Numerical Study on the Acoustic Field of a Deviated Borehole with 2.5D Method

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Introduction

Acoustic well logging is important in oil exploration and development industry. Its model is a wave-guide structure containing a cylindrical borehole filled with fluid penetrating a solid formation. But unlike the traditional problem, the solid formation extends to infinity.

In recent years, significant hydrocarbon reservoirs have been discovered in deep water environments. Offshore development adopts high angle wells to reduce drilling cost. Besides, these offshore reservoir formations often exhibit strong anisotropy.

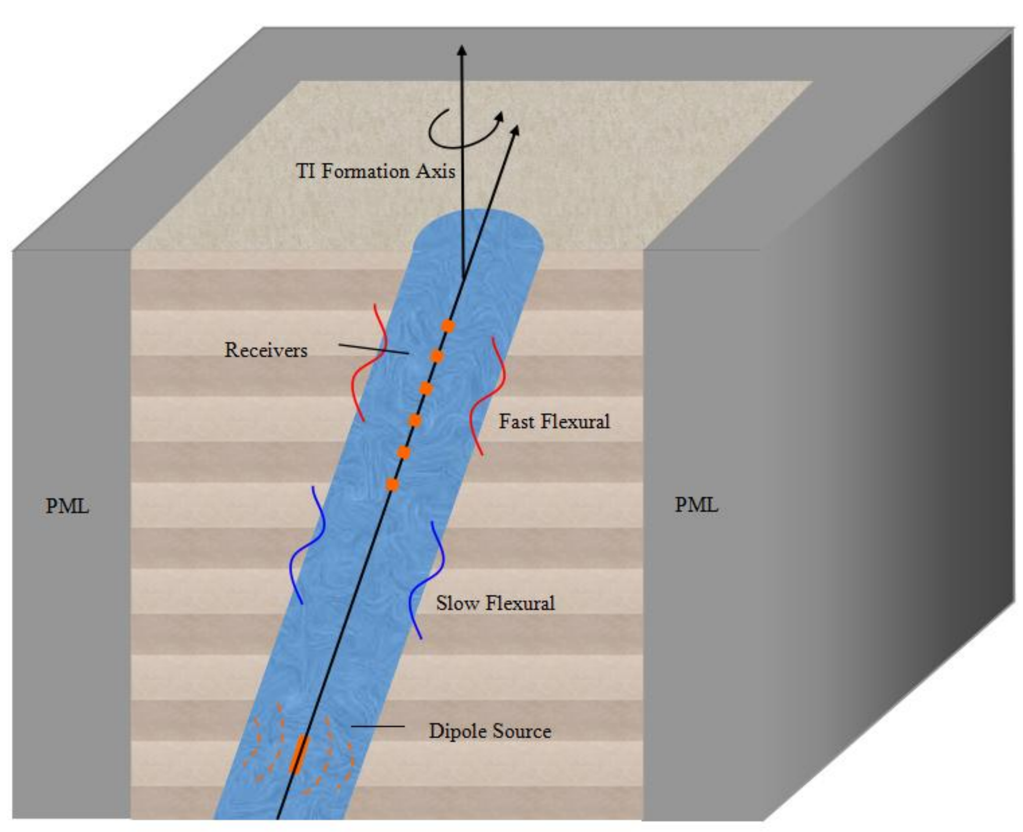

Figure 1 A deviated borehole model

Method

When the borehole structure keeps invariant in z direction, the wave propagation in z direction may be described by exp(ikz), where k is the wave-number in the z direction, then we have:

$$p(x,y,z,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}p(x,y,\omega,k)e^{ikz-i\omega t}d\omega dk$$

Now we just need to compute 2D equations, which reduce the computing scale greatly, especially for the FEM.

