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Supporting Information for

Frictional and Hydraulic Properties of Plate Interfaces Constrained by a Tidal Response Model Considering Dilatancy/Compaction

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Introduction

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Figure S3 shows the numerical and approximate solutions for the tidal responses α and δ in the drained model.

Figure S4 shows the numerical solution of c in equation (12) for the drained model.

Text S1. Derivation of governing equations for the drained model

We explain a drained model in which pore fluids flow out of the shear zone (Figure S1b). The difference between the undrained and drained models is in the presence of fluid flow. The governing equations of the drained model are the same those as in the undrained model (equations (3), (4) and (8)), except for the governing equation for pore fluids.

Following the work of Segall et al. (2010), we assume homogeneous diffusion (HD), which holds under the condition that $T \gg t_w$. In the HD case, the effect of the finite shear zone thickness can be neglected, so the width of the shear zone can be formally defined as $w \to 0$ (Segall et al., 2010). The direction of fluid flow (Figure S1b) is parallel to the z-axis, and the shear zone lies on $z = 0$. c_{hyd} denotes the fluid pressure diffusivity at $z \neq 0$. Then, the governing equation for pore fluids can be written as (Segall et al., 2010)

$$\frac{\partial p}{\partial t} = c_{hyd} \frac{\partial^2 p}{\partial z^2} \ \left(\left. \frac{\partial p}{\partial z} \right|_{z=0} = \frac{M w \dot{\phi}}{2 c_{hyd}} \right) \#(S1)$$

Text S2. Nondimensionalization of the governing equations in the drained model

The governing equations for the drained model are the upper three in equation (10) and the nondimensionalized equation (S1). When we adopt $\sqrt{c_{hyd}T}$ as the representative length in the z-axis direction, the nondimensionalized equation (S1) can be written as

$$\frac{\partial \tilde{p}}{\partial \tilde{t}} = \frac{\partial^2 \tilde{p}}{\partial \tilde{z}^2} \quad \left(\left. \frac{\partial \tilde{p}}{\partial \tilde{z}} \right|_{\tilde{z}=0} = -E_p \frac{1}{\tilde{\theta}} \frac{d\tilde{\theta}}{d\tilde{t}} \right), \#(S2)$$

where $E_p = M\epsilon/2\sigma_{eff}^0\sqrt{w^2/Tc_{hyd}} = U/2\sqrt{w^2/Tc_{hyd}}$. E_p represents the relative importance of the dilatancy/compaction effect to the effective normal stress change in the drained model. Previous experiments and observations suggest that $c_{hyd} \sim 10^{-1\sim 3}$ m^2/s (Yamashita and Tsutsumi, 2018) and $U \sim 10^{0\sim -2}$ (Section 2.2.3). Using $10^{0\sim 1/2}$ m as the value of w (Section 4.3.4), we obtain a possible range of E_p of 10^{-2} to 10^{-4}.

Text S3. A numerical method for the governing equation in the drained model

The upper three equations in equation (10) are calculated numerically using the third-order Adams-Bashforth method. equation (S2) is calculated numerically using the method in Appendix B of Segall et al. (2010). In the following, we discuss the latter method. Near the shear zone, the discretization needs to be sufficiently fine to capture a steep gradient of the pore fluid pressure. On the other hand, for a region far from the shear zone, the discretization does not need to be fine because the pore fluid pressure gradient is small. Thus, we use the following coordinate transformation between z and r (Segall et al., 2010):

$$z(r) = -c + e^{\mathrm{r}} \text{ or, equivalently } r(z) = \ln(c + z).$$

We solve equation (S2) numerically in a new coordinate system using the Crank-Nicolson method. Specifically, we solve

$$\left\{1+\frac{\gamma}{2}e^{-r_k}\left(e^{-(r_k-\delta)}+e^{-(r_k+\delta)}\right)\right\}p_k^{i+1}$$
$$=p_k^i+\frac{\gamma}{2}e^{-r_k}e^{-(r_k-\delta)}\left(p_{k-1}^i+p_{k-1}^{i+1}\right)-\frac{\gamma}{2}e^{-r_k}p_k^i\left(e^{-(r_k-\delta)}+e^{-(r_k+\delta)}\right),\#(S3)$$

where $\gamma=\Delta t/\Delta r^2$, $\delta=\Delta r/2$, and p_i^k is the value of the pore fluid pressure of the k-th grid in the new coordinate system at time step i. Δt andΔr represent increments in time and space, respectively. In this study, the number of grids is 35, the starting position of the grid is $r(0)=\ln(0)$, $\Delta r=0.3$, and $c=10^{-4}$. Therefore, the grid farthest from the shear zone in the numerical calculation using $c_{hyd}\sim10^{-1}$ m^2/s, $T\sim12.4$ h is approximately z=170 m, while the grid farthest to the shear zone in the numerical calculation using $c_{hyd}\sim10^{-3}$ m^2/s, $T\sim12.4$ h is approximately z=17 m.

