UQ Centre for Natural Gas

Dynamic Permeability in the Porous Medium with Broadband Pore Size Distribution

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INTRODUCTION

Analogous to the direct current (dc) and alternating current (ac) electrical conductivity of metals, the static (dc) and dynamic (ac) permeability are prime characteristics of a porous medium. When the fluid pressure gradient is time-harmonic, for example, when induced by elastic waves or oscillating pressure gradient, oscillatory fluid flow arises and then the dynamic permeability concept originally developed by Johnson et al. (1987) is essential with direct applications in the acoustics physics in the porous medium (Fig. 1). The pore space of natural porous medium is highly disordered in pore geometry and widely dispersed in pore sizes, which have a significant influence on the solid-fluid coupling, hydrodynamics of pore-scale oscillating flow and dynamic permeability. We develop a dynamic permeability model for the porous medium by incorporating the measurable pore size distribution into the pore-scale viscous flow and the dynamic permeability (Li, et al. 2021). Our approach for the dynamic permeability provides insight of the fundamental mechanism of the elastic wave propagation in the fluid saturated porous medium with broadband pore size distribution.

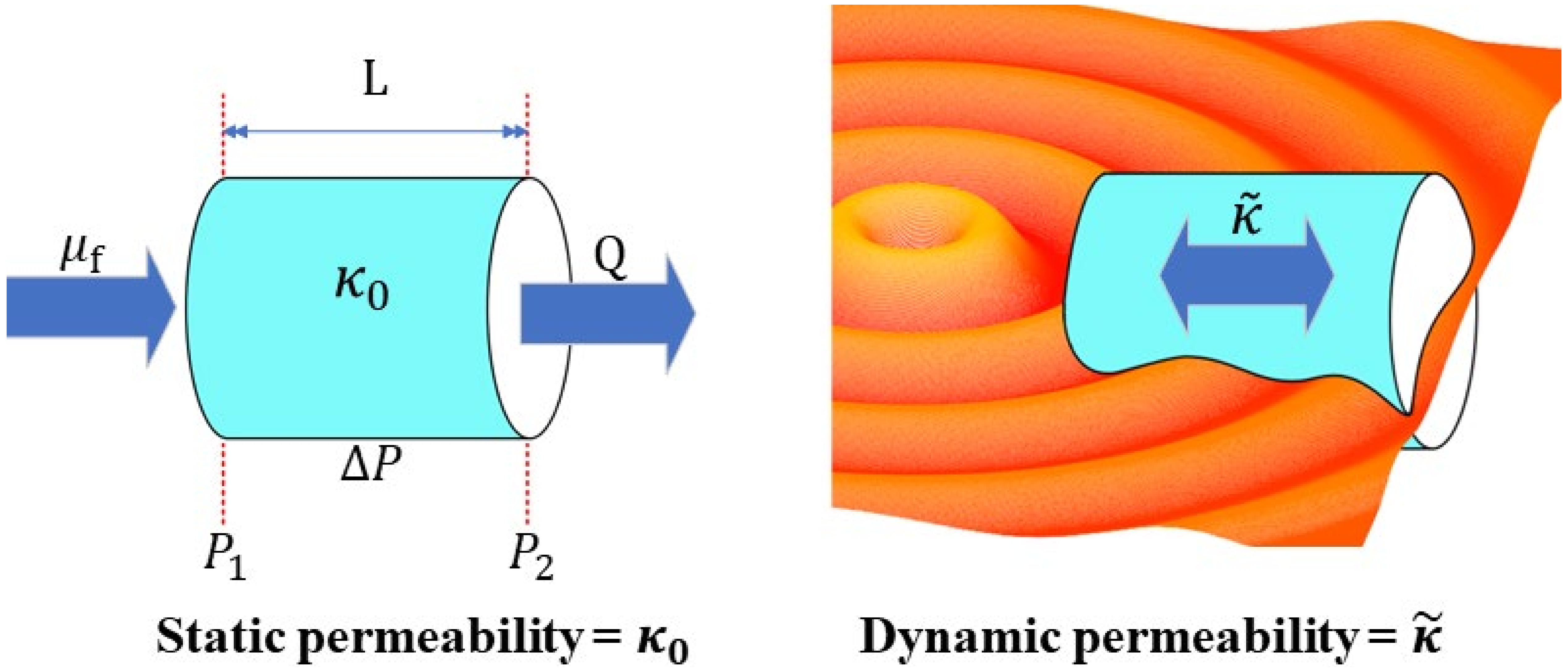

Fig. 1 Static permeability and dynamic permeability.

