Braking effect (velocity strengthening) of Kaolinite under intermediate slip velocities.

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1.Creeping landslide???

- Creep is the slow downslope movement of material under gravity. It generally occurs over large areas. (shallow fault zones)

Velocity class	Description	Velocity (mm/s)	Typical velocity
7	Extremely rapid	$5x10^3$	>5m/s
6	Very rapid	$5x10^1$	3 m/min - 5m/s
5	Rapid	$5x10^{-1}$	1.8 m/h – 3 m/min
4	Moderate	$5x10^{-3}$	13m/month – 1,8m/h
3	Slow	$5x10^{-5}$	1.6 m/year – 13m/ month
2	Very slow	$5x10^{-7}$	16 mm/ year - 1.6 m/year
1	Extremely slow	$<5x10^{-7}$	<16mm/year

Table: International Union of Geological Sciences Working Party on the World Landslide Inventory velocity classes (after IUGS 1995)

Mechanism???

Velocity-strengthening (low velocity)

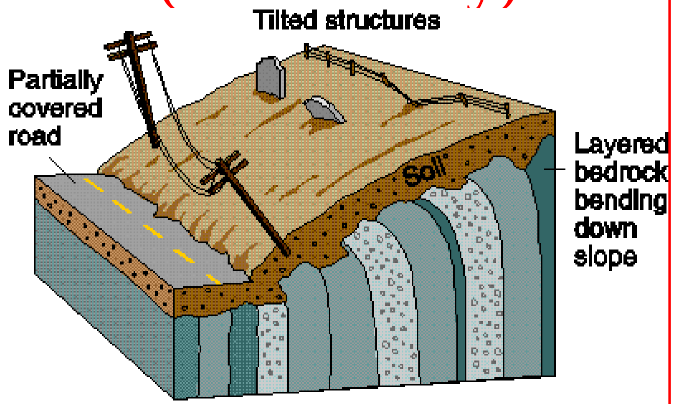


Figure 1. Creeping landslide
Image: emaze.com

- **Slope angle (< 20^0 (Seda Cellek, 2020))**
- **Water (groundwater, rainfall)**
- Material of rock
- Earthquake
- ...

- What is steady state:

- Velocity weakening (SVW)?

- **Velocity Strengthening (SVS) ?**

- Frictional resistance **increases** with sliding velocity

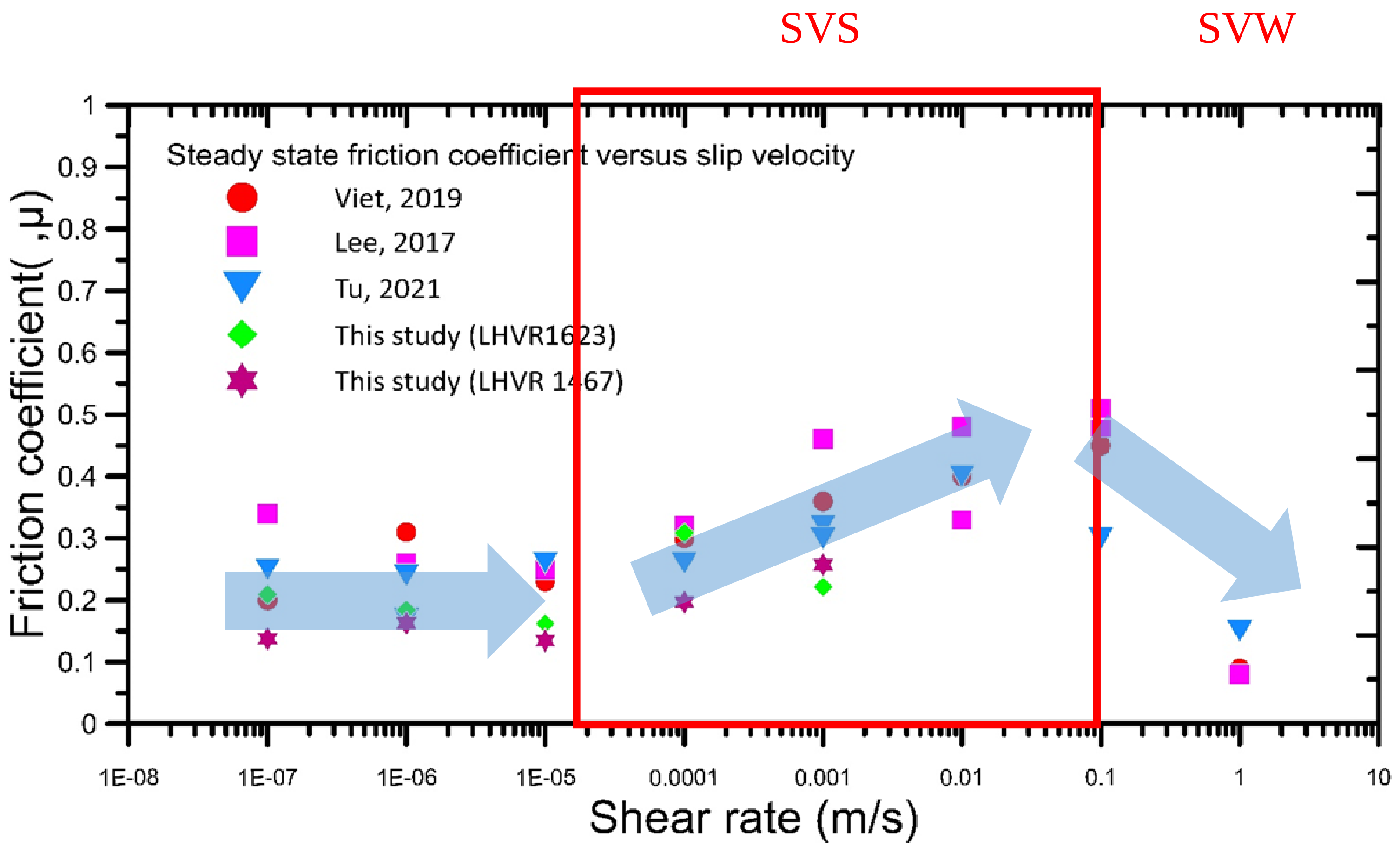


Figure 2. The steady-state apparent friction coefficients under different slip rates

2.Review paper

Newmark proposed a displacement-based analysis method to **calculate the permanent displacement** of artificial embankments and **natural slopes encountered seismic force**.
If **earthquake acceleration > a_c** (critical acceleration), the block will **slide down** the sliding surface
After the block slide low (**$a < a_c$**), **velocity** start to **decrease**
If the velocity of block stops (**$v = 0$**), the **block stops** sliding

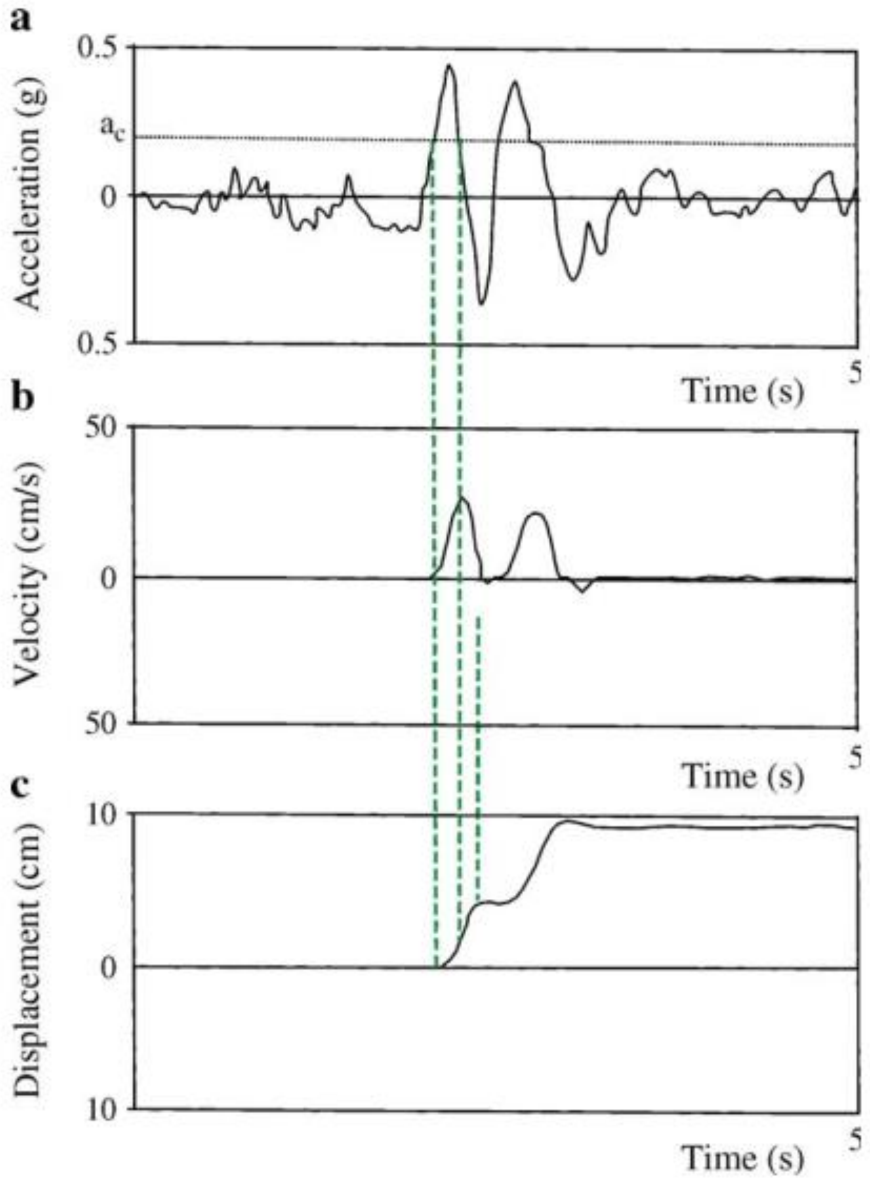


Figure 3. Double-integration approach of Newmark displacement analysis

3. Objective

At low velocity:

1.Height watertable above failure surface

2.Friction coefficient

→ Creeping landslide

- **Purpose of research**:

