Contact stiffness in gas-bearing shales estimated from velocity measurements under pressure

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SUMMARY

- Pore pressure has a direct influence on gas production from shale gas reservoirs. Most pore pressure estimation methods are based on the effective pressure principle. Grain contact models such as Digby’s model have been used to understand velocity variation with effective pressure in dry rocks. Using velocity measurements under pressure, we estimated the contact stiffness ratio of 73 samples from gas-bearing shale reservoirs in Sichuan basin, China.

- \( v_p/v_s \), \( D_n/D_t \), and \( D_t \) all increase with pressure, while \( v_p/v_s \) ratio and \( D_n/D_t \) ratio are nearly constant.

METHODS

- Digby’s model

\[
D_n = \frac{4\mu a}{\pi(1-\nu)} \quad D_t = \frac{8\mu b}{\pi(1-\nu)}
\]

\[
v_p^2 = \frac{3c}{20\pi R_p}(D_n + \frac{2}{3}D_t)
\]

\[
v_s^2 = \frac{c}{20\pi R_p}(D_n + \frac{2}{3}D_t)
\]

\[
\left(\frac{v_p}{v_s}\right)^2 = \frac{6(D_n/D_t)+3}{(2D_n/D_t)+3}
\]

\[
\frac{D_n}{D_t} = \frac{3(\rho_p/\rho_s)^{2-4}}{6-2(\rho_p/\rho_s)^2}
\]

- \( D_n, D_t \) are normal and shear contact stiffness, respectively. \( v_p \) and \( v_s \) are measured P-wave and S-wave velocity, respectively.
- \( a \) and \( b \) are final and initial contact radius respectively, \( R \) is grain size, \( \rho \) is grain density, \( C \) is coordination number, \( \mu \) and \( \nu \) are the grain shear modulus and Poisson’s ratio.

- \( v_p/v_s \) ratio and \( D_n/D_t \) ratio of shale samples are nearly constant even though \( v_p/v_s \), \( D_n \), and \( D_t \) increase with pressure individually.
- The \( v_p/v_s \) ratio and \( D_n/D_t \) ratio of shale samples are larger than those of glass beads and Berea sandstone.

RESULTS

- \( v_p/v_s \) ratio varies from 1.5 to 1.9, depending mainly on mineralogy composition.
- Contact stiffness ratio varies in general from 3 to 40.
- \( v_p/v_s \) ratio larger than 1.73 will result in negative \( D_n/D_t \) ratio, which is unrealistic.
- Digby’s packing model gives reasonable estimation of \( D_n/D_t \) ratio for the majority of studied samples, while the complete Digby’s model including the contact model only gives reasonable estimation for the glass beads. For Berea sandstone and shale samples, the theoretical calculated contact stiffness severely underestimated the value from velocity measurements.
- Digby’s model is able to give nonzero elastic properties of granular media at zero pressure, which is an improvement compared with Hertz-Mindlin model.
- Further improvements are needed for real practical application of contact models to estimate effective pressure from seismic velocity.

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