METHODOLOGY

- The pore-scale fluid velocity $\mathbf{u}$ can be decomposed into a potential flow field $\mathbf{u_p}$ and a viscous flow field which is dominated by the bulk flow $\tilde{\mathbf{v}}$ and is the only one contributing to the Darcy flow.
- In a porous medium with broadband pore size distribution with a range $r \in [r_{min}, r_{max}]$ (Fig 2), the dynamic length scale is,

$$\tilde{\ell}^2 = \sum_{r=r_{min}}^{r=r_{max}} L_i(\omega,r)\,dr = \sum_{r=r_{min}}^{r=r_{max}} r\phi_i\tilde{v}\,dr \qquad (1)$$

- The pore size distribution dependent dynamic permeability is,

$$\tilde{\kappa}(\omega,r) = \kappa_0 \sum_{r=r_{min}}^{r_{max}} L_i(\omega,r) \Big/ \sum_{r=r_{min}}^{r_{max}} L_i(\omega=0,r) \qquad (2)$$

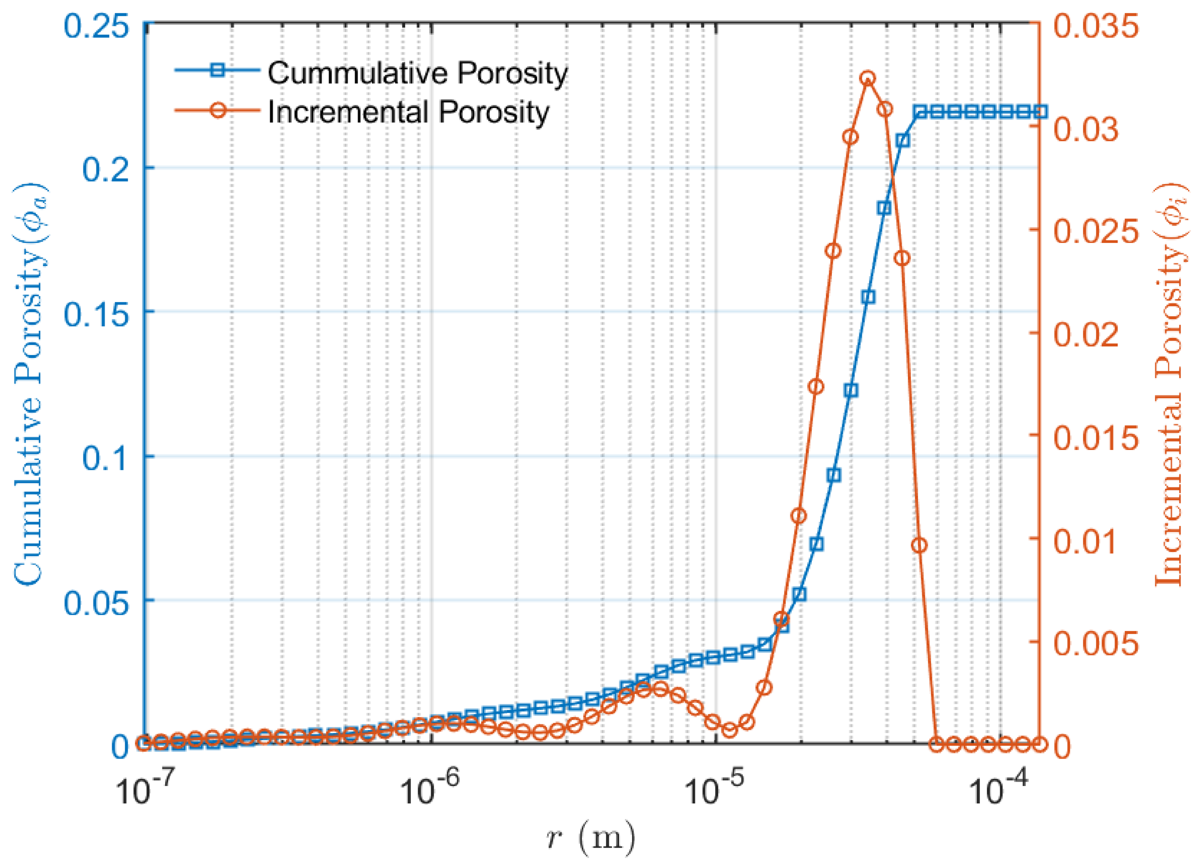

Fig. 2 Pore size distribution (PSD).

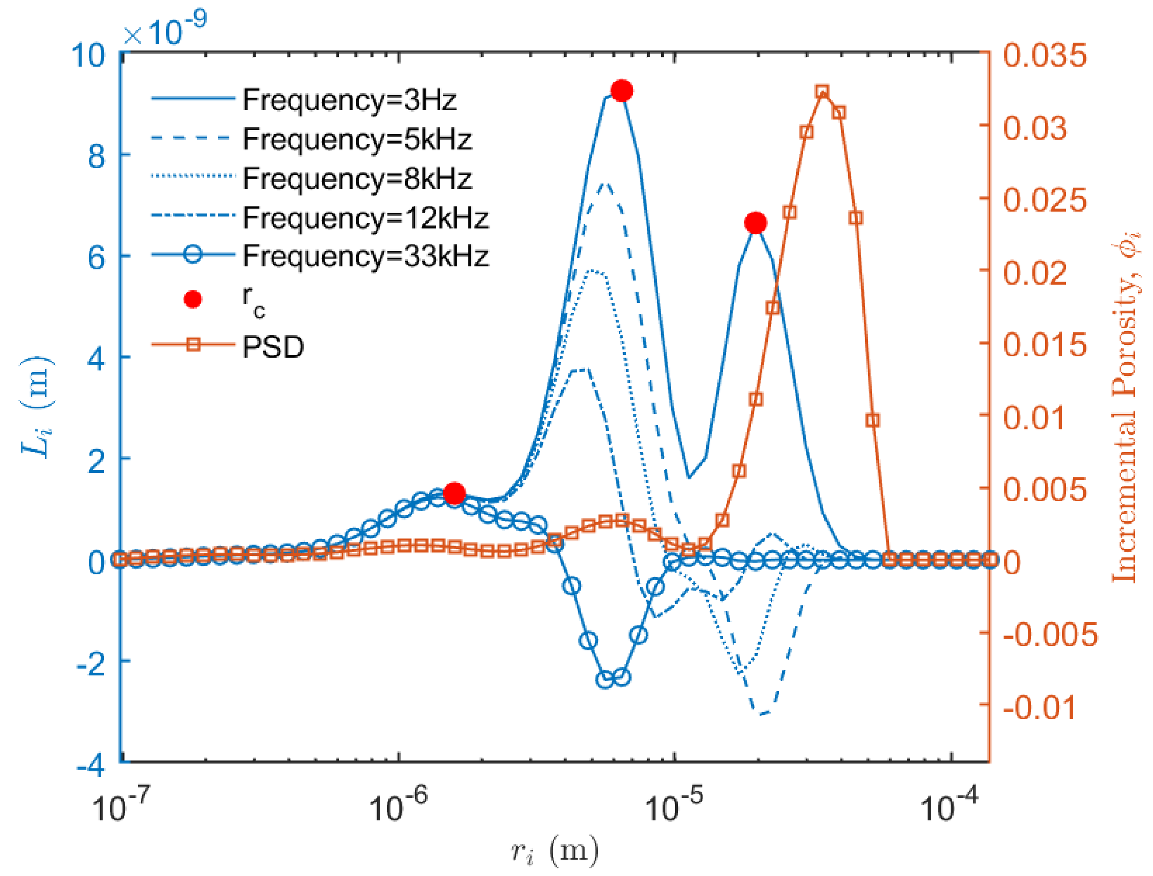

Fig. 3 PSD and length scale L_i at various frequencies.