Contribution: validate and compare data with previous studies

Explanation mechanism velocity-strengthening

Applications, predictions and **warnings** landslides

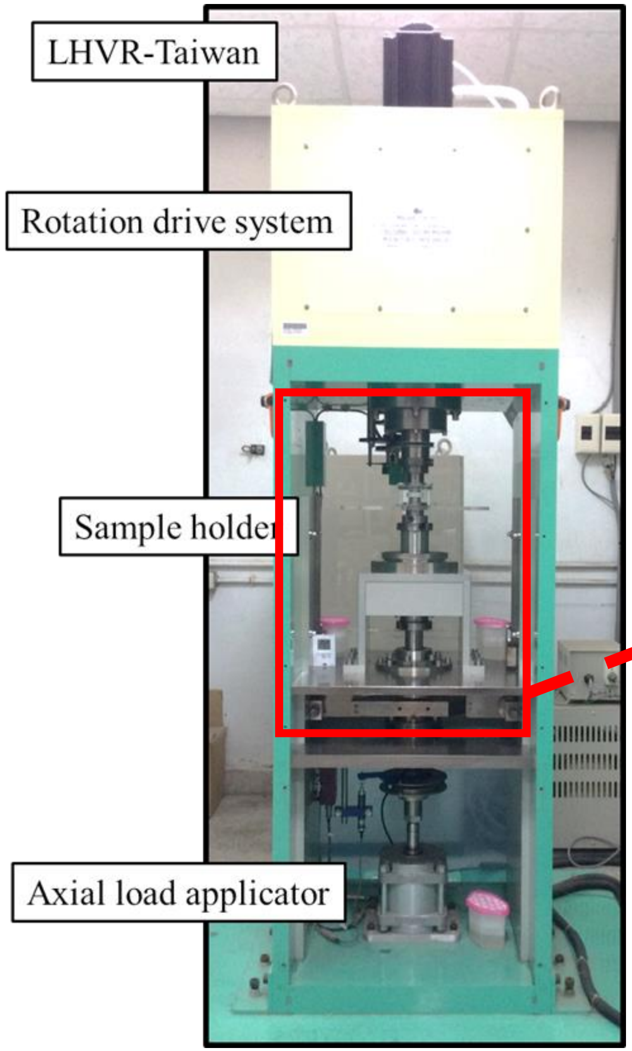
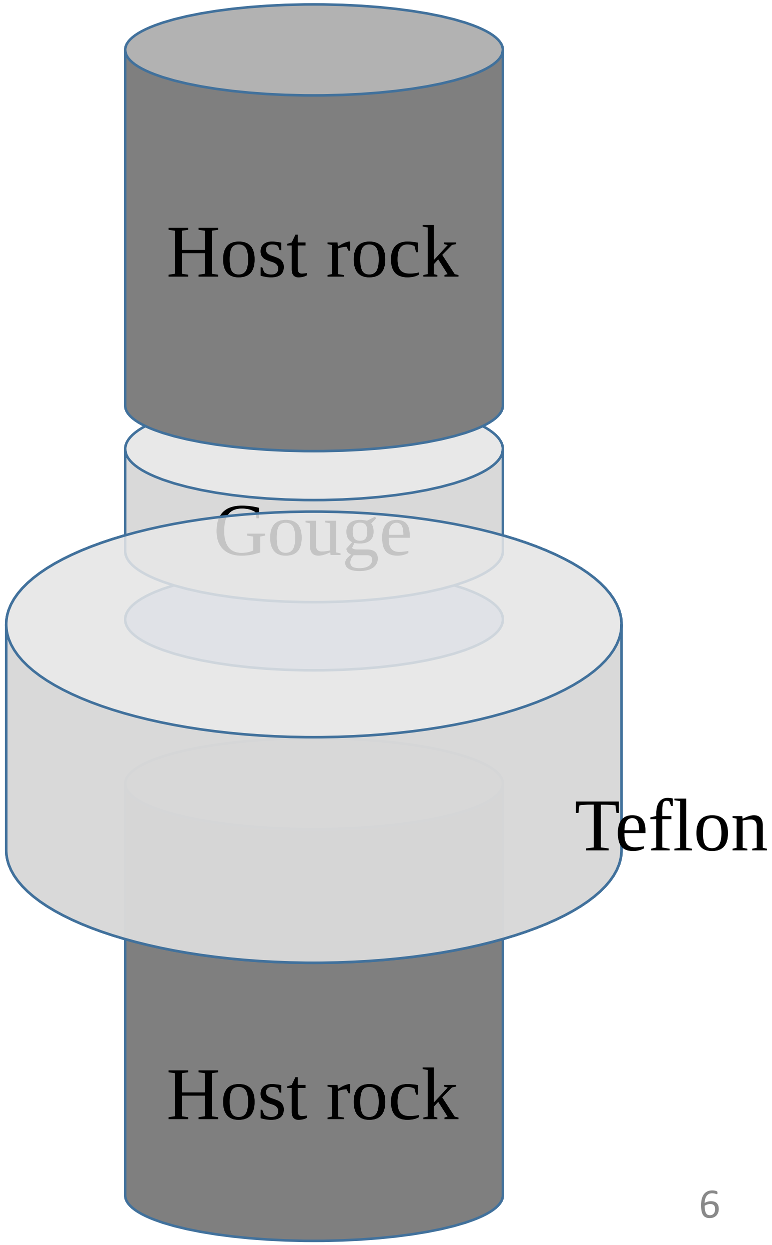
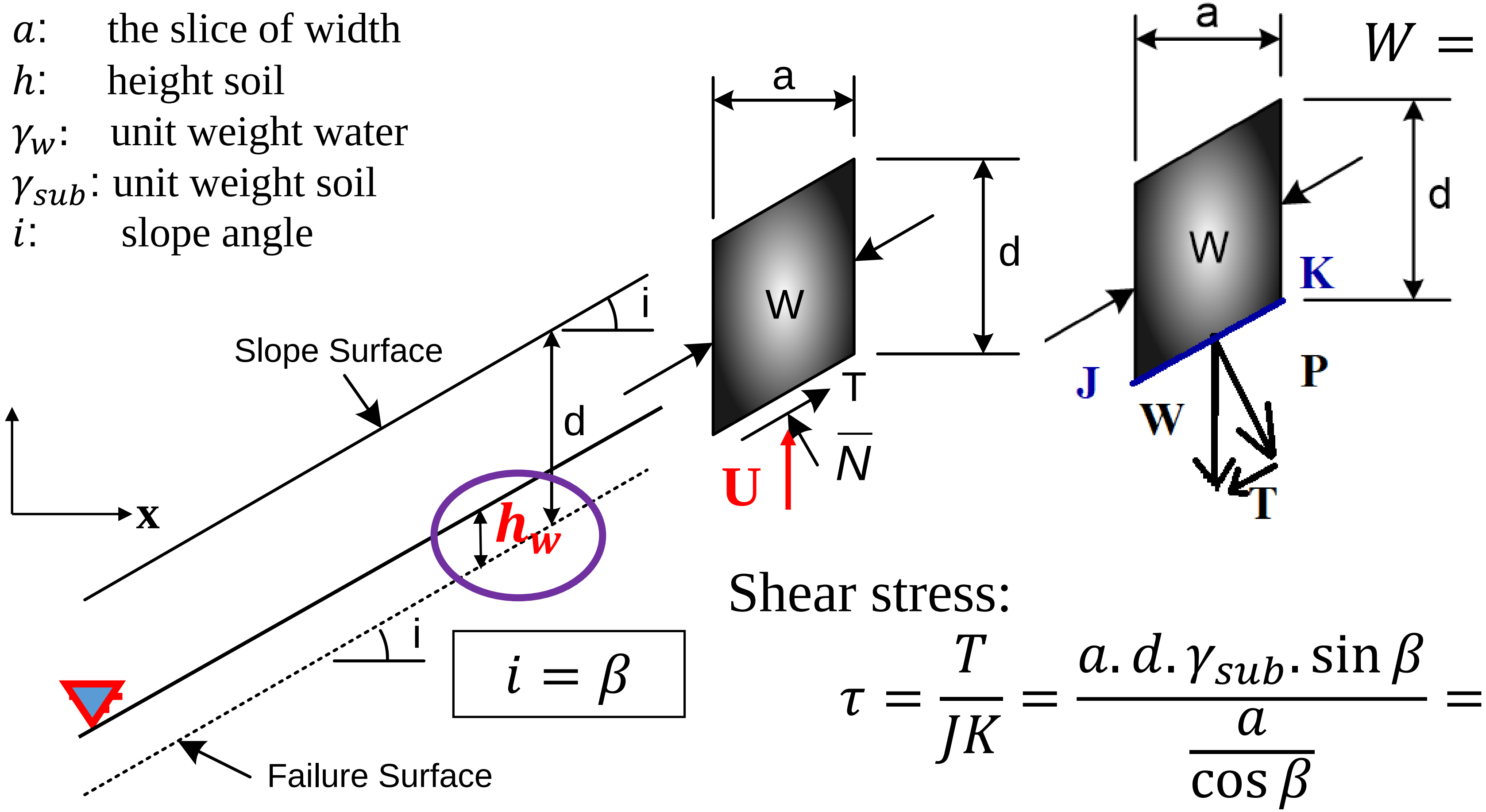


Figure 4. The rotary-shear low- to high-velocity frictional testing apparatus at the National Central University of Taiwan. (Lee, 2017)



Infinite Slopes in Soils with Parallel Seepage

a: the slice of width
h: height soil
γ_w: unit weight water
γ_{sub}: unit weight soil
i: slope angle



$i = \beta$

h_w: height water above failure surface

$W = a.d.\gamma_{sub}$

Shear component of weight:

$T = W.\sin\beta$

$T = a.d.\gamma_{sub}.\sin\beta$

Normal component of weight:

$P = W.\cos\beta$

$P = a.d.\gamma_{sub}.\cos\beta$

Shear stress:

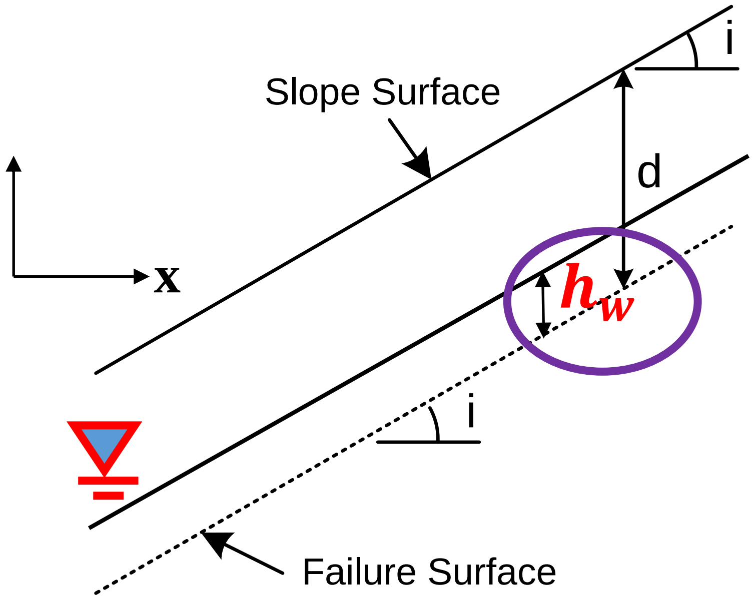
$$\tau = \frac{T}{JK} = \frac{a.d.\gamma_{sub}.\sin\beta}{\frac{a}{\cos\beta}} = \gamma_{sub}.d.\sin\beta.\cos\beta$$

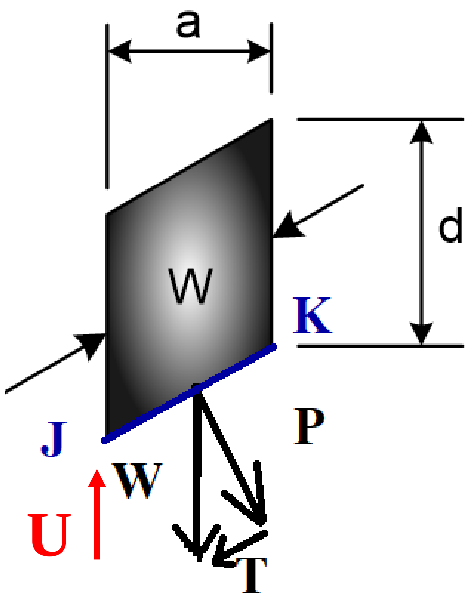
Nornal stress:

$$\sigma = \frac{P}{JK} = \frac{a.d.\gamma_{sub}.\cos\beta}{\frac{a}{\cos\beta}} = \gamma_{sub}.d.cos^2\beta$$

Prove that FS varies with groundwater

$i = \beta$





h_w: height water above failure surface

- Normal component of water weight:

$$P_w = \gamma_w . a . h_w . \cos\beta$$

- Pore water pressure on JK

$$U = \frac{\gamma_w . a . h_w . \cos\beta}{\frac{a}{\cos\beta}}$$

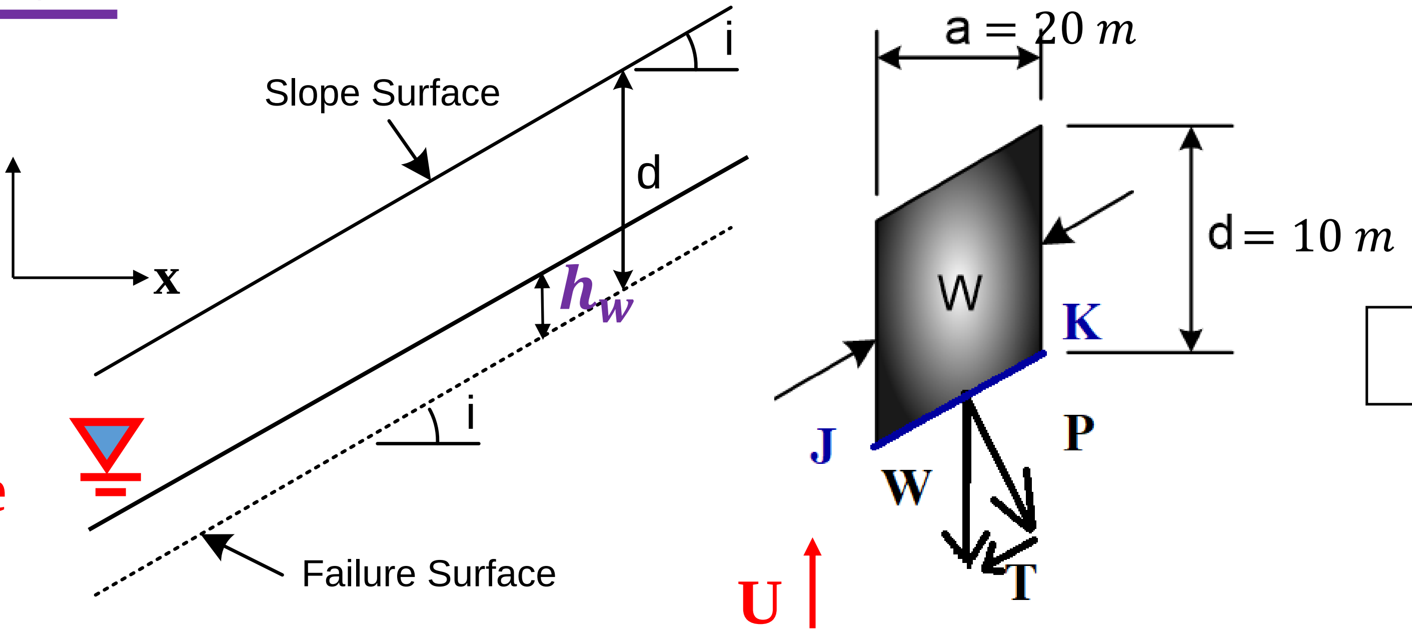
$$= \gamma_w . h_w . cos^2\beta$$

Factor of safety:

$$FS = \frac{C' + (\sigma - U)\tan\emptyset}{\tau} = \frac{C' + (\gamma_{sub} . d . cos^2\beta \; - \gamma_w . h_w . cos^2\beta\;)\tan\emptyset}{\gamma_{sub} . d . \sin\beta . \cos\beta}$$

