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DISCUSSION

Discussion on "On the Measurement of *B* for a Sandstone" [Rock Mech Rock Eng 56:6127–6133]

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Highlights

- The influence of specimen size and testing system on Skempton's B values is discussed.
- The use of stiff measuring systems and precise transducers provides accurate enough B values.
- The use of large specimens is rarely possible and can be disadvantageous.

Keywords Undrained response · Calibration · Anisotropy · Heterogeneity · Time-dependent deformation

In this discussion, we present a critical review of the technical note by Asem and Labuz "On the Measurement of *B* for a Sandstone" (Rock Mech Rock Eng, 56, 6127-6133). The note provides an insight on the accuracy of Skempton's (1954) *B* coefficient measurements for a porous rock and discusses how it is affected by the specimen volume and drainage system. The authors conclude that ideally large enough specimens should be tested (with pore volume exceeding that of the drainage system by a factor of 100), but proper calibration is also helpful in achieving reliable *B* values.

In particular, the measurements of Skempton's *B* coefficient and other poroelastic parameters of Dunnville sandstone are performed on 74 × 75 × 226 mm block and 32 × 25 mm cylinder. It should be noted that Skempton's *B* is associated with the undrained increase in the pore fluid pressure Δp due to the applied increase in the mean stress ΔP. It is a function of porosity ϕ, and moduli of the fluid (K_f—changes with degree of saturation), bulk (K), and the solid bulk (K_s') and pores (K_s''), being also stress-dependent (Rice and Cleary 1976). In addition, the fluid pressure during undrained loading dissipates in the drainage lines and this effect is considered through the correction factor C_{cor} (Bishop 1976):

$$B = \frac{\left(1 - K/K_s'\right)}{\left(1 - K/K_s'\right) + \phi K\left(1/K_f - 1/K_s''\right)} = \frac{1}{\frac{\Delta P}{\Delta p} - C_{cor}}, \quad (1)$$

$$C_{cor} = \frac{1}{1/K - 1/K_s'}\frac{1}{V}\left[\frac{V_1}{K_f} + \frac{1}{\kappa_1}\right]. \quad (2)$$

Here V = specimen volume, V_1 and κ_1 are the dead volume and stiffness of the drainage system, respectively, so C_{cor} depends both on properties of the tested material and experimental apparatus. We agree with the authors' conclusion that calibration of the system response might provide similar values of "true *B*" comparing to those for very large specimens. We also aknowledge the importance of the presented work, especially given that there are neither ISRM nor ASTM standards available for achieving full saturation and measuring Skempton's *B* coefficient of rock. At the same time, a few disadvantages of the presented study have to be emphasized.

(I) Calibration of the system response should be done on the specimens of the same size having distribution of pores resembling the pore structure of a tested rock (Bishop 1976), so the utilized aluminum specimen with one hole is not representative. Calibration specimens should also have a similar compressibility to a tested rock, e.g., PMMA for a soft rock, like porous limestone and shale (Makhnenko

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and Labuz 2016) or sintered glass for a sandstone (Tarokh et al. 2018). This would allow to reduce the stress dependency of the correction factors (Ghabezloo and Sulem 2009). An improper calibration might be the reason of the discrepancy (around 0.07 or more than 10%) between large block ("true *B*") and corrected *B* values shown in Fig. 4 in Asem and Labuz (2023).

(II) The approach highlighted in the technical note is valid for a very specific case, because large prismatic specimens are rarely available for rock engineering projects, especially where wellbore extracted cores are involved. Also, the experimental setup might not allow application of hydrostatic compression and might not have two pressure transducers that can be put very close to the specimen edges. In addition, the effect of rock anisotropy on the measured *B* value could be up to 30–40% (Makhnenko and Tarokh 2018; Elsigood 2023). We illustrate it for Berea sandstone specimens coming from the same block with 40 mD permeability, $\phi = 0.23$, $K = 9.1$ GPa (at $P–p = 5$ MPa), $K'_s = 30$ GPa, $K''_s = 22$ GPa, and $K_f = 2.24$ GPa. While the measured values in hydrostatic and triaxial cells only require the application of the correction factors, those for the devices with passive restraint (plain strain and oedometric cells) also need consideration of the rock anisotropy (Makhnenko and Labuz 2016; Tarokh et al. 2020). When these effects are accounted for, the "true *B*" values are consistent within ± 0.02 (Table 1), even though the uncertainty for specimens with small volume can be 5–10%. Interestingly, $\kappa_l = 0.12–0.35$ mL/GPa for the presented setups contributing to only 2–4% of C_{cor}, making the dead volume the main factor in the correction.

