**Vertical effective stress estimation for unconsolidated sands**

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**Introduction**

Pore pressure and effective stress are essential parameters when it comes to geohazards and drilling hazards assessment. However, pore pressure is rarely measured in the shallow sub-surface, particularly for low-permeable formations, and is poorly quantified with large uncertainties. Formations presenting excess pore pressure pose significant threats to drilling safety, and the cost of mitigation, especially in deep-water settings, is high. In this regard, the role of seismic is of paramount importance, as they are stress dependent. In this paper, we derive an empirical relationship to estimate vertical effective stress especially suited for seabed to reservoir depth and apply it to laboratory data.

**Methods**

Shear wave velocity in a saturated rock is a function of the dynamic shear modulus ($G_{\text{max}}$) and its mass density ($\rho_{\text{sat}}$) as follow: $V_s = \sqrt{G_{\text{max}}/\rho_{\text{sat}}}$. Assuming $V_s$ being known, the dynamic shear modulus can be determined. According to Hardin (1972), Tatsuoka et al. (1979) and Stokoe et al. (1985), the dynamic shear modulus can be expressed as:

$$G_{\text{max}} = B \cdot f(e) \cdot P_a \cdot \left[\sigma'_m/P_a\right]^n,$$

where $B$ (elastic stiffness factor) is a dimensionless parameter depending on the sand type and fabric, $f(e)$ is a function of void ratio ($e$) and is assumed to be $f(e) = 1/(0.3 + 0.7e^2)$, $\sigma'_m$ is the mean effective stress, $n$ is the stress exponent and $P_a$ is the reference pressure (0.1 MPa used for input and results given in MPa). Hardin (1972) used the octahedral stress $\sigma_{\text{oct}}'$ which includes all three principal stress directions. Here, we assumed that the mean effective stress is a function of the effective vertical stress alone, introducing the effective stress ratio ($K_0$): $\sigma'_m = (\sigma'_v + \sigma'_h)/2 = \sigma'_v \cdot (1 + K_0)/2$. The effective vertical stress can then be back-calculated. The method is applied to two uncemented brine-saturated sand samples with very different mineralogical and textural compositions (QA-Quarts Arenite and VA-Volcanic Arenite) (see Lars et al. (2011) for details of the experiment).

**Results**
Figure 1 shows the measured and calculated effective stresses. The experimental data confirm the dependency of the seismic velocities of porosity and effective stress from the model. The $f(e)$ factor changes continuously during the experiment. Porosity reduction is larger for the QA sand compared to the VA sand. We use a constant stress exponent ($n = 0.5$) typical for uncedmented sand based on previous experiences (Madshus, 1997). The elastic stiffness factor $B$ is adjusted to fit the experimental data. At higher stresses, we obtain a satisfactory fit using $B = 560$ for the QA sand and $B = 1000$ for the VA sand, respectively. These values, however, do not result in an equally good fit at high stresses. This may be explained by changes of grain shape, texture and contact during compaction. When the stress level exceeds a threshold level corresponding to the yield stress, grain crushing happens, increasing the velocities and hence, changes in the $B$ parameter. The initial relative packing of sediment will also affect the behaviour during compaction. The initial packing of the VA sand is denser compared to the QA sand. An effect of over-consolidation and a change in slope of the stress vs. porosity (or yield point) occurs for the VA sand.

![Figure 1: Measured and modelled vertical effective strain for QA (left) and VA (right) sands.](image)

Conclusions

Following adjustment of the elastic stiffness factor $B$, the empirical relationship estimating the effective vertical stress from the shear wave velocity proved to fit the results of laboratory experiments. This method can be applied to field scale data, ultimately assisting in better estimation of pore pressure.

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References