Assumption

h_w= 7.5→7.85m: height water above failure surface



$i = \beta = 15^0$

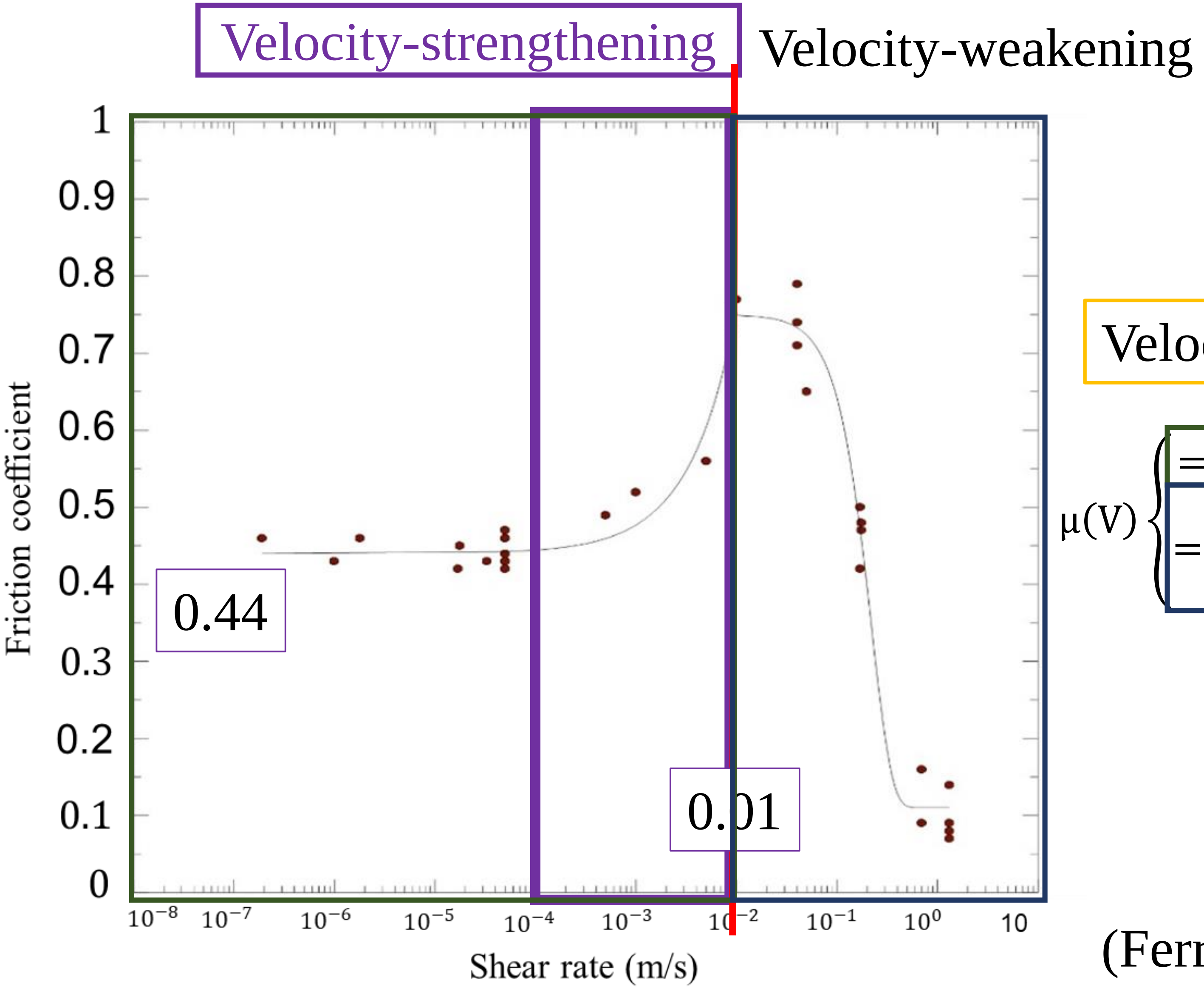
$$\rho_{sub} = 2000\frac{kg}{m^3} \rightarrow \gamma_{sub} = 2000 * 9.81 = 19620\frac{kg}{m^2 * s^2}$$

$$\emptyset = 30^0, C' = 0$$

$$\gamma_w = 9810\frac{kg}{m^2 * s^2}$$

The direction of groundwater flow is **parallel to the slope**

Apply equation to calculate friction coefficient from velocity



Velocity-dependent friction law:

$$\mu(V)\begin{cases} = 0.44 + 22.47V^{0.93} & ,\mathbf{V < 0.01 m/s} \\ = 0.11 + (0.75 - 0.11)\exp\left(\dfrac{-V^{2.13}}{0.04}\right) & ,\mathbf{V > 0.01\ m/s} \end{cases}$$

(Ferri et al., 2011)

Acceleration

$$-(m_{sub} + m_w) * acceleration = Resistance\ force - Driving\ force$$

$$acceleration = -\frac{Resistance\ force - Driving\ force}{(m_{sub} + m_w)}$$

weight

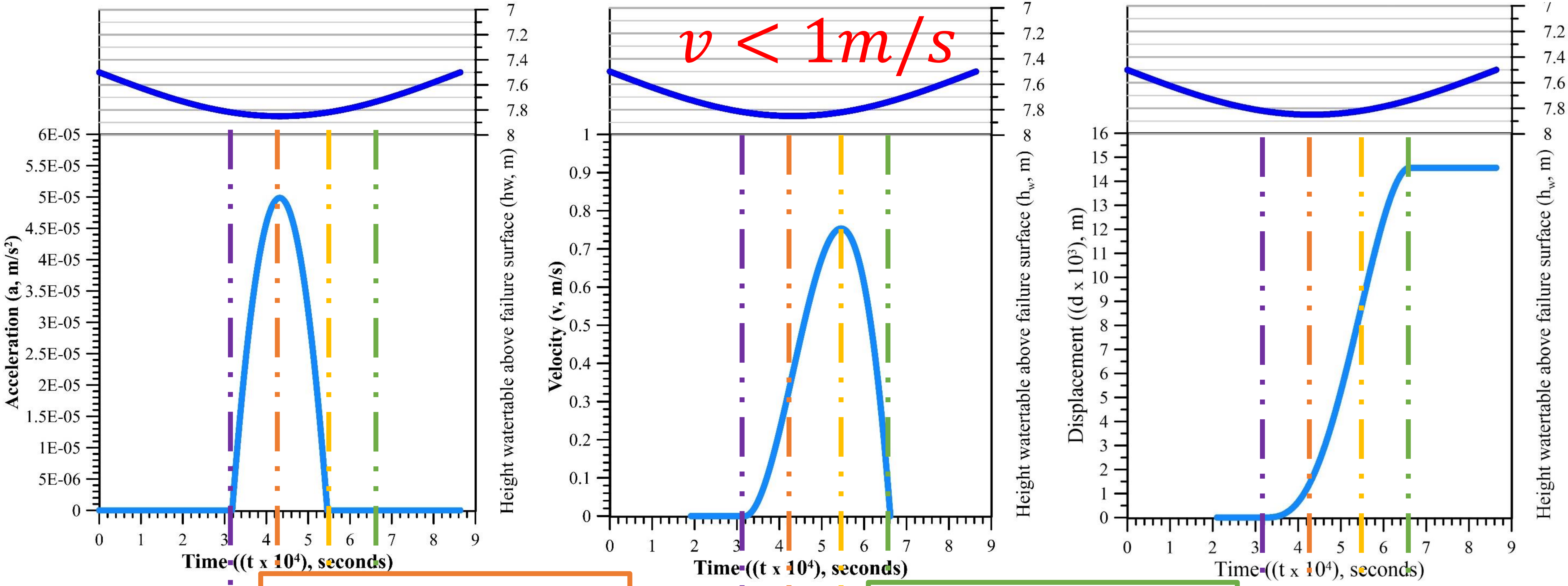
$$m_w = \gamma_w * d_w * a$$
$$m_{sub} = \gamma_{sub} * (d - d_w) * a$$

Integrate with time →velocity (v)→ displacement (d)

$$i = 15^o, h_w = 7.5\ to\ 7.85m, \mu = 0.44$$

Integrate with time

$v < 1m/s$



$t = 43200\ seconds$

$t = 31825\ seconds$

$t = 66183\ seconds$

$t = 54575\ seconds$

Implementing Processes

$t_0 = \cdots$

$\mu_o = 0.44$
$h_{w0} = \cdots, FS_0 = 1, a_0 = 0, v_0 = 0$

Stept 1

$t_1 = t_0 + \Delta t$

$\mu_1 = 0.44$
$h_{w1} = \cdots, FS_1 = \cdots, a_1 = \cdots, v_1 = \ldots$

$\Rightarrow \mu_2 = \ldots.$

$$\mu(V)\begin{cases} = 0.44 + 22.47V^{0.93} & , V < 0.01\text{m/s} \\ = 0.11 + (0.75 - 0.11)\exp\left(\dfrac{-V^{2.13}}{0.04}\right) & , V > 0.01\text{ m/s} \end{cases}$$

Stept 2

$t_2 = t_1 + \Delta t$

From $\mu_2 = \ldots,$
$h_{w2} = \cdots, FS_2 = \cdots, a_2 = \cdots, v_2 = \ldots$
$\Rightarrow \mu_3 = \ldots.$

$\Rightarrow \mu_3 = \ldots.$

Example

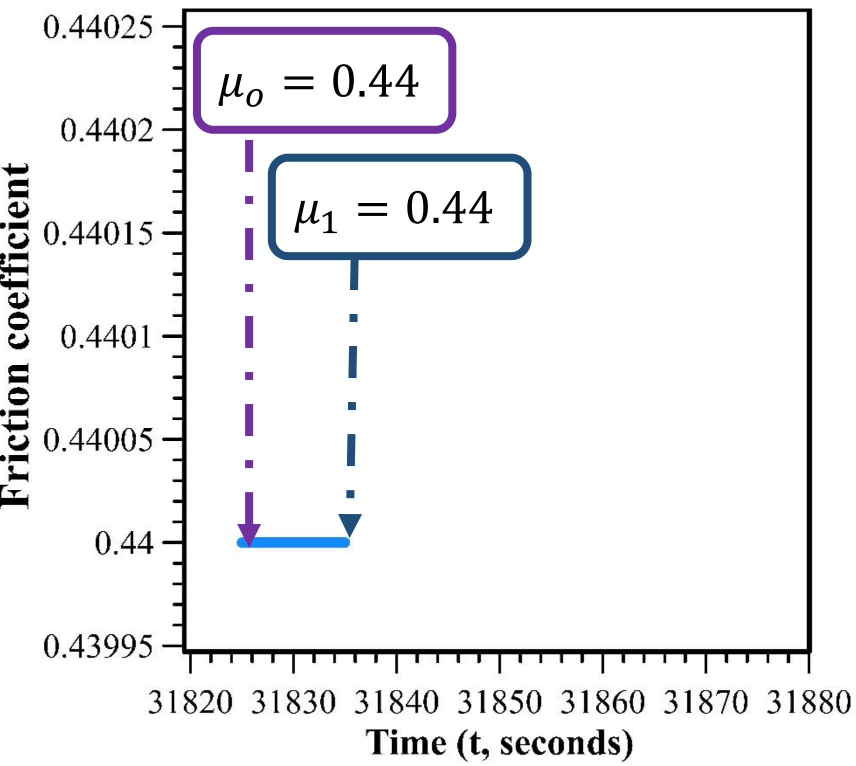
$i = 15^o, h_w = 7.5 \; to \; 7.85m, \Delta t = 10s$

