field–structure interactions is of significant interest in computational engineering [1]. Multiphysical problems of this type become cumbersome when treated using the finite element method (FEM), due to challenges such as mesh deformation, re-meshing, and the treatment of unbounded domains. The boundary element method (BEM) provides an efficient alternative, as it requires discretization only of the domain boundary [2]. When combined with FEM, it offers an effective framework for solving coupled multiphysical interface problems using boundary discretization alone.

In this work, a coupled BEM–FEM framework is employed to investigate the nonlinear electro-elastostatic behavior of carbon nanotube (CNT)-based capacitive MEMS switches. The primary focus is on the deformation and pull-in instability of CNT beams suspended above a grounded conducting substrate. The CNT is modeled as a perfectly conducting structure and described using a geometrically nonlinear shell formulation [3]. A monolithic strategy is adopted to solve the resulting nonlinear system, and its convergence behavior is compared with a staggered approach, as shown in Fig. 1(a), showing better efficiency. The effect of van der Waals (vdW) interactions is also incorporated, and its influence, quantified through the mid-point deflection under a Dirichlet boundary condition with prescribed surface potential V, is illustrated in Fig. 1(b). Furthermore, the influence of CNT length, electrode gap, boundary conditions, and mesh discretization on the nonlinear electro-elastostatic response is investigated. This framework successfully captures pull-in instability and provides a computationally efficient approach for analyzing material structures under coupled multi-field effects.

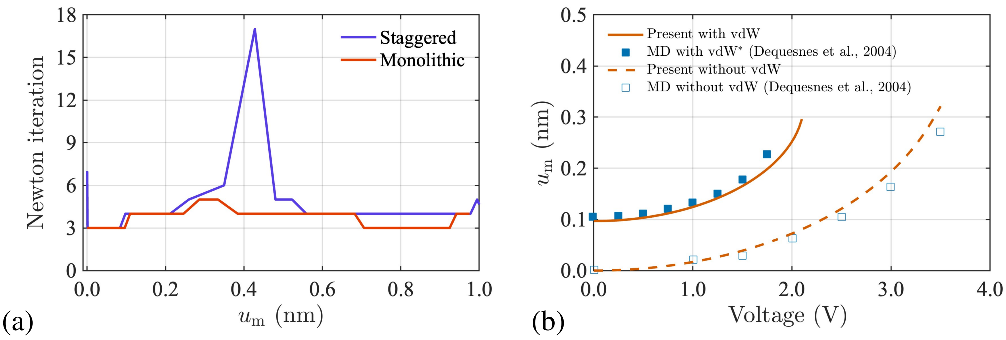

Figure 1: (a) Comparison of monolithic and staggered schemes with arc-length continuation for a 1 nm electrode gap. (b) Mid-point deflection u_{m} of a 20.7 nm long fixed–fixed CNT (10,10) at a 1 nm gap, compared with molecular dynamics (MD) results from [1] (* using vdW parameters from [1]).

[1] M. Dequesnes, Z. Tang, N. R. Aluru, *J. Engrg. Mat. Tech.*, **126**(3), 230–237, 2004. https://doi.org/10.1115/1.1751180

[2] D.K. Vu, P. Steinmann, *Comp. Methods Appl. Mech. Engrg.*, **201**, 82–90, 2012. https://doi.org/10.1016/j.cma.2011.08.024

[3] R. A. Sauer, T. X. Duong, *Math. Mech. Solids*, **22**, 343–371, 2017. https://doi.org/10.1177/1081286515594656