RESULTS

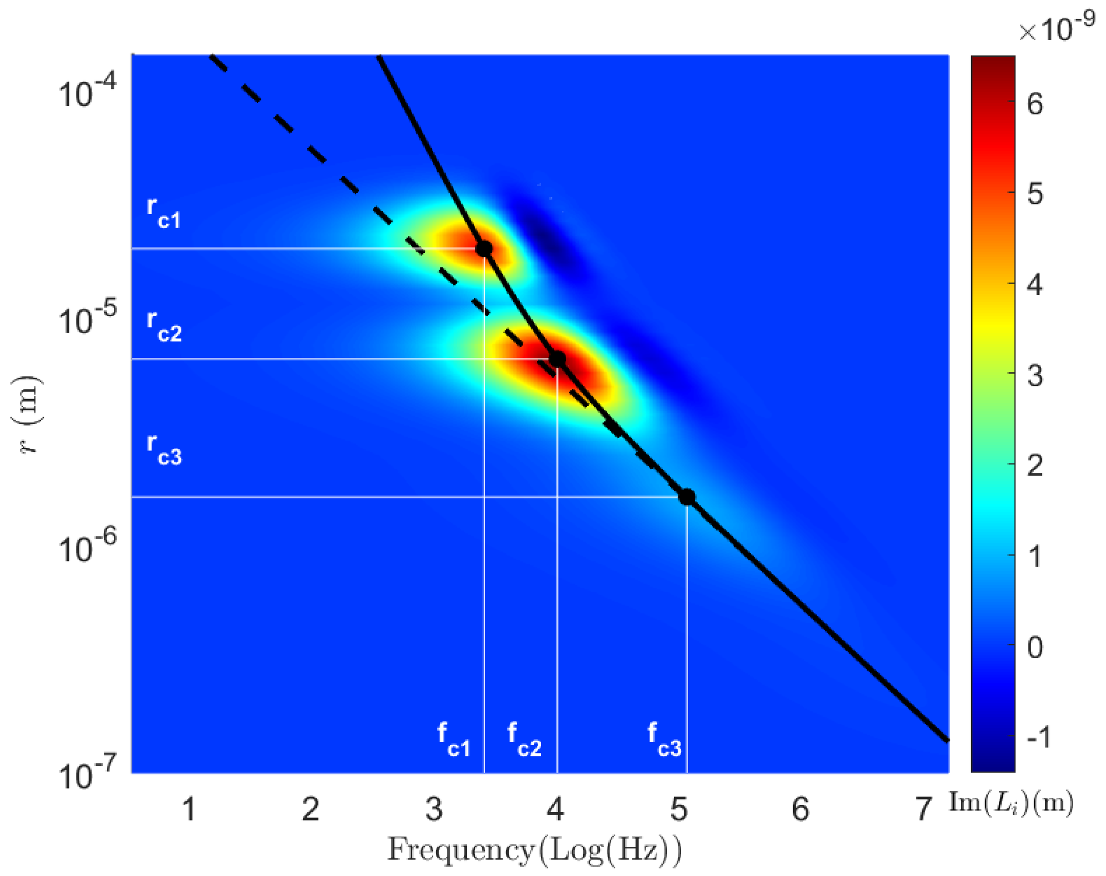

Fig. 4 The length scale L_i is function of frequency and PSD.