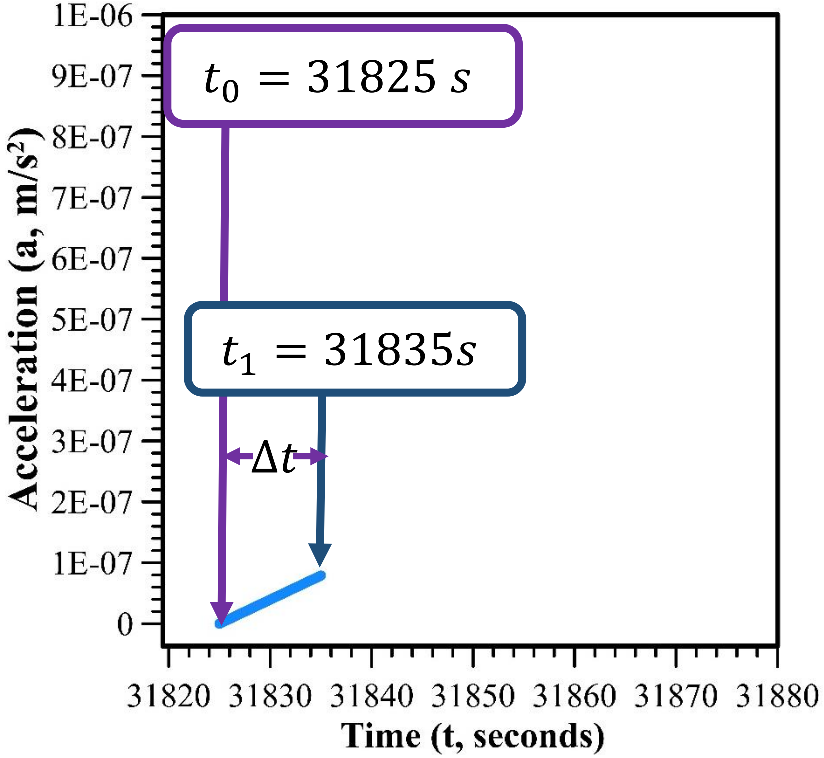
t_0

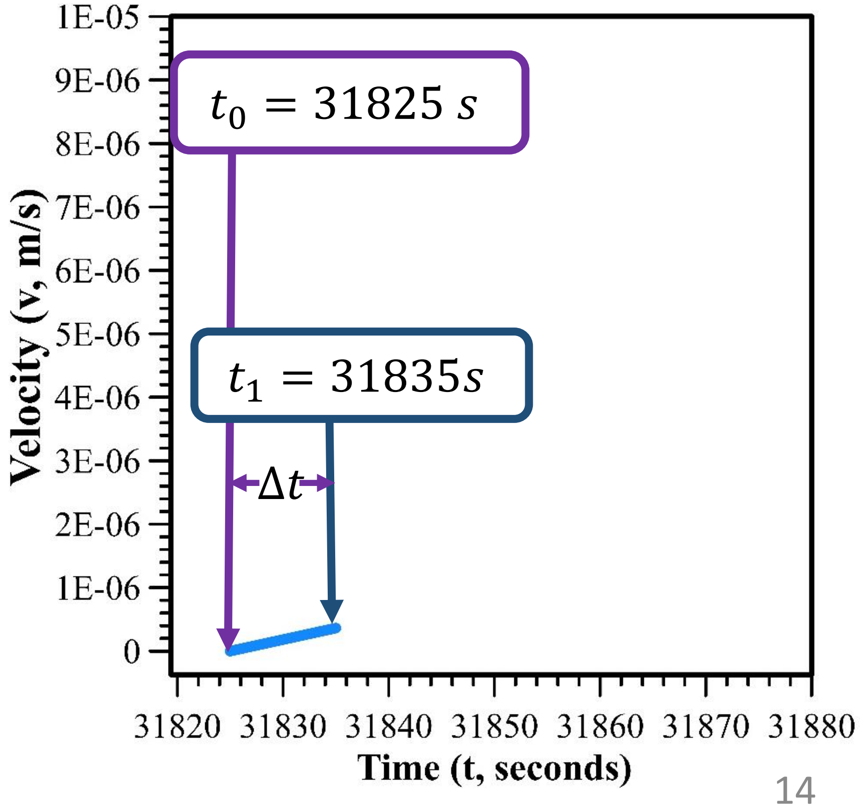
$\Delta t = 10 \; seconds$

Stept 1

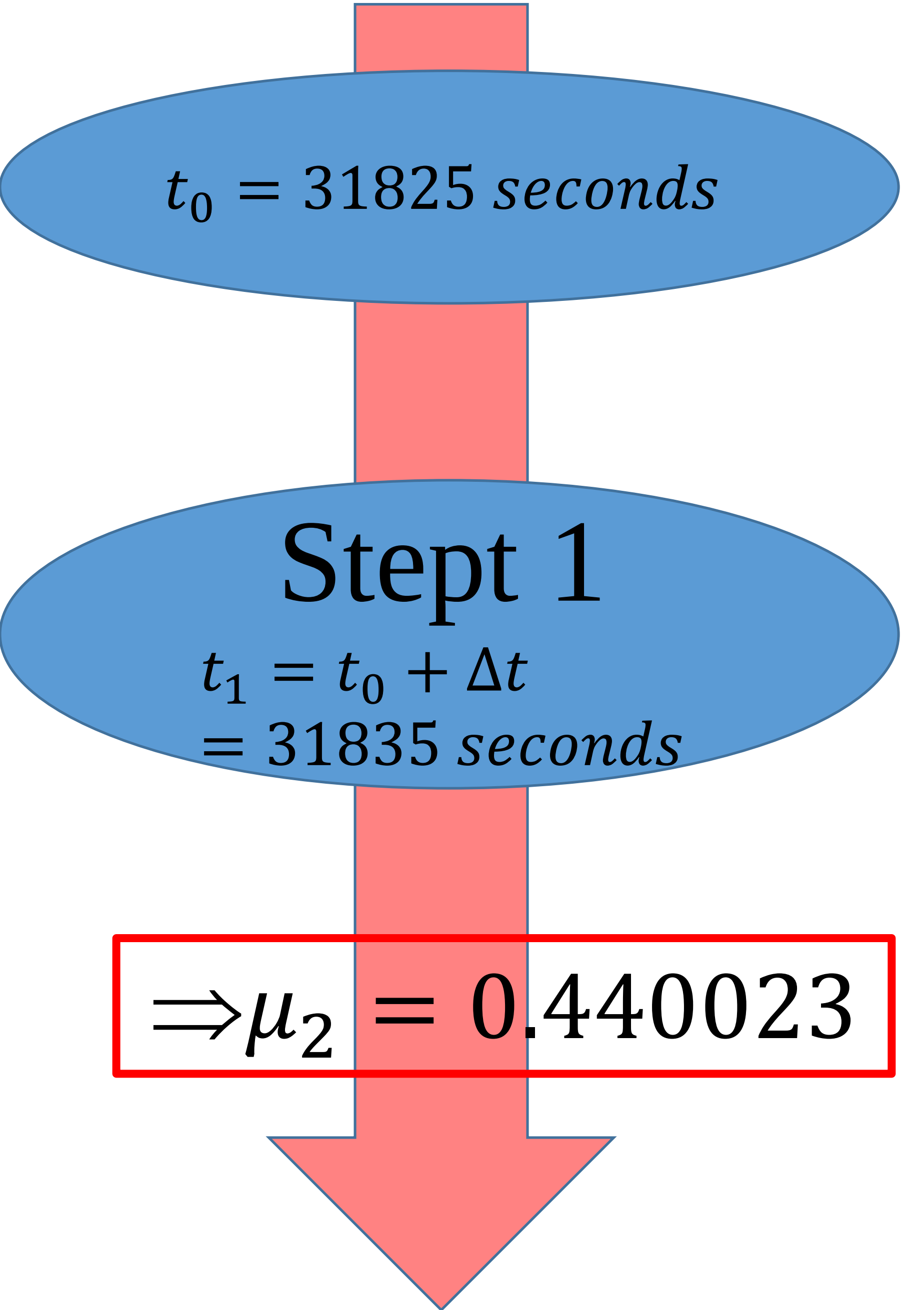
$t_1 = t_0 + \Delta t$







Implementing processes



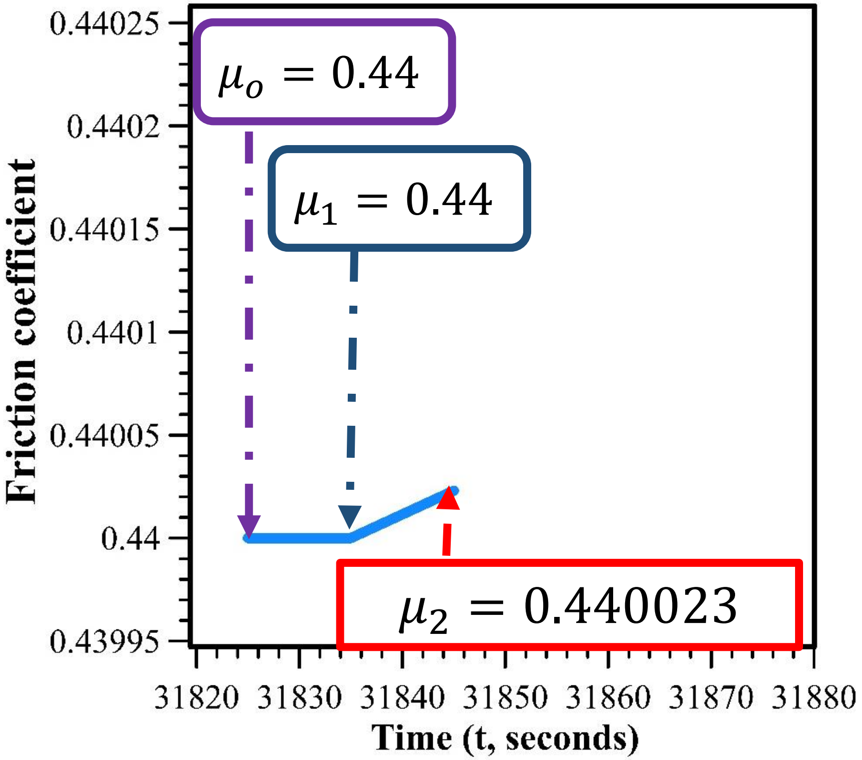
$\mu_o = 0.44$
$h_{w0} = 7.82049 \; m, FS_0 = 1,$
$a_0 = 0, v_0 = 0$

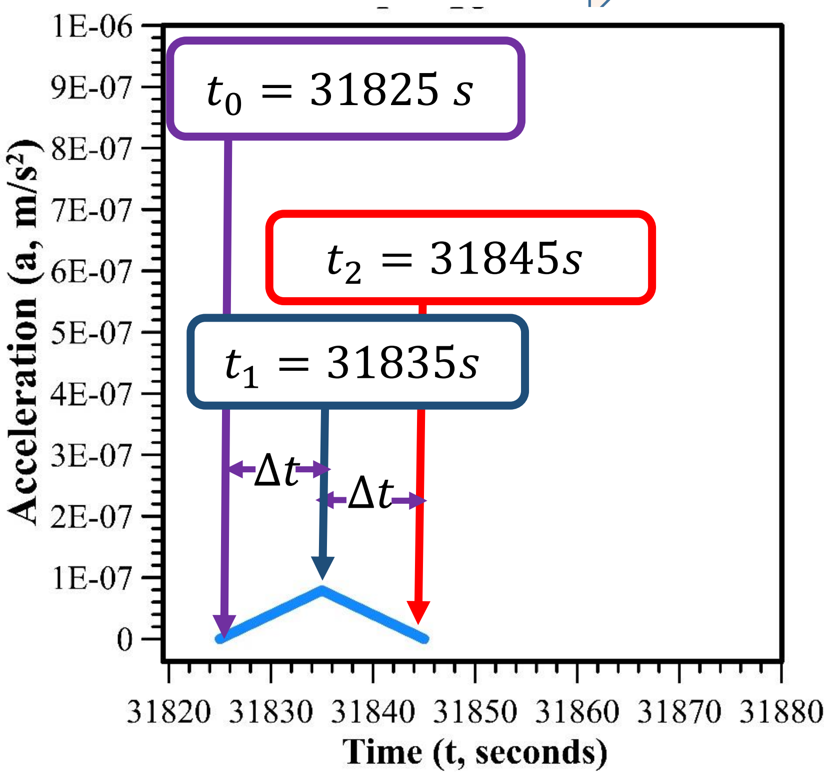
$\mu_1 = 0.44$
$h_{w1} = 7.82054 \; m, FS_1 = 0.9999,$
$a_1 = 7.9037.10^{-8} m/s^2,$
$v_1 = 3.6316.10^{-7} m/s$

