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Quantitative relationship between slow earthquake migration speed and frictional properties

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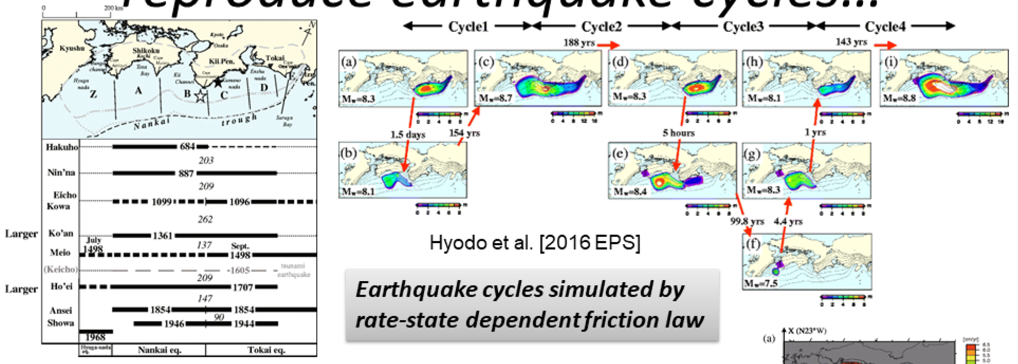
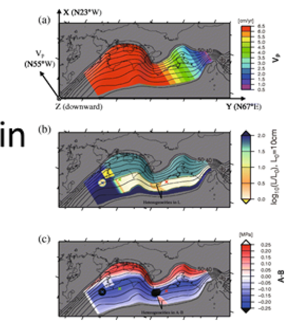
1-1. Introduction: *it's tough work to reproduce earthquake cycles…*

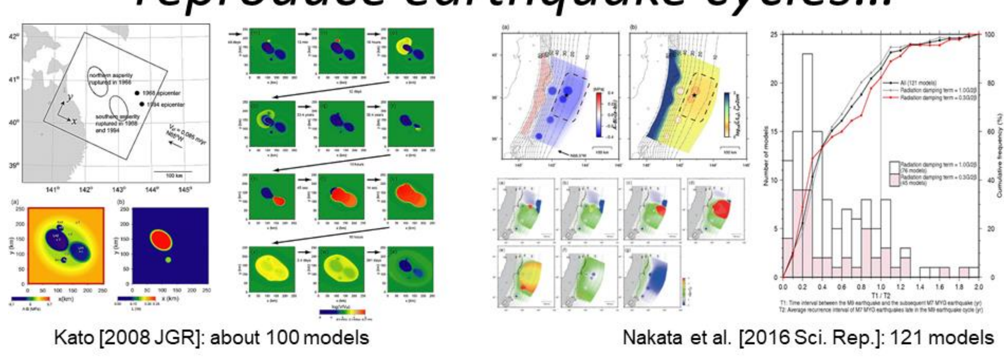




- Actual earthquake cycle is complicated.
- We have to introduce frictional properties in complex form…

⇒ There exists many possible patterns of frictional input parameter combination…

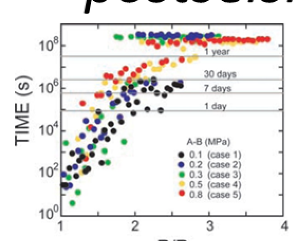
1-1. Introduction: *it's tough work to reproduce earthquake cycles…*



- The number of trial models is so many.
- One of the key factor for reproducing time delay between earthquakes is propagation speed of postseismic slip.

⇒ It is important to know the relationship between frictional properties and the propagation speed.

1-2. Introduction: *previous studies on postseismic slip propagation speed*

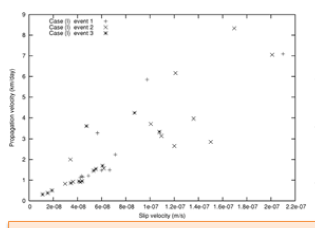


→ Ariyoshi et al. [2007 EPSL]: **related with (aσ)**

$$V_{slip}^{max} \approx V_{pl} \exp\left\{\frac{\Delta\tau}{(a-b)\sigma}\right\}$$

