Effect of soft viscous bio-inclusions on Seismic responses of sediments

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Subsurface microbial activities, particularly bacterial colonization and ensuing biomass production can alter hydraulic properties and seismic responses of porous media. As biofilms and extracellular polymeric substances (EPS) decrease the permeability of the porous media and cause bioclogging, engineered bioclogging has garnered interest as one of the methods for microbial ground modification, such as hydraulic barrier installation and microbial enhanced oil recovery. Meanwhile, there are extended efforts to capture and monitor bacterial growth and activities in subsurface by using geophysical monitoring techniques, which allows to evaluate the status of bio-plugged regions and obtain a feedback for ad hoc basis treatment adjustment. This study complies and presents the laboratory experiment results on seismic responses of porous media during production of soft, viscous biomasses both in high- and low-frequency regimes. The data include the P- and S-wave velocities and attenuations measured at the frequency greater than 1 kHz by using the pulse propagation tests, and the flexural and torsional wave velocities and attenuations measured at the frequency lower than 1 kHz by the resonant column testing. First, in the high frequency range, we monitored the changes in permeability and P- and S-wave responses using the ultrasonic transducers and the bender elements while *Leconostoc mesenteroides* grew and produced insoluble biopolymers in an unconsolidated sand. The results show that P-wave velocity stays almost constant and S-wave velocity increases with the biopolymer accumulation. Both P-and S-wave attenuation, evaluated by using spectral ratio method, increases with increasing biopolymer saturation. Second, in the low frequency range, we carried out the resonant column testing with two model bacteria: *Shewanella oneidensis MR1* and *Leuconostoc mesenteroides*. We monitored the changes in torsional and flexural wave velocities and damping ratios associated with EPS formation in sands. Again, the results show that both torsional and flexural attenuations significantly increase with the accumulation of EPS while their velocities show only minimal changes. The experiment results indicate that the impact of soft viscous bio-inclusions, such as biopolymers and EPS, on the seismic response of water-saturated sands is mainly limited to the seismic energy dissipation when the confining stress is high. There is minimal or no influence on the stiffness of the soil structure and no participation in the transmission of seismic stress. It is concluded that the seismic attenuation can be used to capture time-lapsed accumulation of soft viscous bio-inclusion in the low frequency regime, which is more relevant to the field-scale seismic monitoring, as well as in the high frequency range, relevant to lab-scale experiments. Further effort on theoretical seismic modeling is warranted to correlate the increases in seismic attenuation to the biopolymer saturation and permeability reduction.

*Keywords*: Biogeophysics, Seismic monitoring, Biofilms, Bacteria, Biopolymer, Bioclogging, Velocity, Attenuation, Permeability