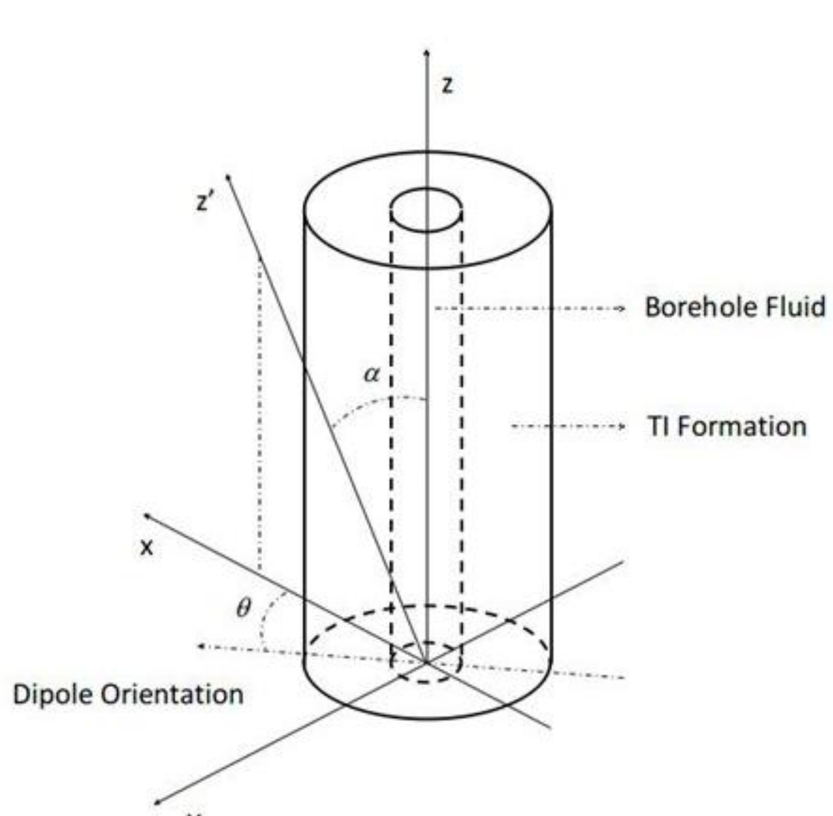

Figure 2 Theoretical structure

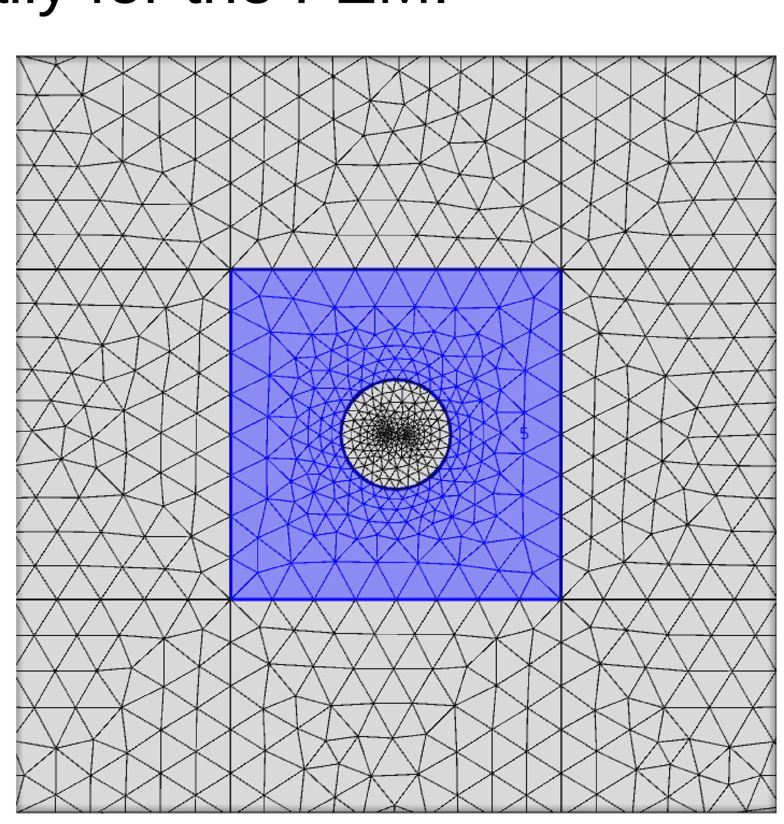

Figure 3 Computational model

Coefficient Form PDE provided by COMSOL (2D):

$$\nabla\cdot(-c\nabla u-\alpha u+\gamma)+\beta\cdot\nabla u+au=f$$
$$n\cdot(c\nabla u+\alpha u-\gamma)+qu=g-h^T\mu$$
$$hu=r$$

For solid area:

$$\frac{\partial\tau_{ij}}{\partial\tilde{x}_j}+\rho_s\omega^2u_i=0$$
$$\tau_{ij}=C_{ijkl}\varepsilon_{kl}$$
$$\varepsilon_{kl}=\frac{1}{2}\left(\frac{\partial u_k}{\partial\tilde{x}_l}+\frac{\partial u_l}{\partial\tilde{x}_k}\right)$$

Bond Transform

$$C=MC_0M^T$$

C-PML

$$\frac{\partial}{\partial\tilde{x}}=\frac{1}{s_x}\frac{\partial}{\partial x}$$

No Absorption

$$s_{x,y,z}=1$$

2.5D

$$\frac{\partial}{\partial z}=ik$$

Results

Dipole source, Austin Chalk and Cotton Valley shale.