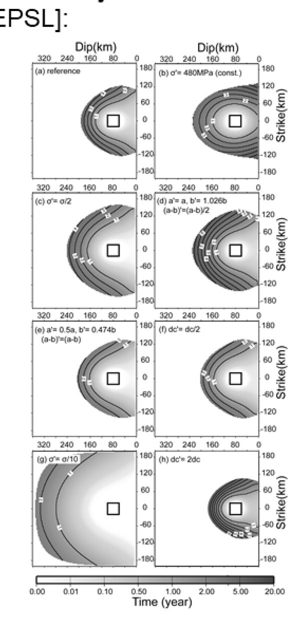
Perfettini & Ampuero [2008 JGR] ↑ :

↑ Kato [2007 GJI]: **related with (a-b)σ**



← Shibazaki & Shimamoto [2007 GJI]:

- $V_{rup} \approx (G/\gamma\Delta\tau)\, V_{max}$
- $\Delta\tau \approx$ **(b-a)σ**



⇒ We have to understand physical reasons of these results & evaluate their validities.

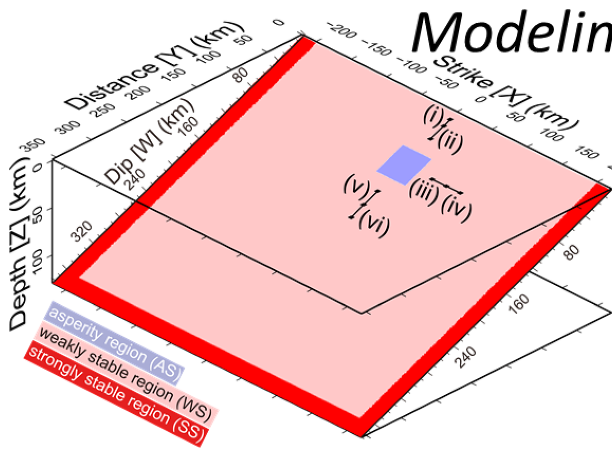
Objective

- We proposal a new relationship between aseismic slip propagation, frictional properties and fault geometry, instead of sliding velocity information.

Strategy

- Analyzing a test simulation of earthquake cycle on the basis of a RSF law, we describe stress change due to the passage of postseismic slip.
- Introducing the stress change description to the RSF law, we get a theoretical relationship and compare it with numerical simulation results.

2-1. Numerical simulation: *Modeling of afterslip*



$\mu = \tau/\sigma_n = K(x_i - x_j) - (G/2c)V_i$

$\mu = \mu_0 + a\ln(V_i/V_0) + \sum_i^N b_i \ln(\theta_i V_0/d_c)$

$d\theta_i/dt = 1 - V_i\theta_i/d_c$

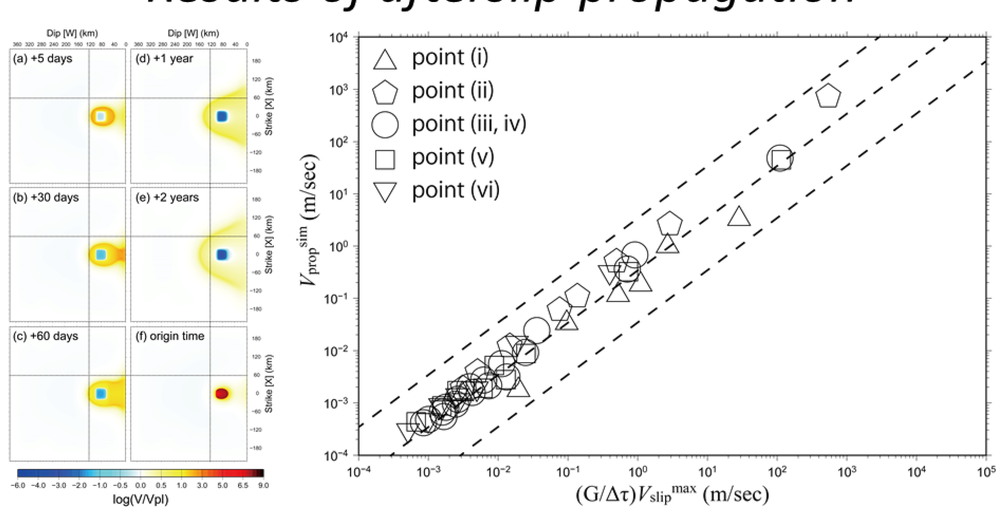
K : greenfunction (Okada1992)

G : rigidity, c : shear wave velocity

solving by using Runge-Kutta Method.

