The Maurice A. Biot Lecture

Department of Civil Engineering & Engineering Mechanics, Columbia University
Engineering Mechanics Committee, ASCE Metropolitan Section
Engineering Mechanics Institute, ASCE

Intrinsic Material Constants of Poroelasticity

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Abstract: When Biot first derived the constitutive equations of poroelasticity in 1941, he adopted a phenomenological approach, using apparent stress and strain quantities that are easily observable from the exterior of the sample, which also clearly defined as boundary conditions, for the solution of boundary value problems. The phenomenological model used the total stress rather than solid stresses, the frame deformation rather than the solid deformation, and the variation in fluid content (amount of fluid expelled from the frame) rather than the fluid strain, as the modeling parameters. The associated material constants, such as the drained and undrained bulk modulus, Biot effective stress coefficient, etc., are bulk constants that combine the properties of the solid, the fluid, and the pore structure. The mathematical system formed by this model is widely used for engineering purposes.

There are certain applications, however, that require the insight into what is happening within the porous medium. For example, when the porous frame is deformed, how much of the volume change is derived from the deformation of the solid phase, and how much is due to the closing and deformation of pore space? Gassmann in 1951 derived a model which clearly identified the roles of the compressibilities of the solid, the fluid, and the pore space played in the deformation. Gassmann's model, however, assumed that the solid phase is homogeneous and isotropic at the microscopic (grain) scale (though not necessarily at the macroscopic scale), which has been called an ideal porous medium. Geomaterials, such as rocks, are not homogeneous at the grain level. The microhomogeneity and microisotropy constraints were removed by Biot and Willis in 1957. The resultant micromechanical model contains an additional material constant: rather than one solid bulk modulus, there exist two such moduli, which become equal only under the ideal porous medium assumption. However, these material constants are still not "intrinsic" as the physical mechanisms are not isolated.

Lopatnikov and Cheng in 2002 presented a physically based model using the composite material volume averaging process and the variational energy principle. Following this approach, the material constants are resolved into intrinsic constants, each corresponding to a fundamental deformation mechanism. Particularly, a solid bulk modulus relating the self-similar volume change of the solid phase, a porosity bulk modulus relating to the self-similar deformation of the pore space, and bulk modulus relating to the volume conserving shape changes of the solid phase, are identified. The ideal porous medium assumption is directly tied to the third bulk modulus, which becomes zero under such assumption. Relations among the intrinsic material constants, the Biot-Willis constants, and the bulk material constants are provided. Physical insights revealed by the intrinsic constants are discussed.

Biosketch: Alexander Cheng obtained his Ph.D. from Cornell University, M.S. from University of Missouri-Columbia, and B.S. from National Taiwan University, all in Civil Engineering. He is currently Dean of Engineering at the University of Mississippi. Prior to joining the University of Mississippi, as Department Chair of Civil Engineering in 2001, he served as a faculty member at Cornell University, Columbia University, and the University of Delaware. His research interest covers poromechanics, groundwater, saltwater intrusion, boundary element method, meshless collocation method, and nanomechanics. He is the author/co-author of three books, on "Modeling Groundwater Flow and Contaminant Transport" (with Jacob Bear), "Multilayered Aquifer Systems", and "Trefftz and Collocation Methods". He has also edited about a dozen specialty books and conference proceedings, and authored about 150 journal articles on the above and other subjects. He currently serves as the President of Engineering Mechanics Institute, ASCE, and was formerly Vice President of Academic Affairs of American Institute of Hydrology. He is the Editor-in-Chief of the journal Engineering Analysis with Boundary Elements (Elsevier), Associate Editor of Journal of Nanomechanics and Micromechanics, ASCE, Associate Editor of Transport in Porous Media (Springer), International Associate Editor of Journal of Mechanics (Cambridge University Press), and formerly Associate Editor for Journal of Engineering Mechanics, ASCE. He has co-founded two conference series, the Biot Conference on Poromechanics, and the Saltwater Intrusion and Coastal Aquifers. He was a recipient of the Walter L. Huber Civil Engineering Research Prize, ASCE, the Basic Research Award, U.S. National Committee for Rock Mechanics, NRC, and Eminent Scientist Award, Wessex Institute of Technology, U.K. Currently he is the PI or Co-PI of several Department of Homeland Security projects, on nanomaterials applied to infrastructure protection (blast and impact), and on retrofitting New Orleans levees.

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The Maurice A. Biot Lecture was established at Columbia University in 2004 in remembrance of the late Prof. Maurice Anthony Biot and his renowned achievements as an engineer, physicist, and applied mathematician.
Biot was a professor of mechanics at Columbia University in the period 1937-1945.
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