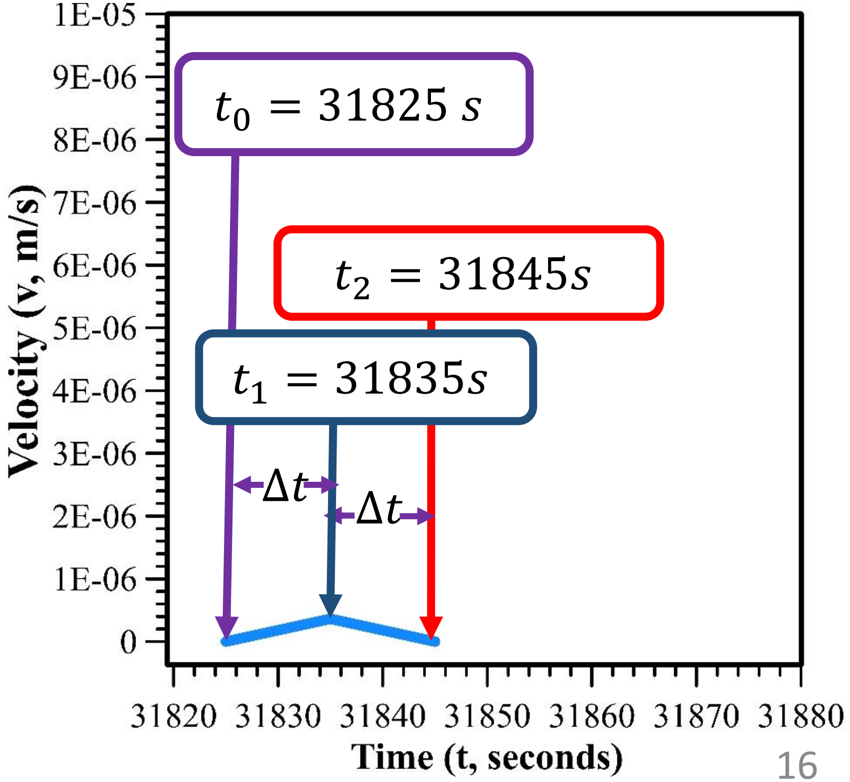
$$\mu(V) \begin{cases} = 0.44 + 22.47V^{0.93} & , V < 0.01 m/s \\ = 0.11 + (0.75 - 0.11)\exp\left(\frac{-V^{2.13}}{0.04}\right) & , V > 0.01 \; m/s \end{cases}$$

$\Rightarrow \mu_2 = 0.440023$

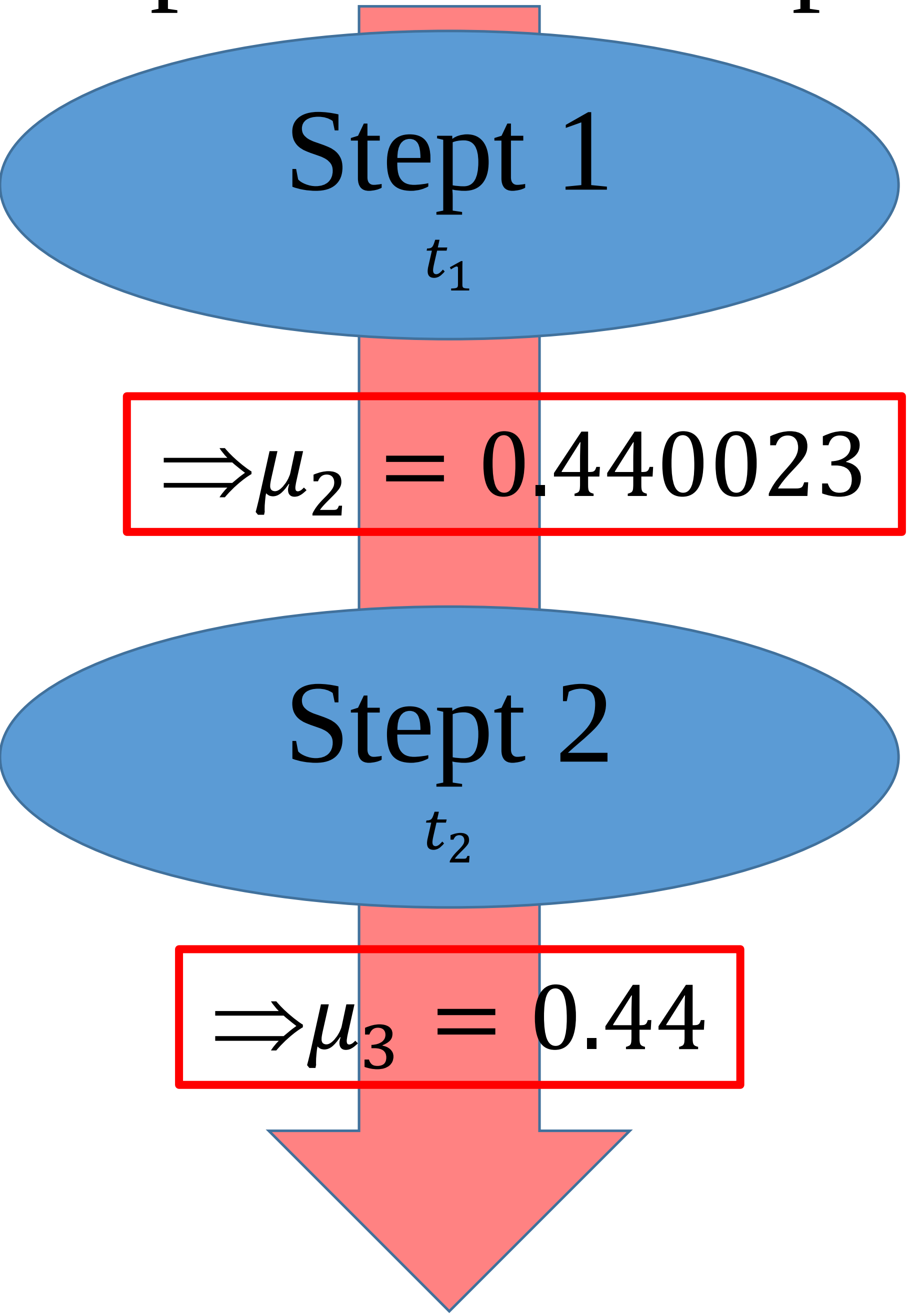
From $\mu_2 = 0.440023$ find acceleration and velocity next t_2







Implementation process



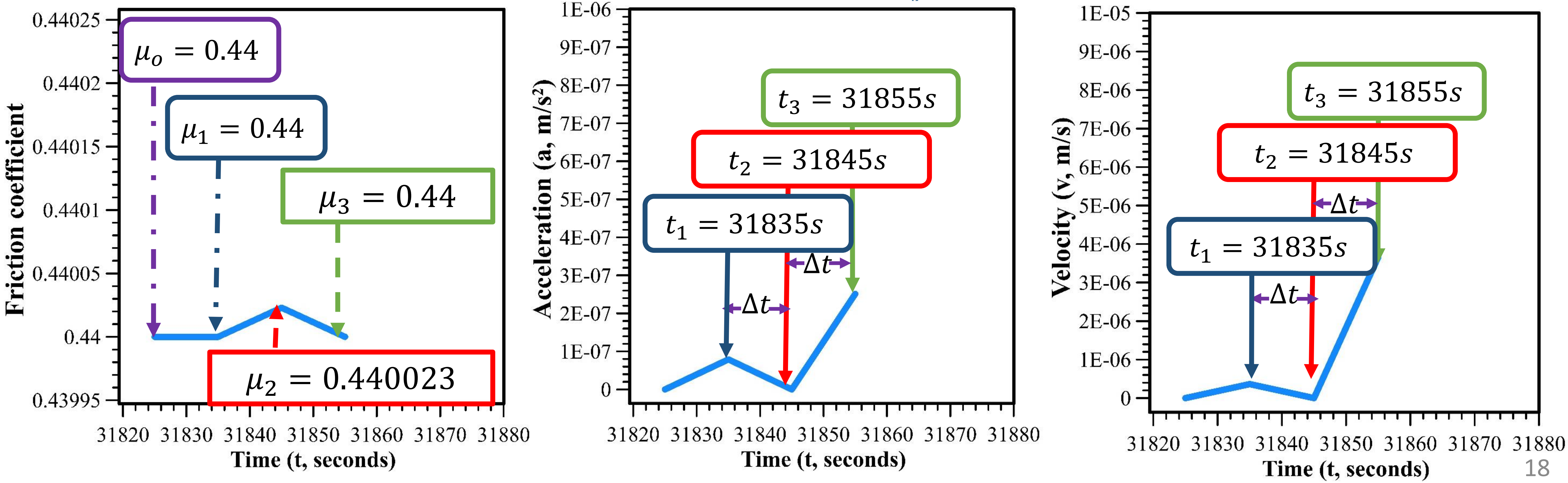
$\mu_1 = 0.44$
$h_{w1} = 7.82054\, m, FS_1 = 0.9999,$
$a_1 = 7.9037.10^{-8} m/s^2,$
$v_1 = 3.6316.10^{-7} m/s$

From μ_2
$h_{w2} = 7.82059\, m, FS_2 = 1.00004,$
$a_2 = 0\; m/s^2, v_2 = 0\; m/s$

$$\mu(V) \begin{cases} = 0.44 + 22.47\mathrm{V}^{0.93} & ,\mathrm{V} < 0.01\mathrm{m/s} \\ = 0.11 + (0.75 - 0.11)\exp\left(\dfrac{-\mathrm{V}^{2.13}}{0.04}\right) & ,\mathrm{V} > 0.01\ \mathrm{m/s} \end{cases}$$