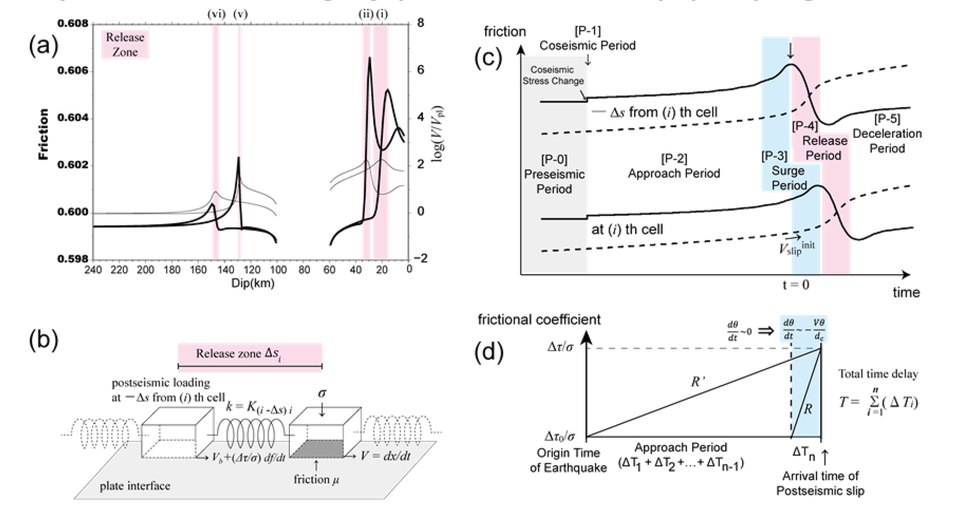
- Main shock: Mw 7.3 & Tr 50 years, 40 × 40 (km²)
- afterslip propagates in the weak stable region.
- Calculation results are independent of mesh size.

2-2. Numerical simulation: *Results of afterslip propagation*



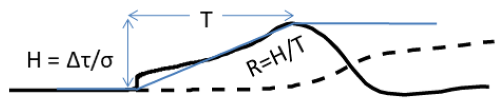
- $V_{rup} \propto (V_{max}/\Delta t)$ can explain most of propagation
- Difficult to estimate V_{max} in advance

3-1. Analytical solution for aging-law of RSF: *Physical modeling of postseismic slip propagation*



- Afterslip propagation is treated as "domino reaction" connected to nearby blocks ⇒ We should calculate ΔT for Release Zone (Δs).
- [Surge Period] ≒ [Release Period]
- ΔT ⇒ time difference on peak time of maximum slip velocity (or shear stress) between nearby two blocks

3-1. Analytical solution: *Physical modeling of postseismic slip propagation*



$$V_{prop}^{ramp} = \frac{\eta G V_b}{\sigma\left\{a\log\left(L_{ramp} + \frac{kV_b}{\gamma\sigma V_{init}}\right) - \frac{\Delta\tau}{\sigma}\right\}} \qquad L_{ramp} = \frac{\sigma R}{kV_b + R\sigma}\left\{\exp\left(\frac{H(kV_b + R\sigma)}{a\sigma R}\right) + \frac{kV_b}{R\sigma}\right\}$$

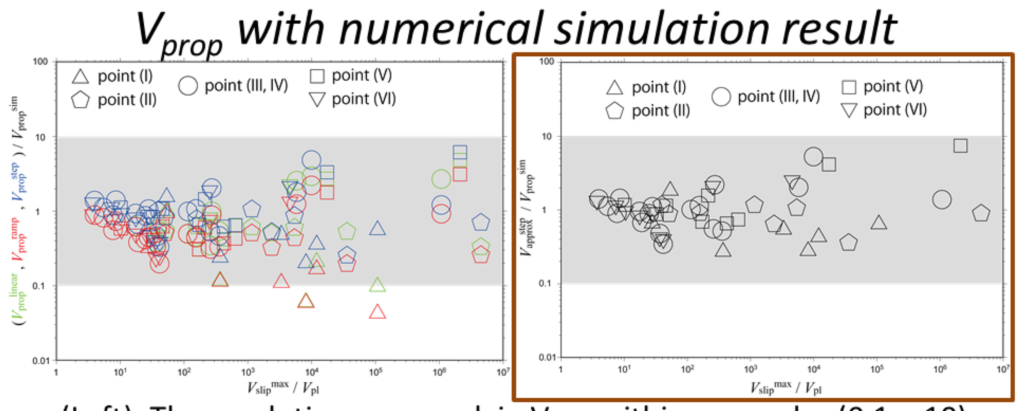
$$V_{prop}^{step} = \frac{\eta G V_b}{a\sigma\log\left(1 + \frac{kV_b}{\gamma\sigma V_{init} L_{step}}\right)} \approx \frac{b\Delta s}{a d_c}\exp\left(\frac{\Delta\tau}{a\sigma}\right)V_b \qquad L_{step} = \exp\left(\frac{\Delta\tau}{a\sigma}\right)$$