Text S4. The approximate solution of the tidal response for the drained model

The approximate solution for the drained model is derived in the same manner as in Section 3.1. The pore fluid pressure change due to fluid flow is represented as $p(z,t)=p_0+\Delta p(z)e^{i\omega t}$, where $p(0,t)$ corresponds to the pore fluid pressure in the shear zone. The equations for the drained model corresponding to equations (13) and (14) for the undrained model are

$$\frac{\Delta\tilde{V}}{\tilde{V}_{pl}}=\frac{2\pi i}{\tilde{K}\tilde{V}_{pl}+2\pi iC}|\Delta\tilde{S}(t)|\#(S4)$$

and

$$C=a-\frac{1}{1+i\frac{T_\theta}{T}}\left(b-\mu_{pl}E_p\sqrt{2\pi i}\right),\text{respectively.}\#(S5)$$

The equations of the drained model corresponding to equations (17) and (18) for the undrained model are

$$\alpha=Re\left(\frac{2\pi i}{(\tilde{K}\tilde{V}_{pl}+2\pi iC)\sigma_{eff}^0}\right)\#(S6)$$

and

$$\delta = arg\left(\frac{2\pi i}{\widetilde{K}\tilde{V}_{pl} + 2\pi i C}\right), \text{respectively.} \#(S7)$$

Furthermore, by applying the argument from which equations (19) and (20) were derived for the drained model, the approximate solutions of α and δ can be expressed as

$$\alpha \sim Re\left\{\left(C\sigma_{eff}^{0}\right)^{-1}\right\} \#(S8)$$

and

$$\delta \sim arg\{C^{-1}\}, \text{respectively.} \#(S9)$$

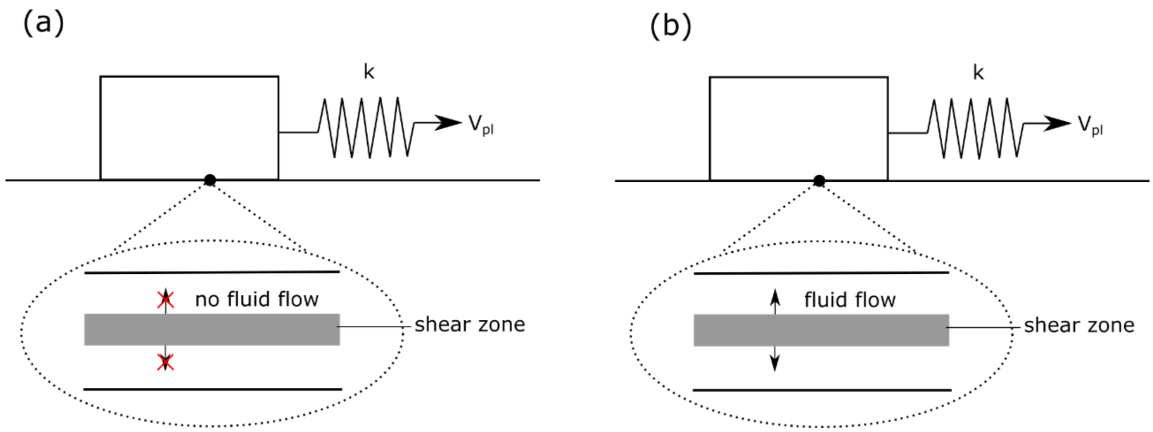

Figure S1. A schematic of the undrained (a) and drained (b) models. The difference between the two models is whether fluid flows outside the shear zone**.**

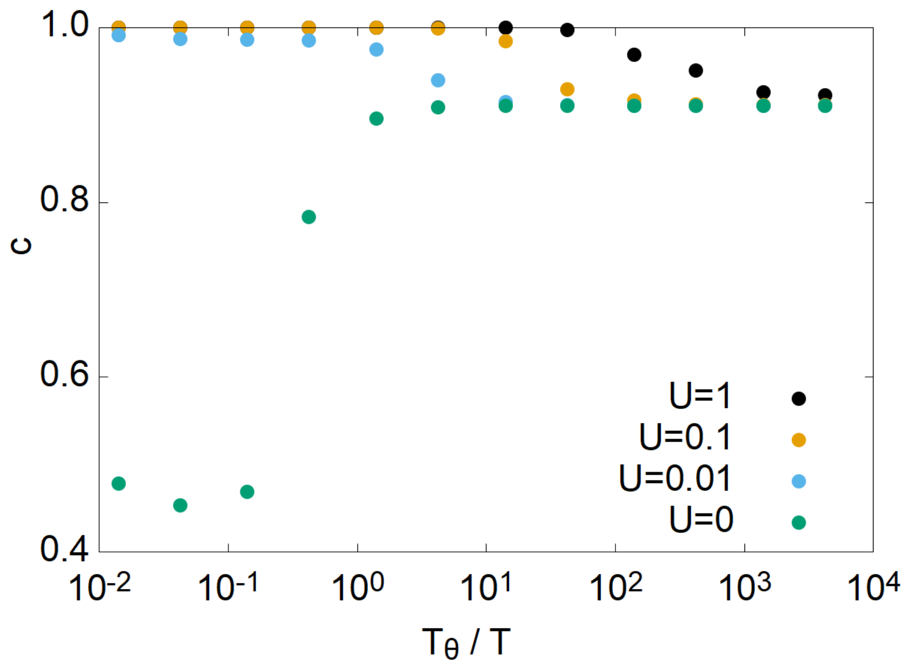

Figure S2. The numerical solution of c (dots). The differences in color represent differences in the dilatancy parameter U.