(III) Use of large blocks can actually be disadvantageous. The saturation times are longer for larger specimens and the effect of heterogeneities (including fractures) and anisotropy (tested block is three times longer in one direction) can be stronger. Surprisingly, the large specimen was saturated at a lower pressure comparing to the small one (Fig. 2, Asem and Labuz 2023). In addition, some fluctuations of reported *B* at full saturation were observed, possibly due to temperature changes that are difficult to keep under 1 ℃. Moreover, the pore pressure diffusion may start competing with the viscous deformation even in a porous rock. Figure 1 illustrates the pressure increase due to applied undrained loading and consequent pressure buildup for Berea sandstone, Apulian limestone, and Opalinus Clay (Makhnenko and Podladchikov 2018). Even for a time scale of a few hours—the response of rock is not purely poroelastic. These effects are even more pronounced for tight rock with small pore sizes and often times small porosity (Kim and Makhnenko 2020).

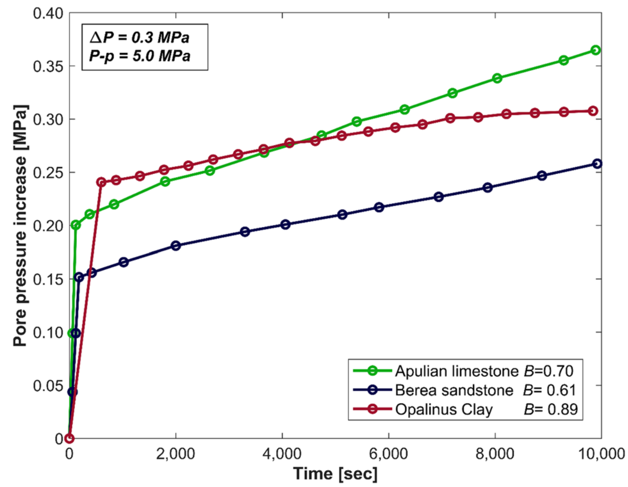

Fig. 1 Undrained pore pressure increase due to poroelastic and viscous effects in Apulian limestone, Berea sandstone, and Opalinus Clay caused by the increment of $\Delta P = 0.3$ MPa

(IV) Generally, what is the accuracy of Skempton's *B* that can be guaranteed and necessary for rock engineering applications? Geophysical evaluations of *B* from the wave velocities report 20–30% difference with the static values (Mavko et al. 2020; Elsigood 2023). Even in the laboratory, the accuracy of ± 0.02 is hardly achievable because of the limitations in measuring systems (e.g., applying larger mean stress increments makes the stress dependence more pronounced) and environmental factors. Finally, natural geological formations are

Table 1 Measured vs "true" B values along with the "dead" volumes and correction factors for Berea sandstone reported at $P–p=5$ MPa for triaxial, hydrostatic, plane strain, and oedometric compression devices

Setup	Dimensions	Dead volume V_1	Correction factor C_{cor}	B^{meas}	B^{true}
Triaxial	108 × 51 mm (cylinder)	8.9 ml	0.26	0.53	0.61
Hydrostatic	55 × 30 × 30 mm (prismatic)	2.5 ml	0.29	0.51	0.60
Plane strain	100 × 87 × 44 mm (prismatic)	13.8 ml	0.21	0.52	0.61[a]
Oedometric	15 × 35 mm (cylinder)	3.2 ml	1.29	0.31	0.58[a]

[a]Also corrected for rock anisotropy

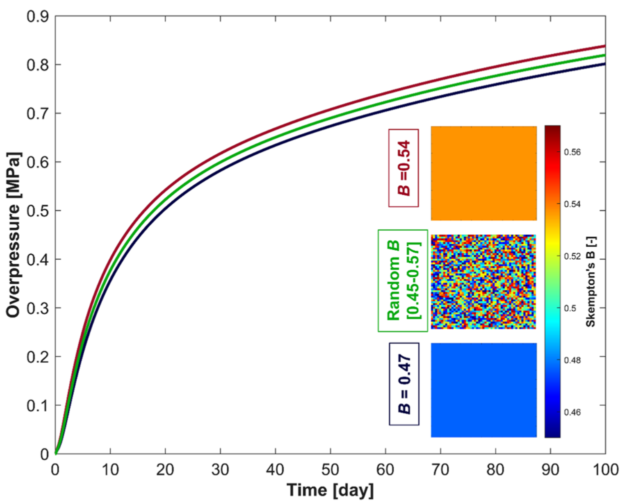

Fig. 2 Influence of B-value on evolution of pore pressure 200 m from the injection point with overpressure of 1 MPa

rarely homogeneous starting from meter scale. Figure 2 shows changes in pore pressure at distance of 200 m due to the applied overpressure of 1 MPa simulated for Dunnville sandstone formation with properties reported by Asem and Labuz (2023). Inconsistency in B measured for large ($B=0.54$) and small ($B=0.47$) specimens results only in minor difference in pore pressure diffusion process. In addition, natural heteregeneities expected for geological formations almost dimish this difference, making long measurements with large specimens not practical.

Concluding, the use of stiff measuring system and precise pressure transducers provides accurate enough Skempton's B values for most applications, while the use of large blocks is rarely possible and can be disadvantageous.

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Data availability Not applicable.

Declarations

Conflict of interest The authors declare no conflict of interest.

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