Extraction of Gassy Sediments: The Bubble Pressure

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When extracting a gassy sediment from the deep sea bed and unloading it under undrained conditions, one observes that the sample fails at some time during the unloading process. We aim to explain why.

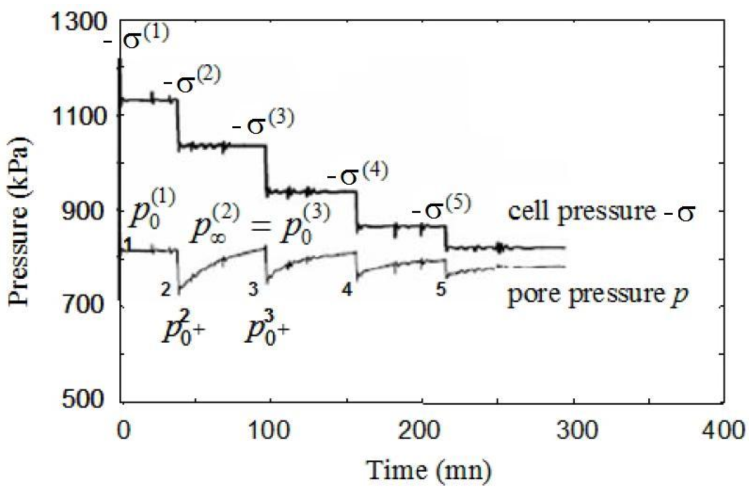

Figure 1: Successive unloadings of a gassy sediment sample.

1 - The solid matrix constituting the solid part of gassy sediments is much less compressible than the sample itself: what does it imply for the poroelastic constants?

2 - The skeleton of a sediment is mainly formed of particles in contact and can not sustain a tensile stress: it fails when the Terzhagi effective stress $\sigma + p$ becomes positive. In this question, we wonder whether regular undrained poroelasticity can explain why the sample fails.
K and K_F are the compressibility of the sample and of the pore fluid respectively. We assume that the sample is much more compressible than the pore fluid as well (i.e., $K \ll K_F$).
In an undrained evolution, calculate how a variation dp of fluid pressure is linked to a variation $d(-\sigma)$ of confining stress. Can regular undrained poroelasticity explain the failure of the sample?

3 - During successive unloadings of the same gassy sediment sample under undrained conditions, a delayed increase of the pore pressure is observed when the confining pressure is low enough (see Fig. 1). Why is it so?

4 - We now consider that the saturating fluid is a mixture made of a liquid and gas bubbles. The compressiblity of the liquid is K_L. The pressure of the bubbles and that of the liquid are assumed to be equal. The volume fraction of gas bubbles with respect to the pore fluide is υ. We will admit that the mass density ρ_F of the bubble-liquid mixture is governed by:

$$\frac{\mathrm{d}\rho_F}{\rho_F} = \left(\upsilon_0 \frac{p_0}{p^2} + \frac{1-\upsilon_0}{K_{\mathrm{L}}}\right) \mathrm{d}p + \alpha \mathrm{d}\left(\frac{x - x_0}{p}\right) \tag{1}$$

where α is a constant, where x is the mole fraction of solute, and where p_0 is a reference pore pressure, at which the volume fraction of bubbles in the mixture is υ_0 and the mole fraction of solute is x_0.

Explain the meaning of the various terms in this equation (for the full derivation of this equation, refer to Sec. 4.2.2 in Coussy's book).

5 - Find an equation that links a change $d\phi$ of porosity to a change $d\sigma$ of confining pressure and a change dp of pore pressure.

6 - Starting with expressing that the unloading is performed under undrained conditions, derive the following relation that links the pore pressure p, the mole fraction x of solute in the liquid and the cell confining stress σ:

$$(p - p_0)\left(\beta + \frac{\upsilon_0}{p}\right) + \alpha\frac{x - x_0}{p} = -\frac{1}{K\phi_0}(\sigma - \sigma_0) \tag{2}$$

where β is a constant.

7 - What is the drop of pore pressure observed directly after unloading? Is the instantaneous response of the sample significantly different depending on whether the pore pressure is below or above the bubble pressure?

8 - When unloading and waiting for a long time, what is the pore pressure? Is the long-term response of the sample significantly different depending on whether the pore pressure is below or above the bubble pressure?

NOTATIONS

σ is the confining stress (a negative confining stress corresponds to a compression)
p is the pore pressure
ϕ is the porosity
ϕ is the change of porosity
ϵ is the volume strain
K is the drained bulk modulus of the sample
K_U is the undrained bulk modulus of the sample
k_s is the bulk modulus of the solid matrix
K_F is the bulk modulus of the pore fluid
ρ_F is the mass density of the pore fluid
b is the Biot coefficient
N is a poroelastic constant
K_L is the bulk modulus of the liquid in the pore fluid
ρ_L is the mass density of the liquid in the pore fluid
υ is the volume fraction of gas bubbles with respect to the pore fluid
The subscript 0 refers to the state of reference.