Foreword

WHAT IS NANOMECHANICS?

Nanomechanics is a research field that studies material behaviors at nanoscale level. In recent years, nanomechanics has become an indispensable part of theoretical foundation for many engineering fields and emerging technologies such as nanotechnology as well as biomedical and bioenvironmental technologies. Because of its multidisciplinary characteristics, the term nanomechanics has ‘multidisciplinary interpretations’, and it has been used with different meanings in different contexts. In the area of applied mechanics, nanomechanics is often referred to as a hierarchical mechanics and mathematics paradigm that is mainly used to study the effective material properties of composite materials. A major objective of this kind of study is to find the statistical average material properties of the heterogeneous material through various homogenization methods. In condensed solid state physics and statistical mechanics, this process is called the Coarse Graining. One of the fundamental challenges of the contemporary statistical physics is how to construct accurate coarse grain models.

Traditionally, the standard nanomechanics methodology in engineering applications treats a composite material as a generic continuum model with a two-level paradigm: nanoscopic structure and macroscopic structure. The material properties at nanoscale are usually given as a priori, and the task is to find the material behaviors at nanoscale, which are also called as the effective or overall material properties. From this perspective, a material point at the macro-level may be viewed as a nanoscopic material ensemble. In principle, the constitutive relations at macro level should be able to be derived from the ensemble average of nano-objects that are governed by the nanoscale physical laws, which can be quantum mechanics, lattice dynamics, nanoscale plasticity, or elasticity, etc. Two subtle points worth further clarification:
(1) the constitutive relations or material behaviors at macroscale may be very much different from their counterparts at nanoscale, so the task of nanomechanics is to find the unknown macroscale constitutive laws.

INTRODUCTION TO NANOMECHANICS

The conventional two-level paradigm of nanomechanics is a special mathematical homogenization model that is usually not associated with any fixed length scale. When studying material properties of a metal, 1 mm may be viewed as macroscale, and the length scale at nanolevel may range from 1nm to 100 nm; whereas studying the deformation of a dam, the macroscale may be up to 103 m.

In engineering applications, the conventional nanomechanics deals with practical engineering problems of a broad spectrum: effective material properties of composite/synthetic materials, such as cementitious materials, geotechnical materials, etc.; constitutive modeling of bio-materials, such as bone, muscle, blood flow, etc.; phase transformations; defects in solids, such as dislocation motion and crack growth; and environmental problems, such as air pollution, ground water flow and chemical transport, etc.

A Contemporary condensed matter physics and applied mechanics in general agree that the physics at molecular or atomic level can be described by the quantum mechanics or related approximation theories, e.g. density functional theory; the physics between the nm scale to sub-μm scale is governed by nanomechanics though presently we are mainly relying on the molecular dynamics simulation; from μm scale to or sub-mm length scale, nanomechanics and related mesoscale mechanics are playing more important roles; and the macroscopic phenomenological theory is generally valid at the length scale mm level or up.

In this book, we shall focus on several areas of nanomechanics and nanomechanics. Different from traditional nanomechanics, a salient feature of nanomechanics is its multiscale and multiphysics characteristics. It has some features presented in quantum mechanics, or quantum statistical mechanics, manifesting the statistical effects at atomic or sub-atomic level; on the other hand, it also shares many features of continuum mechanics, because a nanostructure could contain millions of atoms.

The impetus for contemporary nanomechanics is primarily due to the emergence of nanoscience and biomedical technology. It appears that traditional physics alone is not sufficient to deal with many engineering problems that are emerging from nanotechnologies and nanoengineering. There is a call for nanomechanics and
nanocomputational mechanics to serve as the infrastructure of these developing engineering fields. For instance, much attention has been focused recently on material properties of thin films; manufacturing devices and components of a nanoelectromechanical system (NEMS), such as nano sized sensors, motors; mechanics of nanotubes and nanowires; and nanobiophysics/biochemistry systems, e.g. protein/DNA interaction in biomolecular simulation, etc.

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