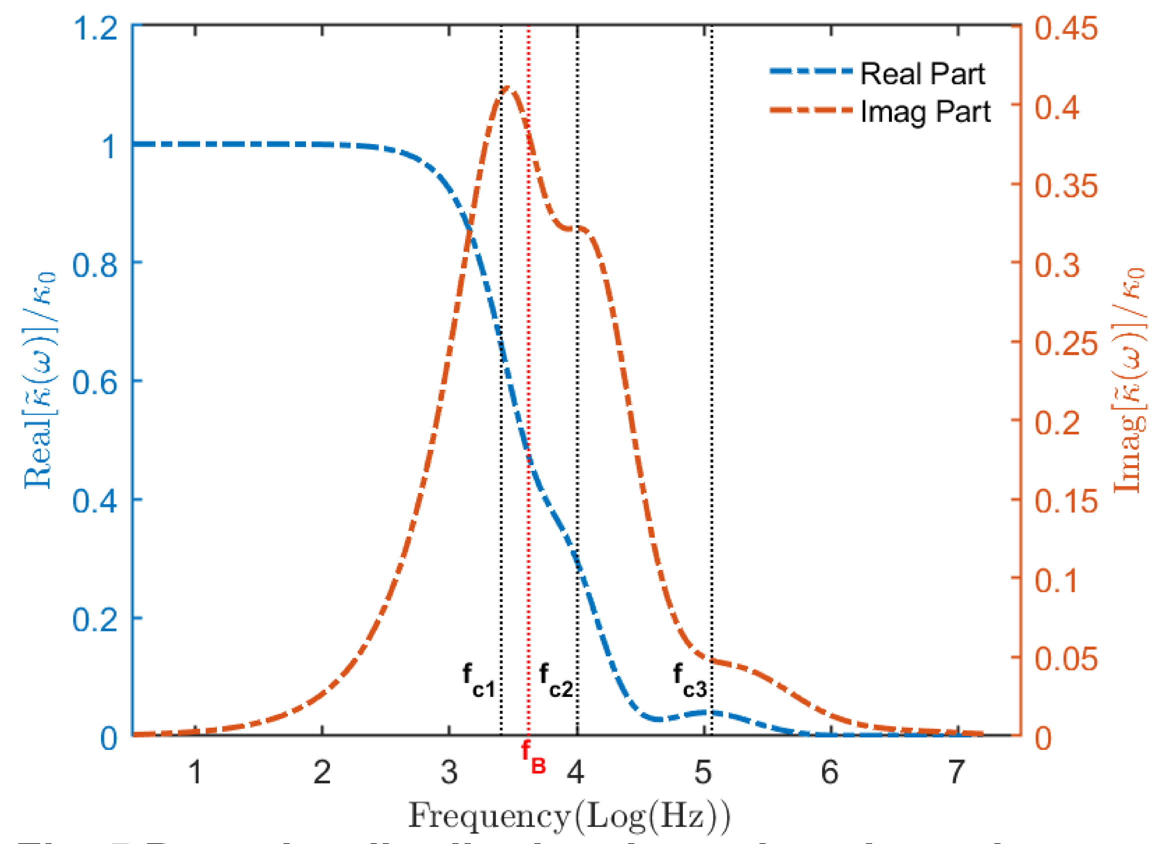

Fig. 5 Pore size distribution dependent dynamic permeability.

CONCLUSIONS

- The dynamic permeability model based on the measured pore size distribution (PSD) data is developed.
- The dynamic permeability of porous medium is proportional to the total hydraulic conductivity at the pore scale.
- PSD dependent dynamic permeability is still scaled by Biot frequency ω_B and static permeability κ_0 : $\tilde{\kappa}/\kappa_0 = f(\omega/\omega_B)$.
- The characteristic frequencies (f_{ci}) are associated with the characteristic pore sizes (r_{ci}) which result in the dynamic permeability deviated from the smooth curve especially at the high frequencies .

Reference:

Johnson, D. L., et al. (1987). "Theory of dynamic permeability and tortuosity in fluid-saturated porous media." Journal of fluid mechanics **176**: 379-402.

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Acknowledgements

This study was supported by an Australian Government Research Training Program (RTP) Scholarship.

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