(for $b/d_c >> G/\sigma\Delta s$ && $V_{init} \approx V_b$ && $\eta \approx 1$)

$$V_{prop}^{linear} \approx \frac{b\Delta s}{a d_c} V_{slip}^{init} \qquad \gamma = {}^{b}/_{d_c} - {}^{k}/_{\sigma}$$

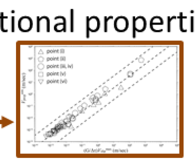
- Pre-stage (increasing shear stress): $d\theta/dt \approx -V\theta/d_c$
- Loading process is described as step/ramp/linear function.
- Input parameter: ramp (T, Δτ/T), linear(Δτ/T), step(Δτ)

3-2. Analytical solution: *Comparison of V_{prop} with numerical simulation result*



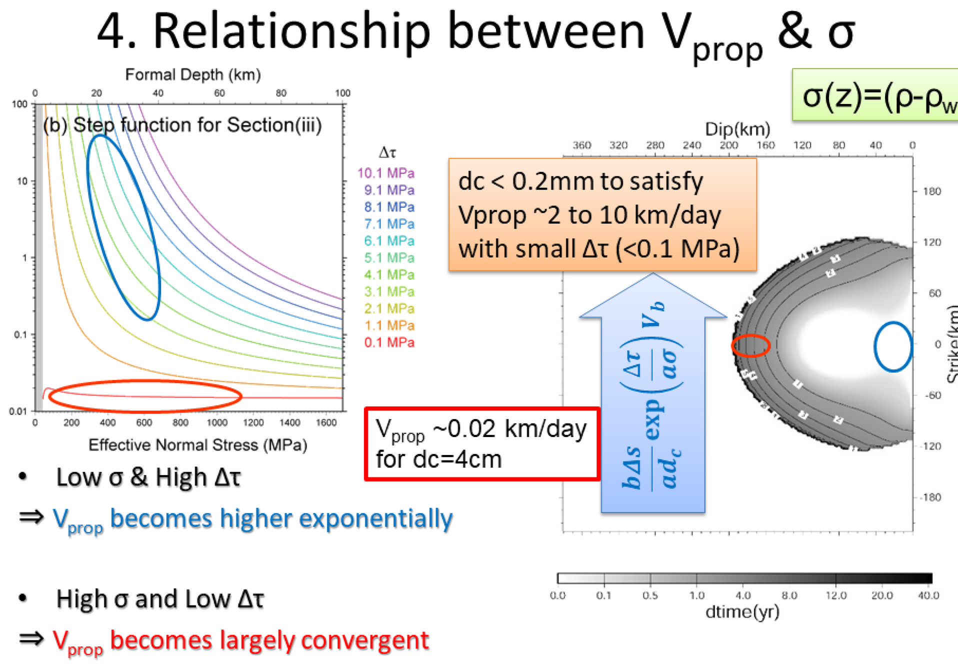
- (Left): Three solutions can explain V_{prop} within one order (0.1〜10)
- (Right): Approximated solution can also explain it in the same order.
- Underestimate for shallow focal depth due to free surface condition where V_{max} becomes higher than expected from frictional properties

Both of analytical solutions can describe V_{prop} as well as $V_{rup} \approx (G/\gamma\Delta\tau)\, V_{max}$