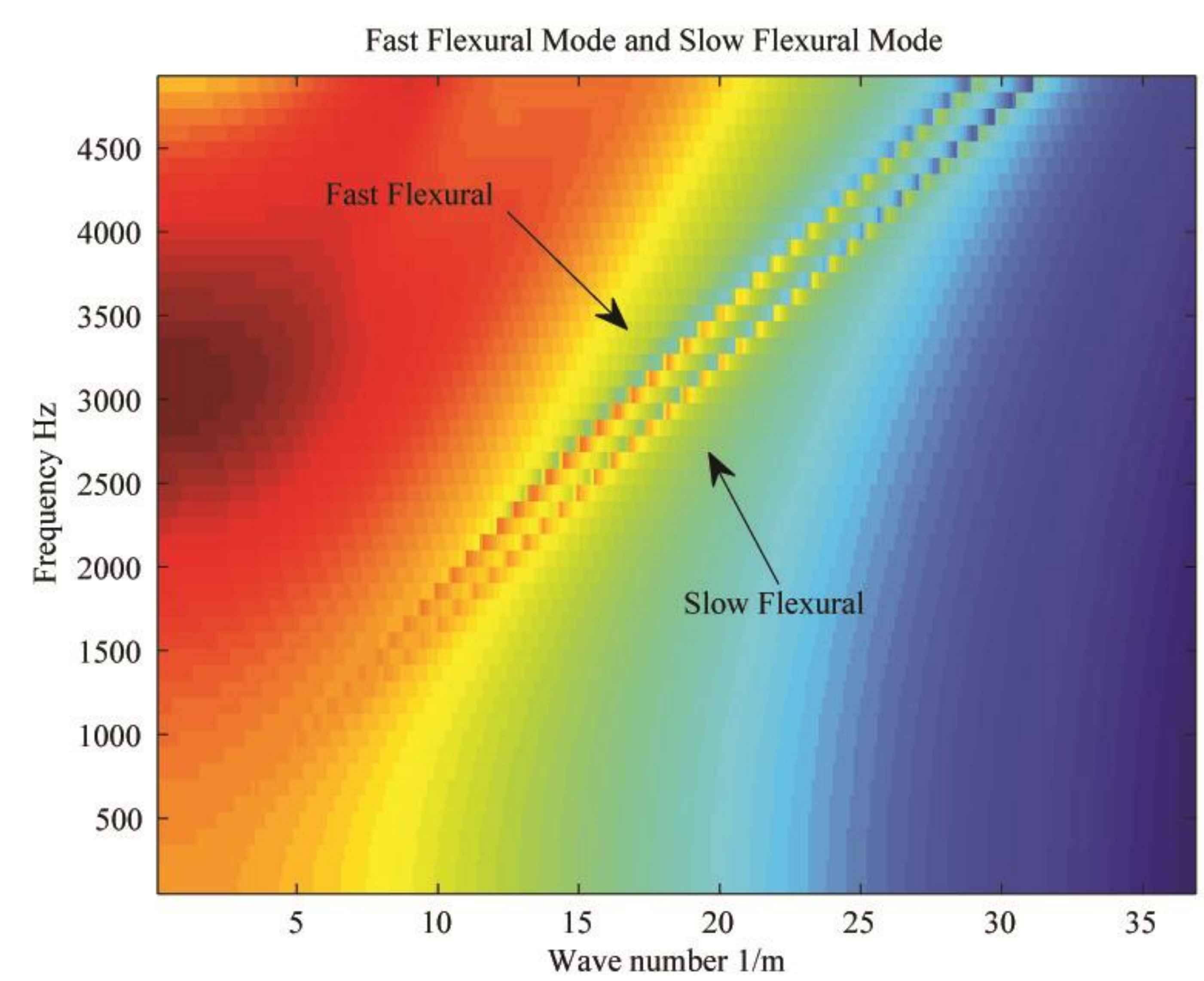

Figure 4 Flexural mode in frequency wave-number domain

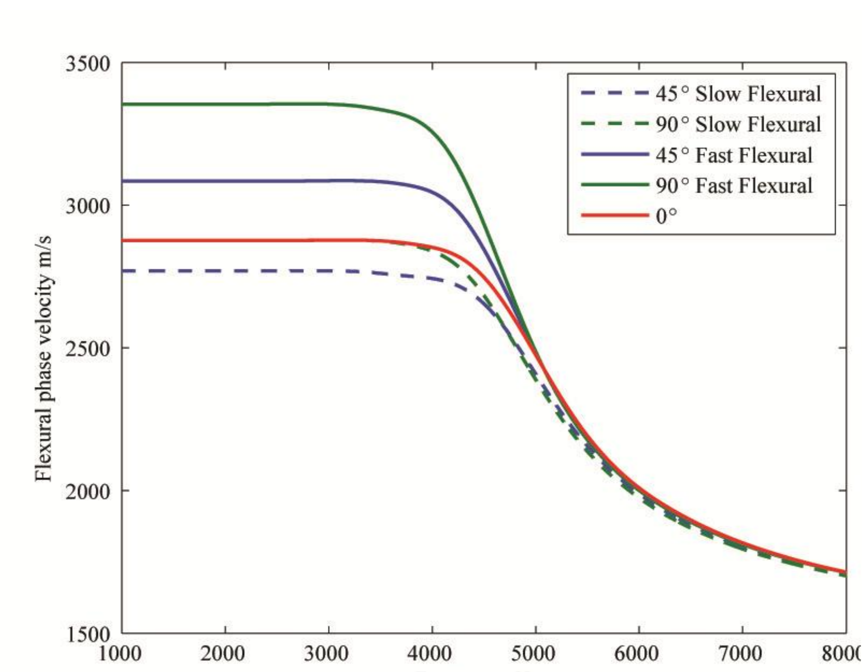

Figure 5 Flexural dispersion curve

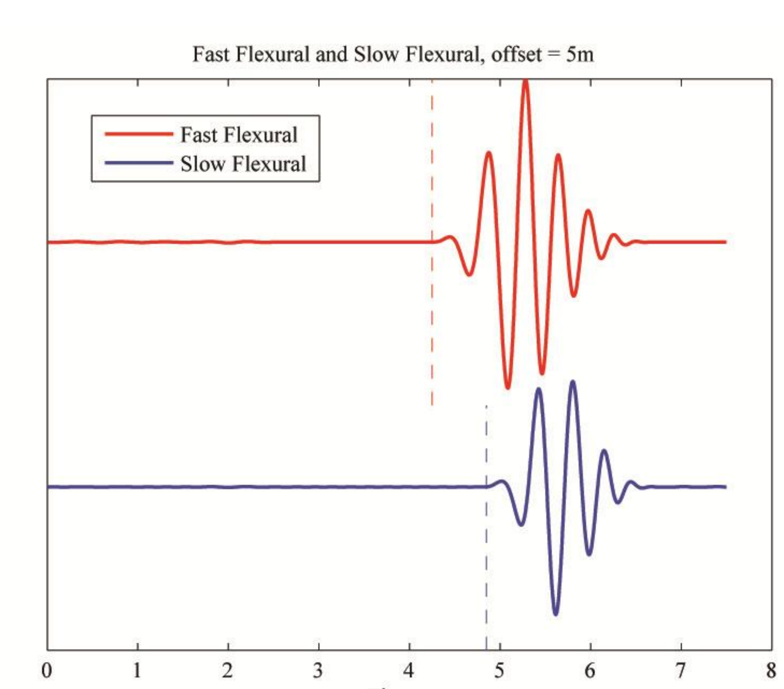

Figure 6 Wave form in time domain

Conclusions

1. The PDE interface is a strong tool to conduct equation based modeling and analysis.
2. This 2.5D method can be used to analyze other borehole structure such as elliptical borehole and logging-while-drilling with a little modification.
3. As based on FEM, it is more accurate than traditional finite difference method, especially when the structure is irregular.

Acknowledgements

This work is supported by the Natural Science Foundation of China (No. 11134011).