$\Rightarrow \mu_3 = 0.44$

From $\mu_3 = 0.44$ find acceleration and velocity next t_3

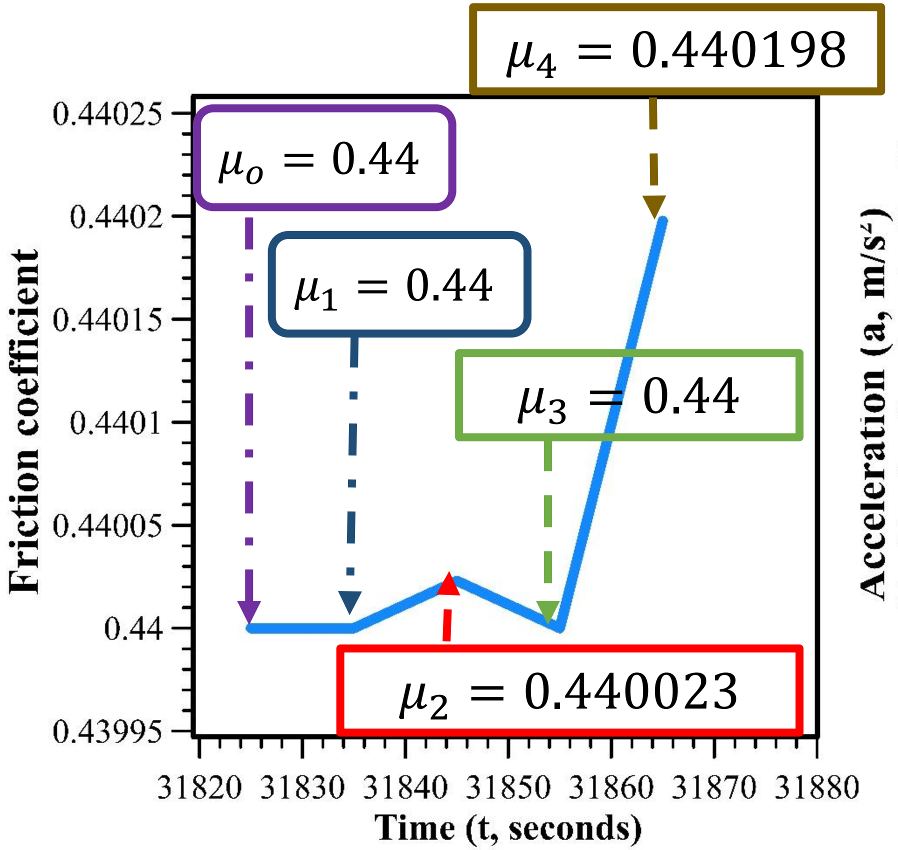


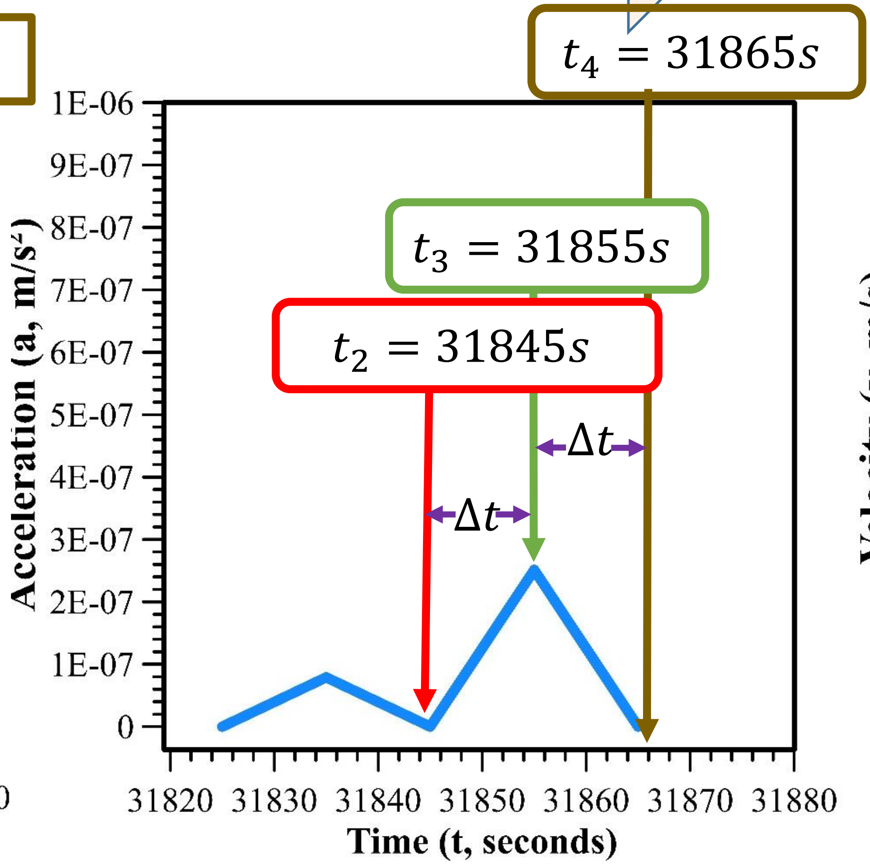
From $\mu_4 = 0.440198$ find acceleration and velocity next t_4