4. Relationship between V_{prop} & σ

σ(z)=(ρ-ρw)gz



- Low σ & High Δτ

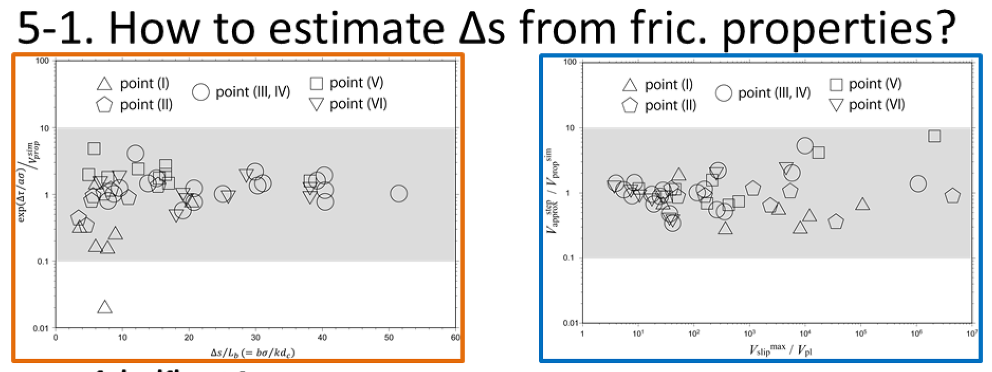
⇒ V_{prop} becomes higher exponentially

- High σ and Low Δτ

⇒ V_{prop} becomes largely convergent

⇒ consistent with far field V_{prop} in the test simulation result in that V_{prop} is not proportional to slip velocity.

5-1. How to estimate Δs from fric. properties?

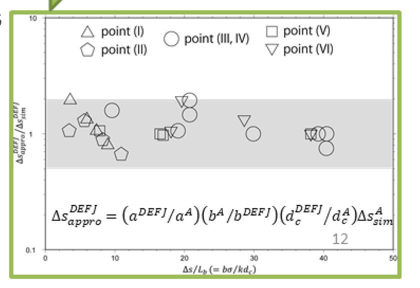


In case of significant Δτ:

$$V_{simple}^{step} \approx V_{const}\exp\left(\frac{\Delta\tau}{a\sigma}\right) \qquad \Delta s \approx (a/b)(V_{const}/V_{pl})d_c \qquad V_{prop}^{step} \approx \frac{b\Delta s}{a d_c}\exp\left(\frac{\Delta\tau}{a\sigma}\right)V_{pl}$$

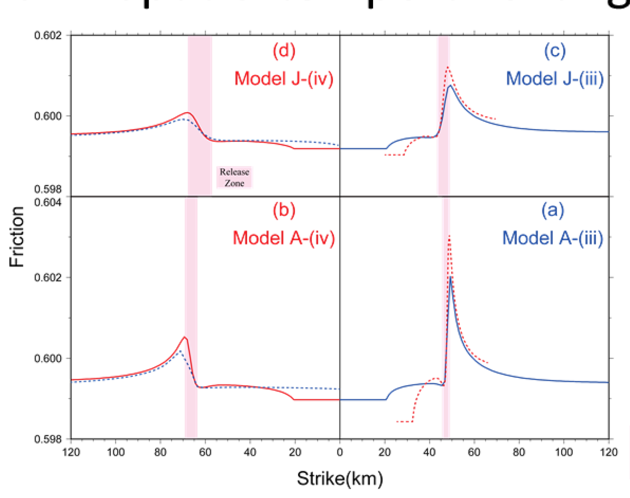
(V_{const} : 0.1-10 km/month)

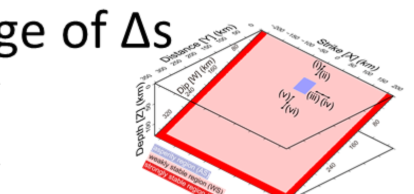
Model A: a=0.002, b=0.0019
Model D: a=0.002, b=0.00195
Model E: a=0.001, b=0.0009
Model F: dc=dc/2
Model J: dc=2dc



- Δs is approximately proportional to (a/b)dc, which explains in the range from 1/2 to 2 times.
- Since Δs becomes larger in case of small σ (shallower part), Δs is also dependent on σ as shown by other models and different depth.

