The Maurice A. Biot Lecture

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

COMPACTION LOCALIZATION, PERMEABILITY EVOLUTION AND EFFECTIVE STRESS BEHAVIOR OF POROUS ROCK

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Abstract: How a porous rock fails in response to inelastic compaction, as well as the permeability evolution, have significant impact on many applications related to natural energy resources and the environment. For a long time, the conventional thinking has been that the only mode of failure is by diffuse compaction, without any involvement of strain localization. However, in the past two decades field observations in porous sandstone have documented localized deformation in the form of relatively narrow tabular zones with intense compaction but negligible shear. Within such compaction bands, reduction of both porosity and connectivity can lead to significant permeability decrease and enhanced anisotropy, which can modify the hydrological flow field. Discovery of this intriguing phenomenon has motivated systematic experimental, theoretical and numerical investigations to probe the mechanics of compaction localization on multiple scales. In the first part, I will review these efforts and the advances in our understanding and insights gained from them, concerning the phenomenology and micromechanics of compaction localization and permeability evolution.

The interplay of confining stress and pore pressure in controlling a hydromechanical property can be described in terms of an effective stress law. In a microscopically homogeneous assemblage, the effective stress coefficients for permeability, bulk strain and porosity change are predicted to be equal to or less than unity. Experimental measurements for many rocks are in agreement with this prediction, but there are exceptions particularly in clay-rich sandstones, for which effective stress coefficient for permeability as high as 7.1 has been documented. Most previous studies are limited to either permeability or bulk strain, and not much is known about carbonate rocks. In the second part, I will summarize our recent investigation of the effective stress behavior in four porous limestones related to permeability, bulk strain and porosity change. In three limestones the pore space comprises significant proportions of macropores and micropores. For the first time we observed that in such a limestone with dual porosity, the effective stress coefficients for both permeability and porosity change were generally greater than unity. Berryman (1992) analyzed theoretically a rock made up of two porous constituents, and our experimental data are in agreement with inequalities that he derived for their effective stress coefficients.

Biosketch: Teng-fong Wong is professor and director of the Earth System Science Programme in the Faculty of Science, The Chinese University of Hong Kong. After matriculation in Hong Kong, he came to the United States where he obtained undergraduate and graduate degrees from Brown, Harvard and MIT. Before returning to Hong Kong in 2013 to assume his current position, Wong has taught for thirty years at Stony Brook University, where he served as chair of the Department of Geosciences. He is a coauthor, with Mervyn Paterson, of the monograph "*Experimental Rock Deformation, The Brittle Field*" 2nd edition, and with Yong Chen and Enru Liu, of the textbook "*Rock Physics*" in Chinese. A fellow of the American Geophysical Union, Wong received the Basic Research Award of the U.S. National Committee for Rock Mechanics in 1986, and the Louis Néel Medal of the European Geosciences Union in 2010, for his contributions in rock physics and earthquake mechanics.

The Maurice A. Biot Lecture was established at Columbia University in 2004 in remembrance of the late Professor 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.