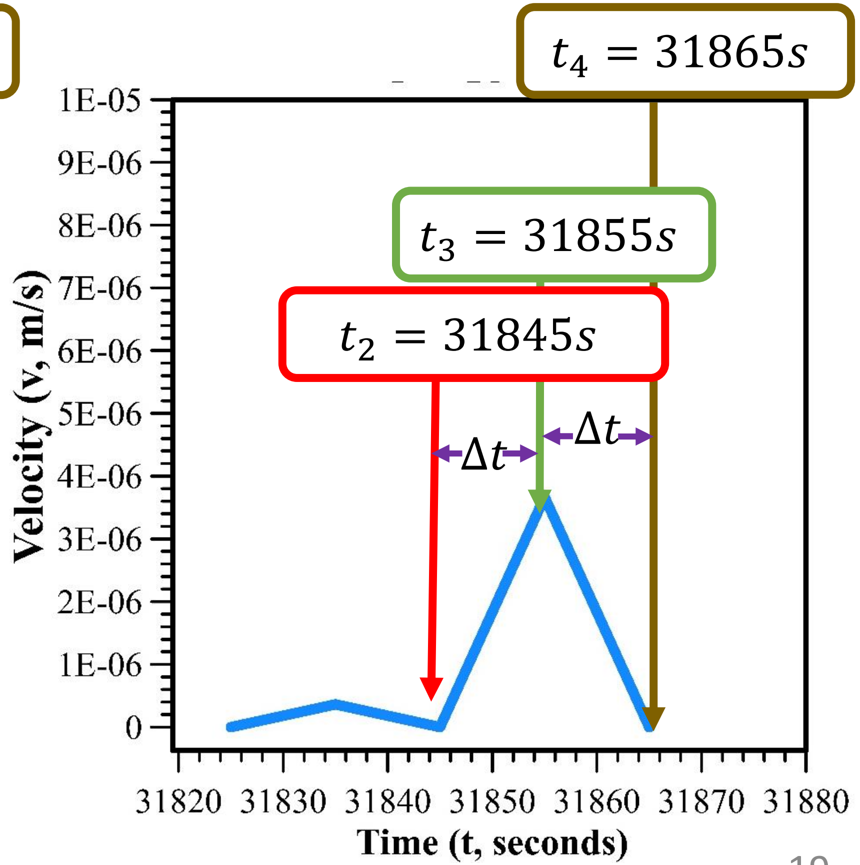
Stept 3 t_3

$\Delta t = 10$ ***seconds***

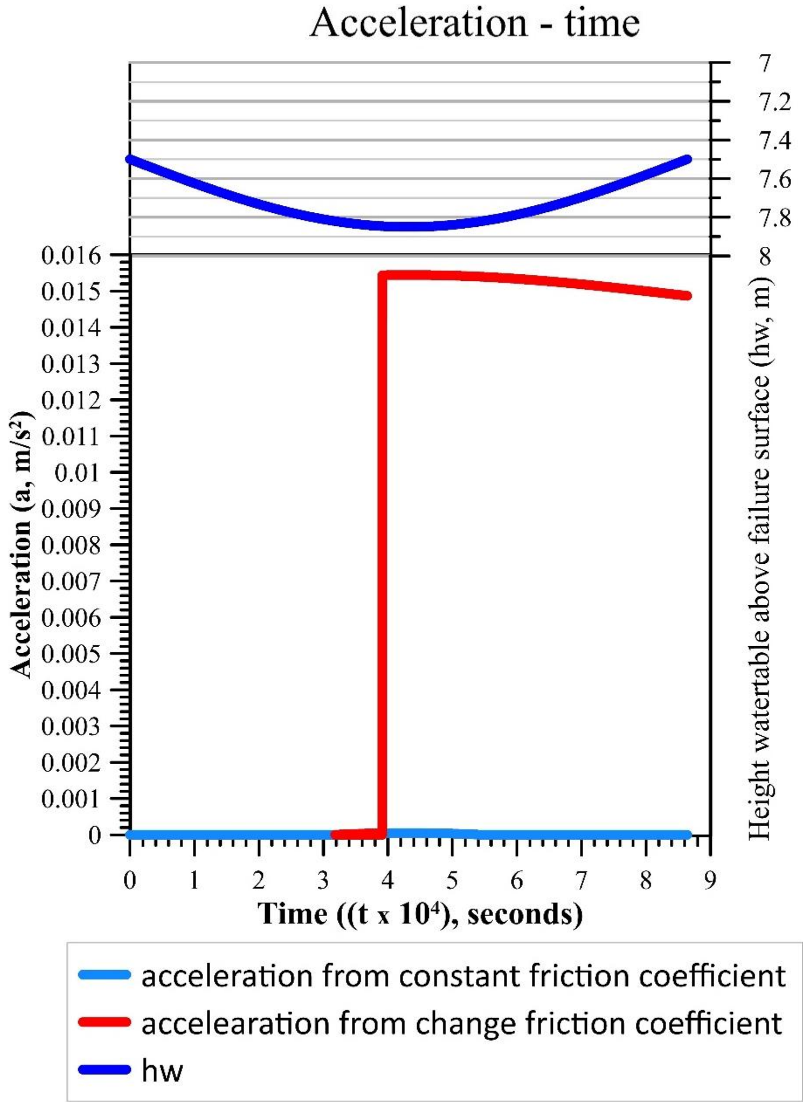
Stept 4 t_4

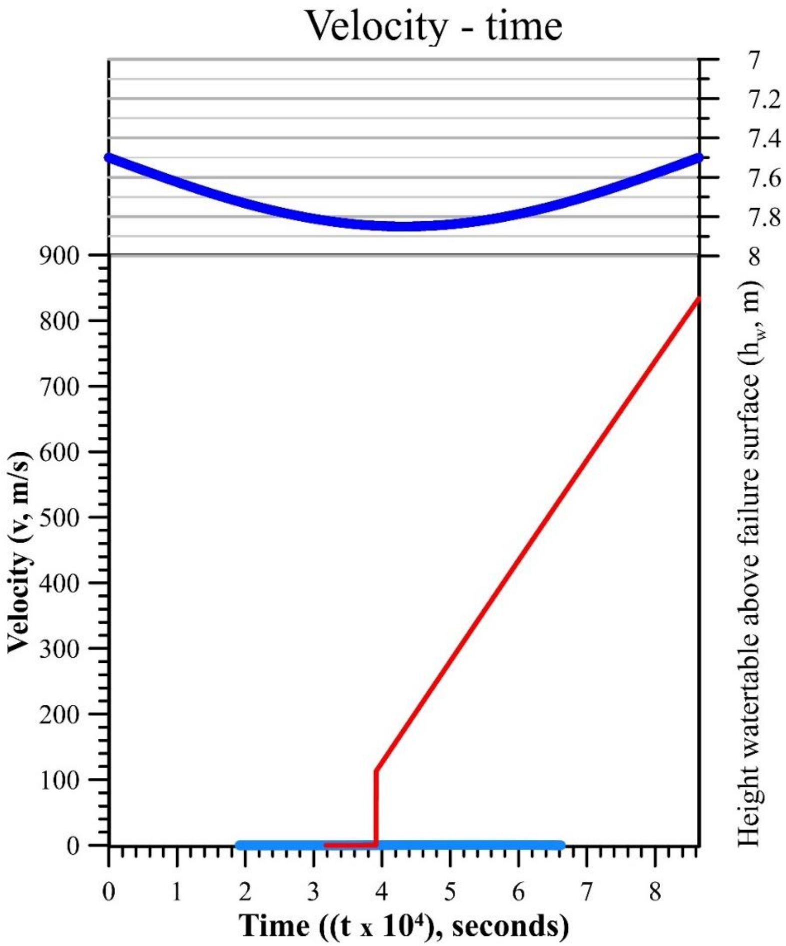


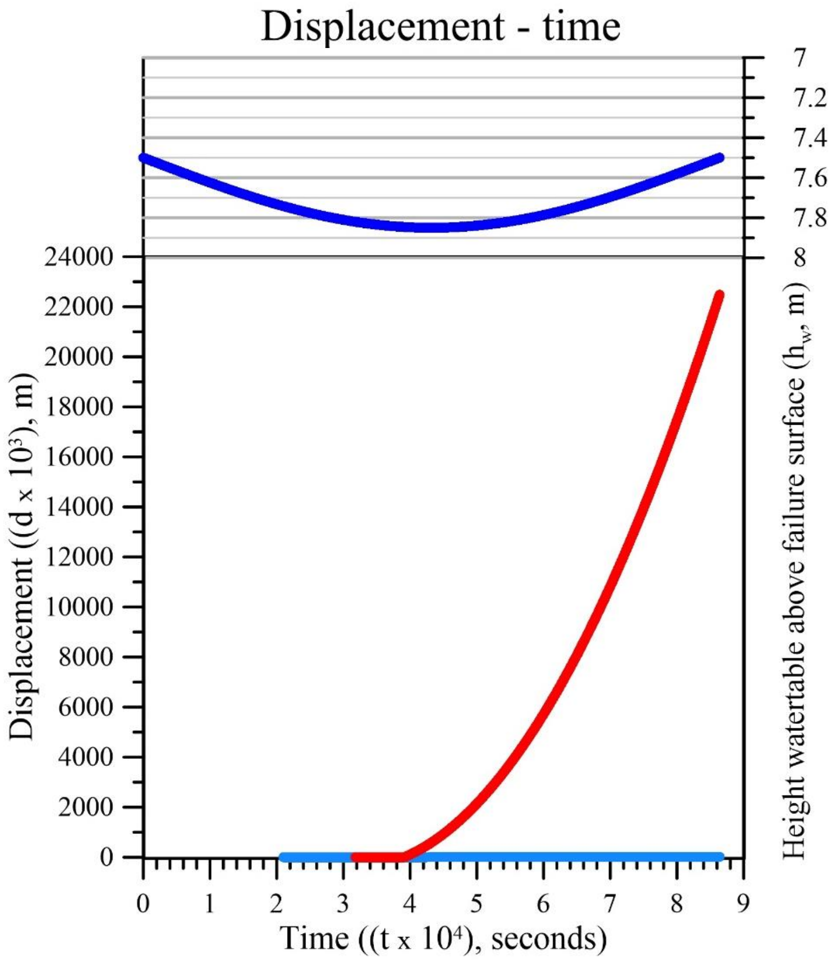




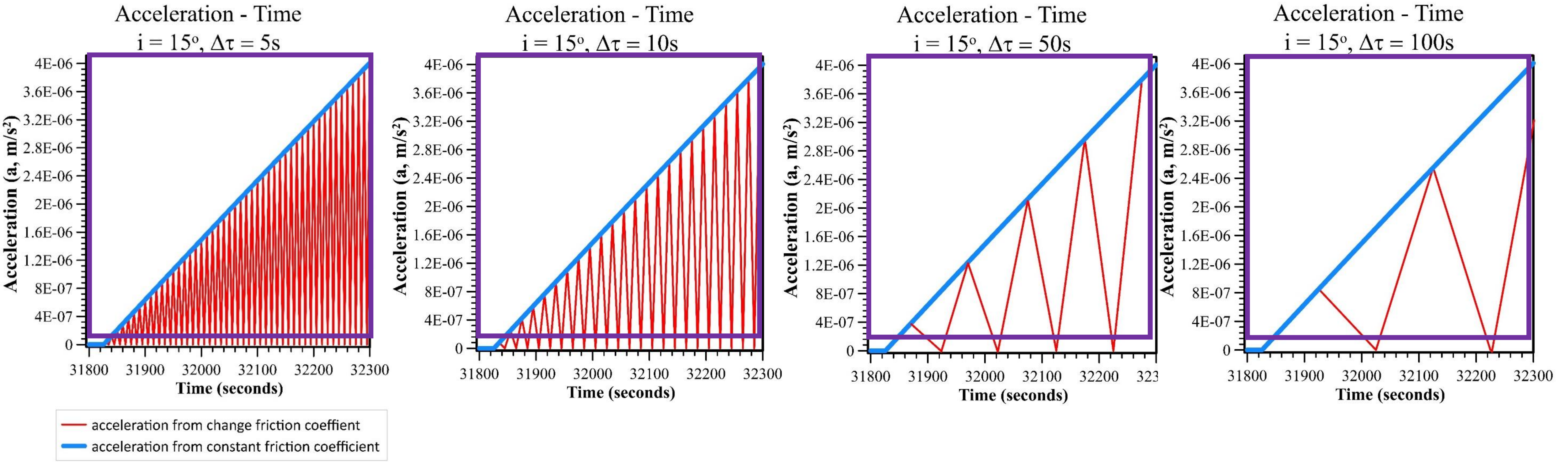
$$i = 15^o, h_w = 7.5\ to\ 7.85m, \Delta t = 10s$$







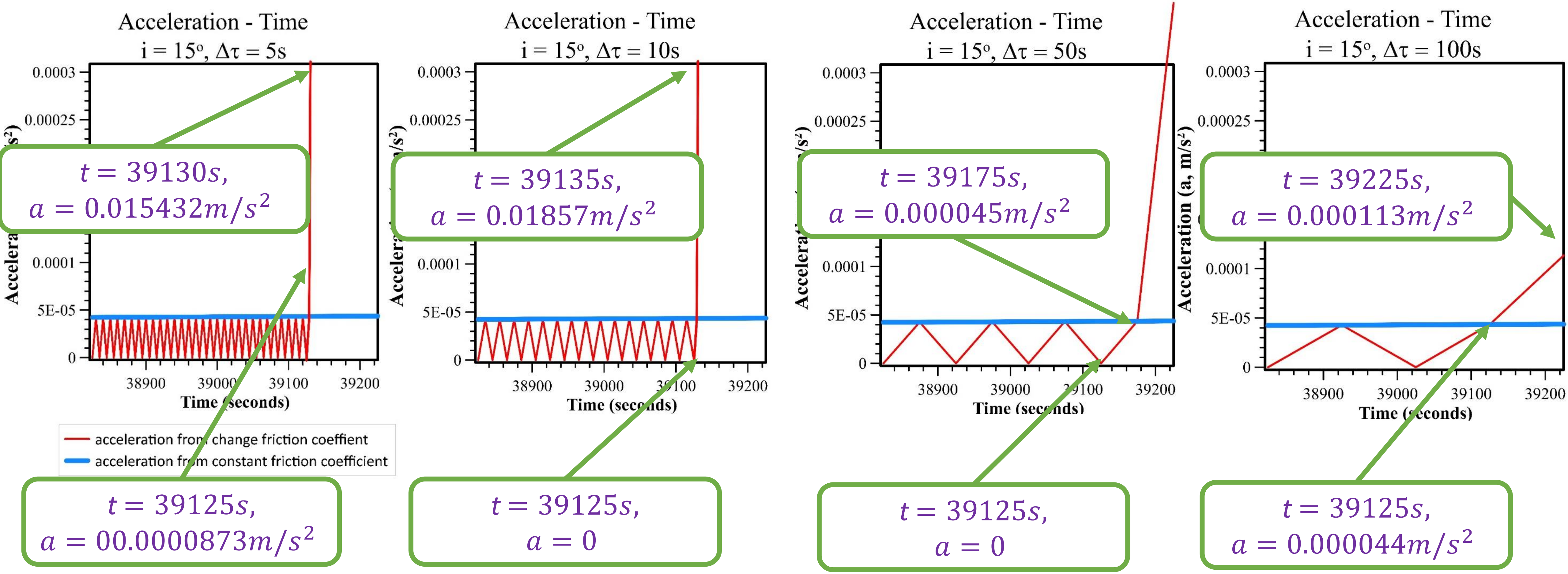
Acceleration with different Δ*t*



Acceleration like figure **zigzag**

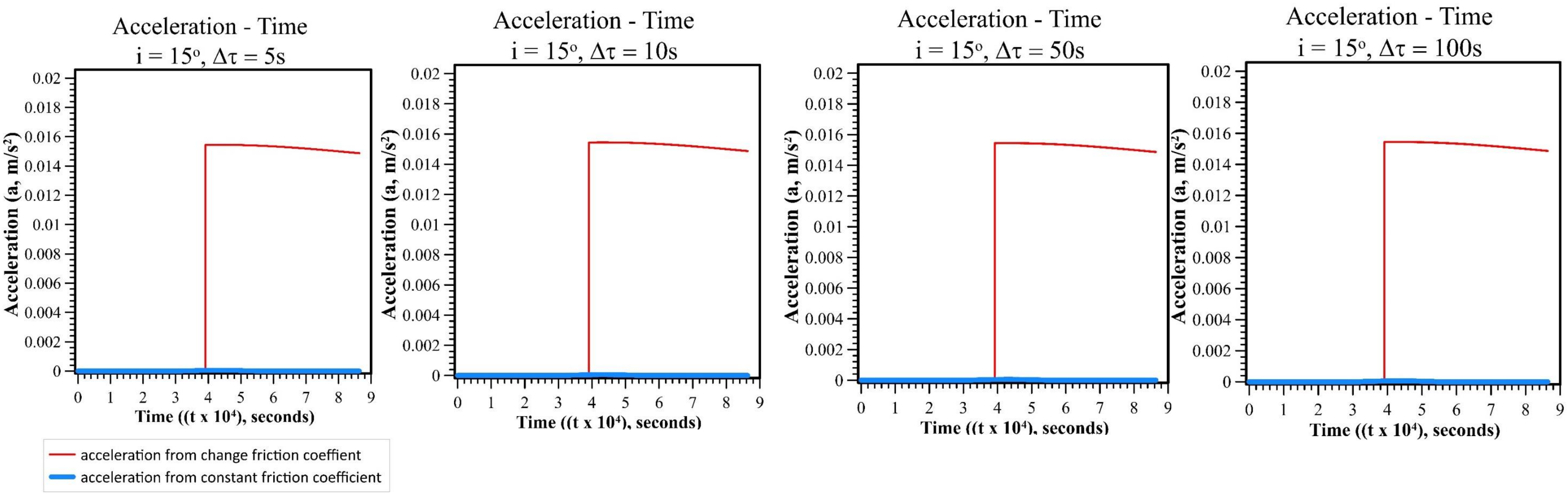
Acceleraton from change friction coefficient is **limited** by acceleration from constant friction coefficient

Acceleration with different Δt



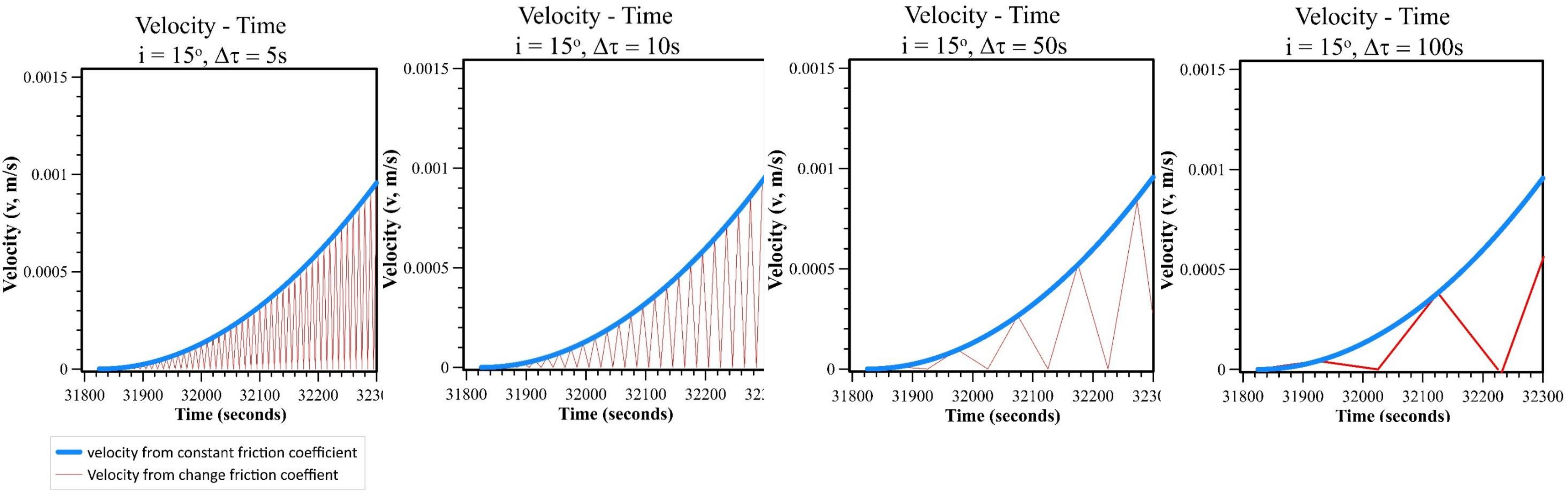
Acceleration **changes slightly** before sudden acceleration