5-2. Spatio-temporal change of Δs





Similarity Check:
Bold: original
Dotted: converted by (X/T, μT)

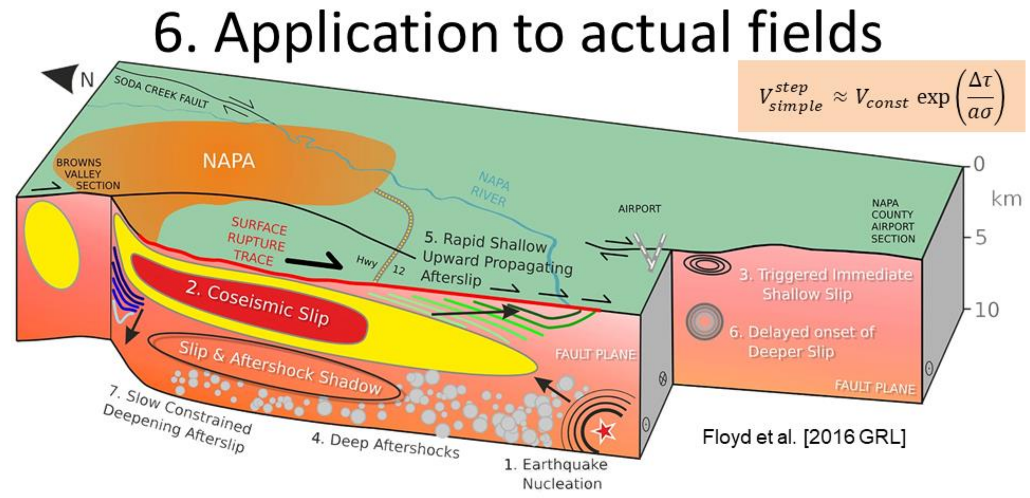
Model A: dc=4cm
Model J: dc=8cm (more stable)

Background: Release Zone Δs

- postseismic propagation behaves as a thermal diffusion process under the steady state [Viesca & Dublanchet, under revision for JGR].
- Δs becomes broader as the time passage *T* from the origin time of mainshock.
- This approximation is applicable to constant frictional properties: sections (iii) and (iv) in our model.

6. Application to actual fields

$$V_{simple}^{step} \approx V_{const}\exp\left(\frac{\Delta\tau}{a\sigma}\right)$$



- Time delay reflects **the magnitude of σ: (3) < (6) < (7)**
- Why did (4) Deep Aftershock occur earlier than (6) & (7) ?

⇒ Because of **high Δτ** due to the stress concentration between (1) & (2)

- Why was (5) Afterslip rapid shallow upward ? ⇒ **small σ**
- Slip & Aftershock Shadow suggests the condition of **$b/d_c < G/\sigma\Delta s$**

6. Summaries & Conclusions (1)

- We are succeeded in explaining V_{prop} quantitatively by using approximated solution as a form of $\frac{b\Delta s}{a d_c}\exp\left(\frac{\Delta\tau}{a\sigma}\right)V_b$
- This approximation helps us to understand the relationship between frictional properties and V_{prop} more easily.
- Two contradict relationships of V_{prop} with ***aσ*** or ***(a-b)σ*** are explained as follows (if $V_{pl} << V_b$) :

$$V_{prop}^{ramp} \approx V_{prop}^{step} \approx \left(\frac{b}{a}\right)\frac{\eta\Delta s}{d_c}\exp\left(\frac{\Delta\tau}{a\sigma}\right)V_b = \left(1 + \frac{b-a}{a}\right)\frac{\eta\Delta s}{d_c}\exp\left(\frac{\Delta\tau}{a\sigma}\right)V_b$$

- For significant Δτ/aσ : V_{prop} is practically dependent on ***aσ***
- For negligible Δτ/aσ : V_{prop} is dependent on ***(a-b)σ***

6. Summaries & Conclusions (2)

- The size of Release zone (Δs) is larger than $L_b = \eta G d_c/b\sigma$, proportional to ***(a/b)dc***.
- Δs is also dependent on the passage time (T) from the origin time of mainshock.
- By converting Δs'=Δs/T on the basis of thermal diffusion theory, we can roughly evaluate the temporal change of Δs approximately under the condition of steady state and constant frictional properties.
- If frictional properties are not constant, such as effective normal stress proportional to depth, it is not valid to apply above relationships, which is our future study.