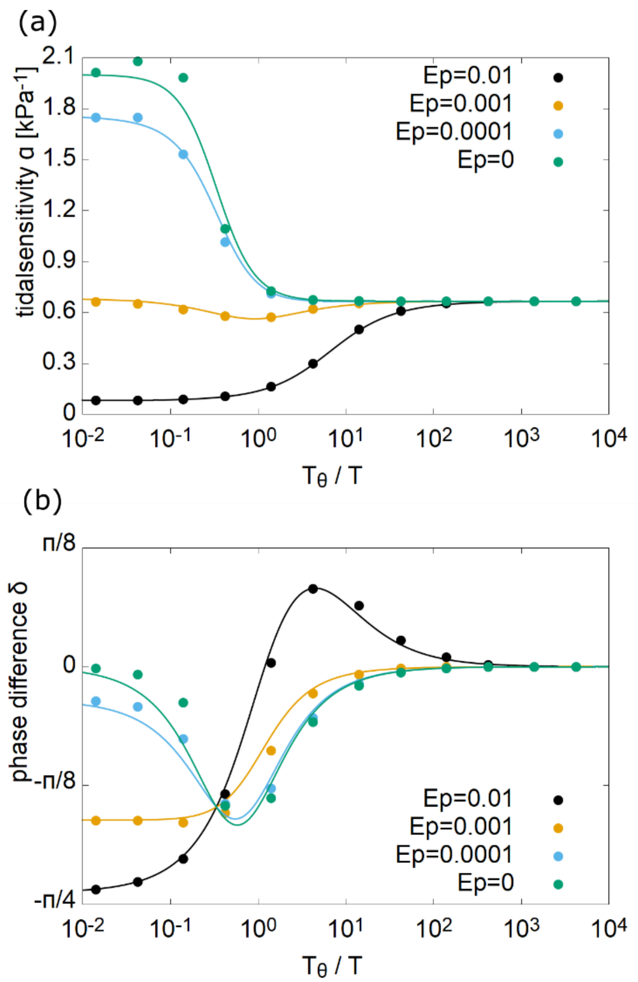

Figure S3. (a) The numerical solution of α (dots) and the approximation solution (i.e., equation (S8)) (solid line). (b) The numerical solution of δ (dots) and the approximation solution (i.e., equation (S9)) (solid line). The differences in color represent differences in the dilatancy parameter E_p for the drained model.

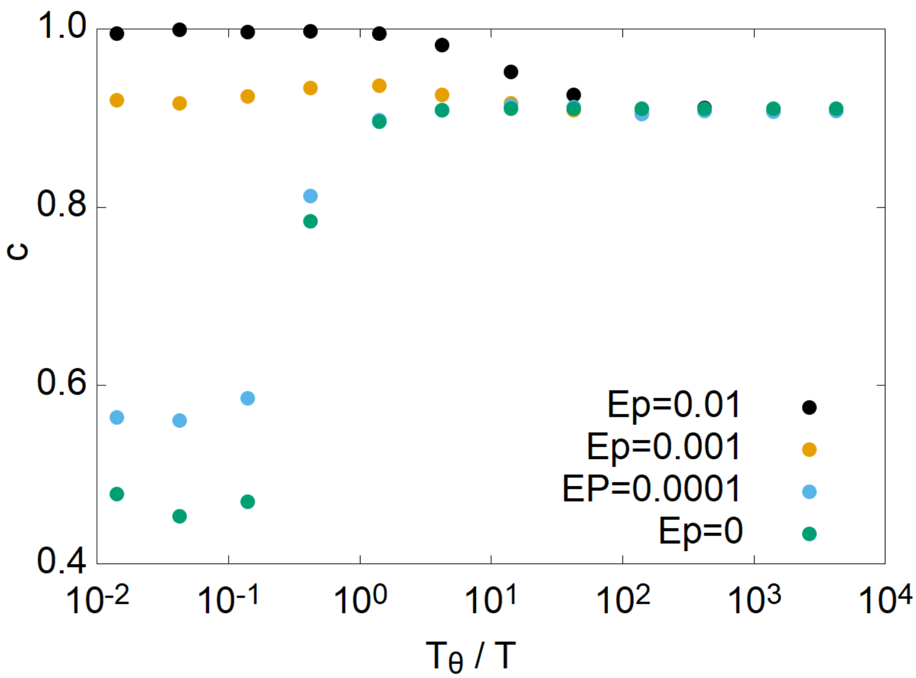

Figure S4. The numerical solution of c (dots). The differences in color represent differences in the dilatancy parameter E_p for the drained model.