Acceleration with different Δt



Acceleration of different Δt is similar

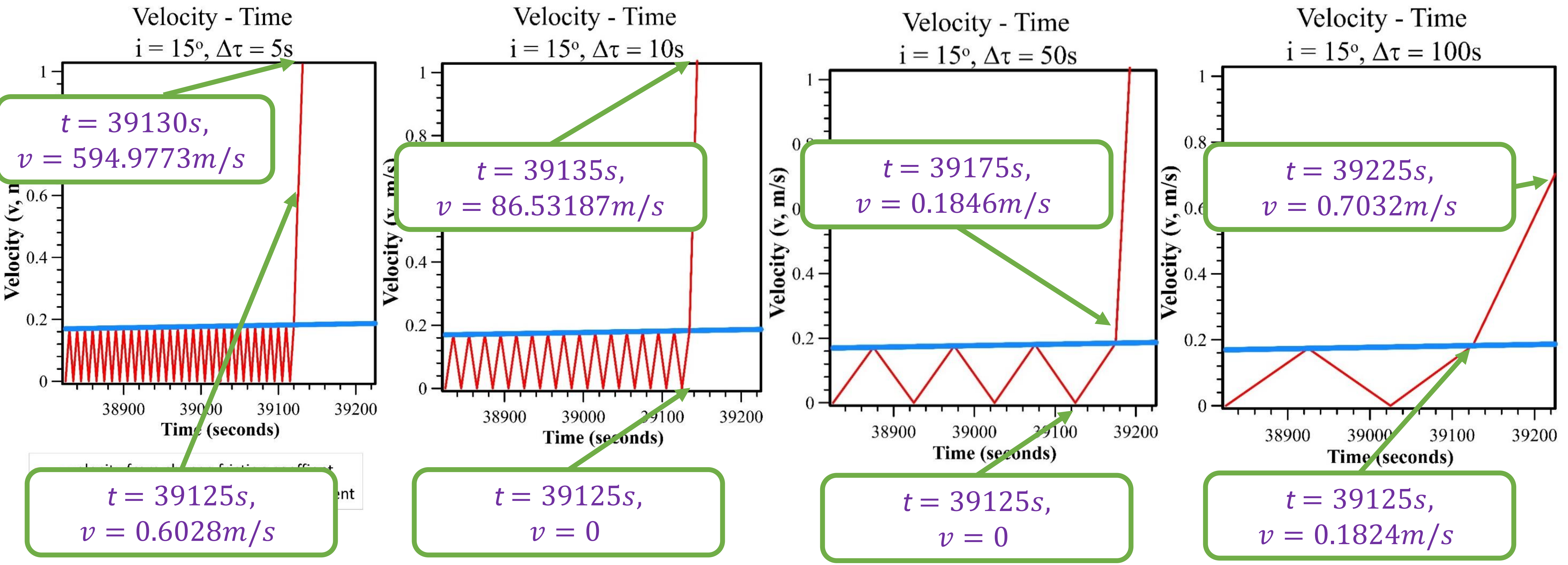
Velocity with different Δ*t*



Velocity like figure **zigzag**

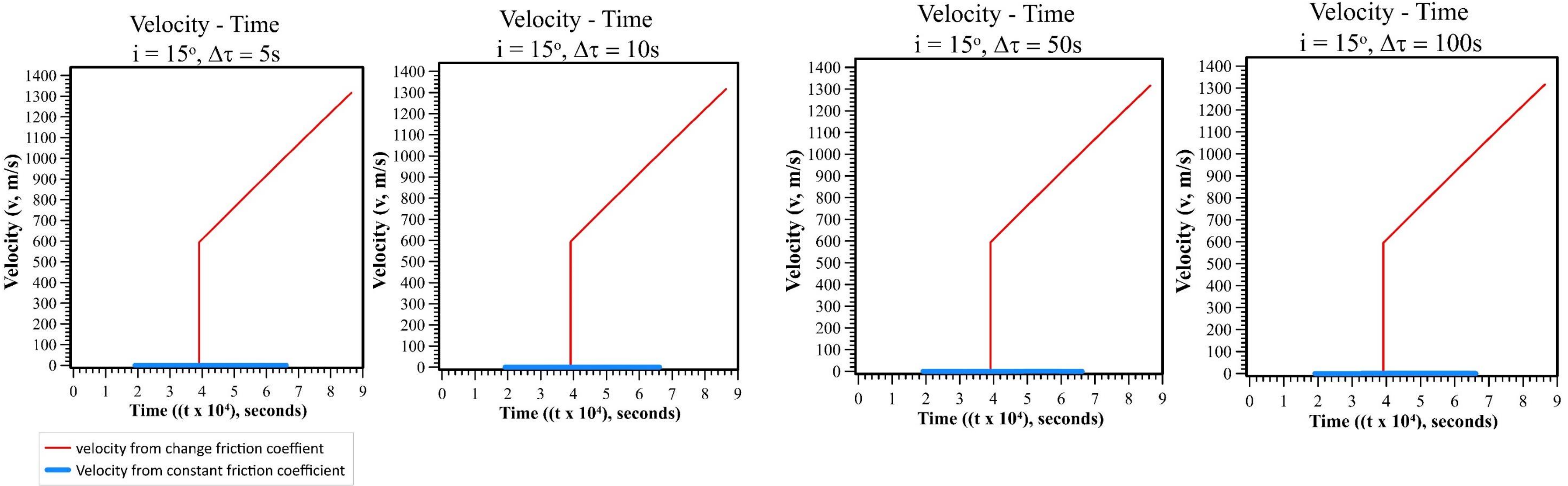
Velocity from change friction coefficient is **limited** by velocity from constant friction coefficient

Velocity with different Δt



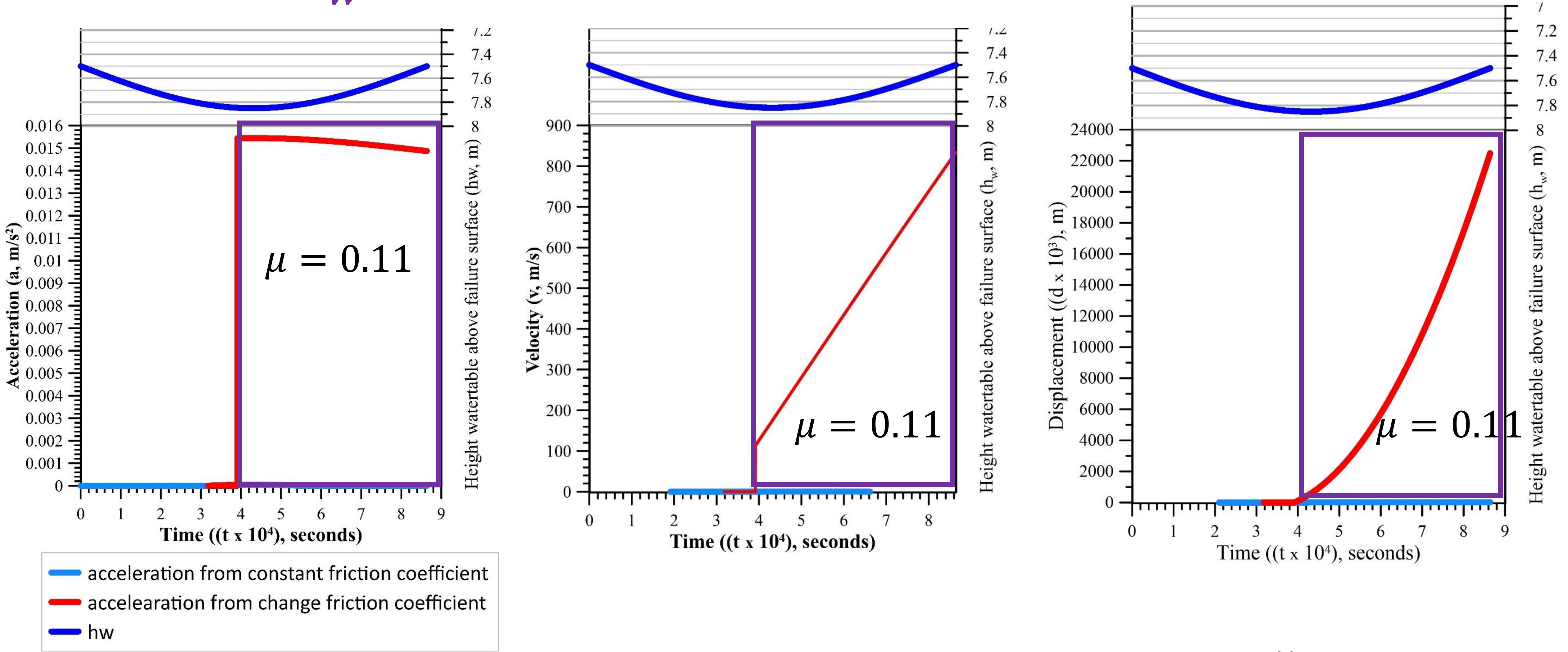
Velocity **changes slightly** before sudden velocity

Velocity with different Δ*t*



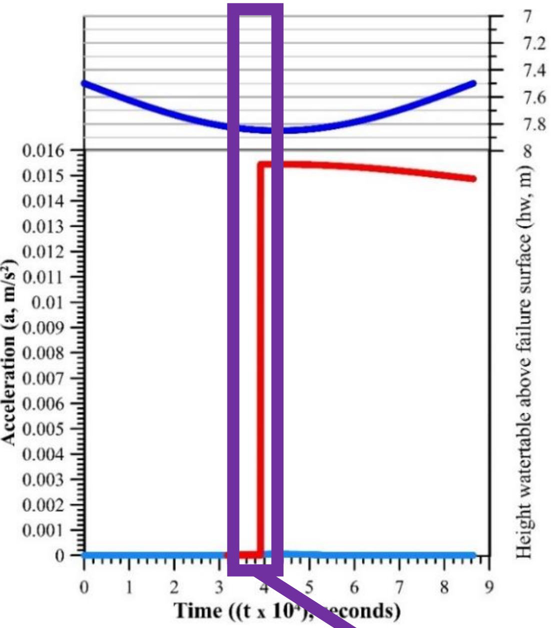
Velocity of different Δt is similar

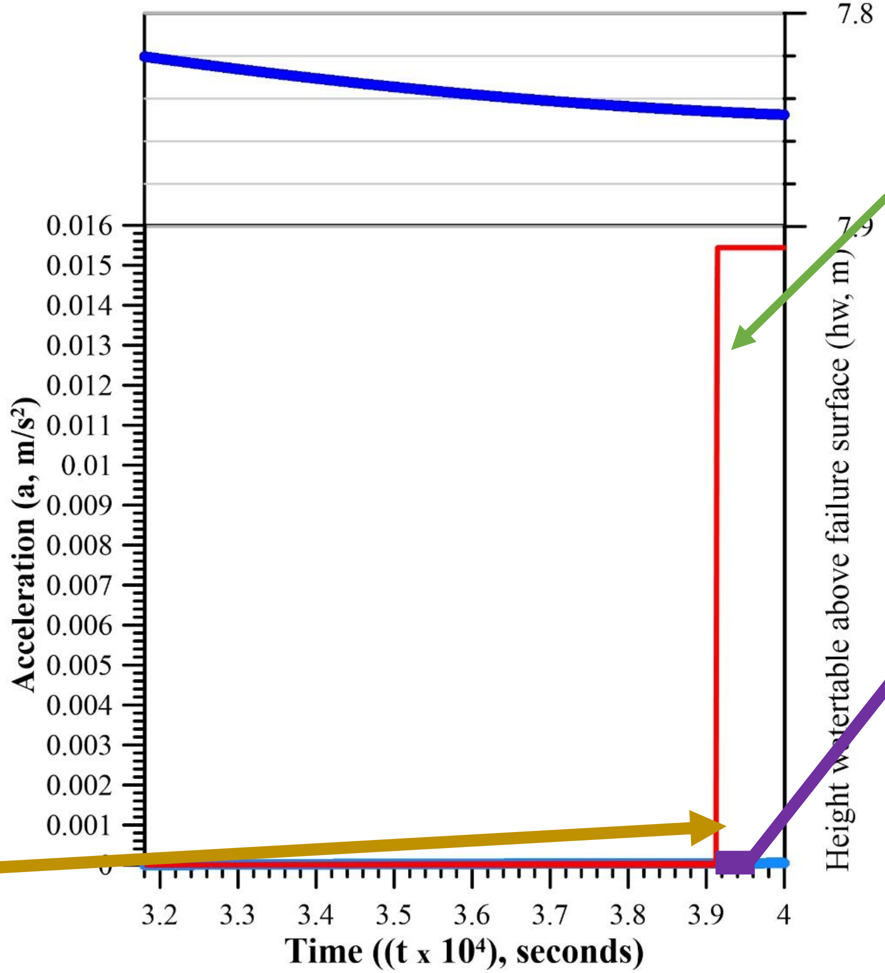
$i = 15^o, h_w = 7.5\ to\ 7.85m, \Delta t = 10s$



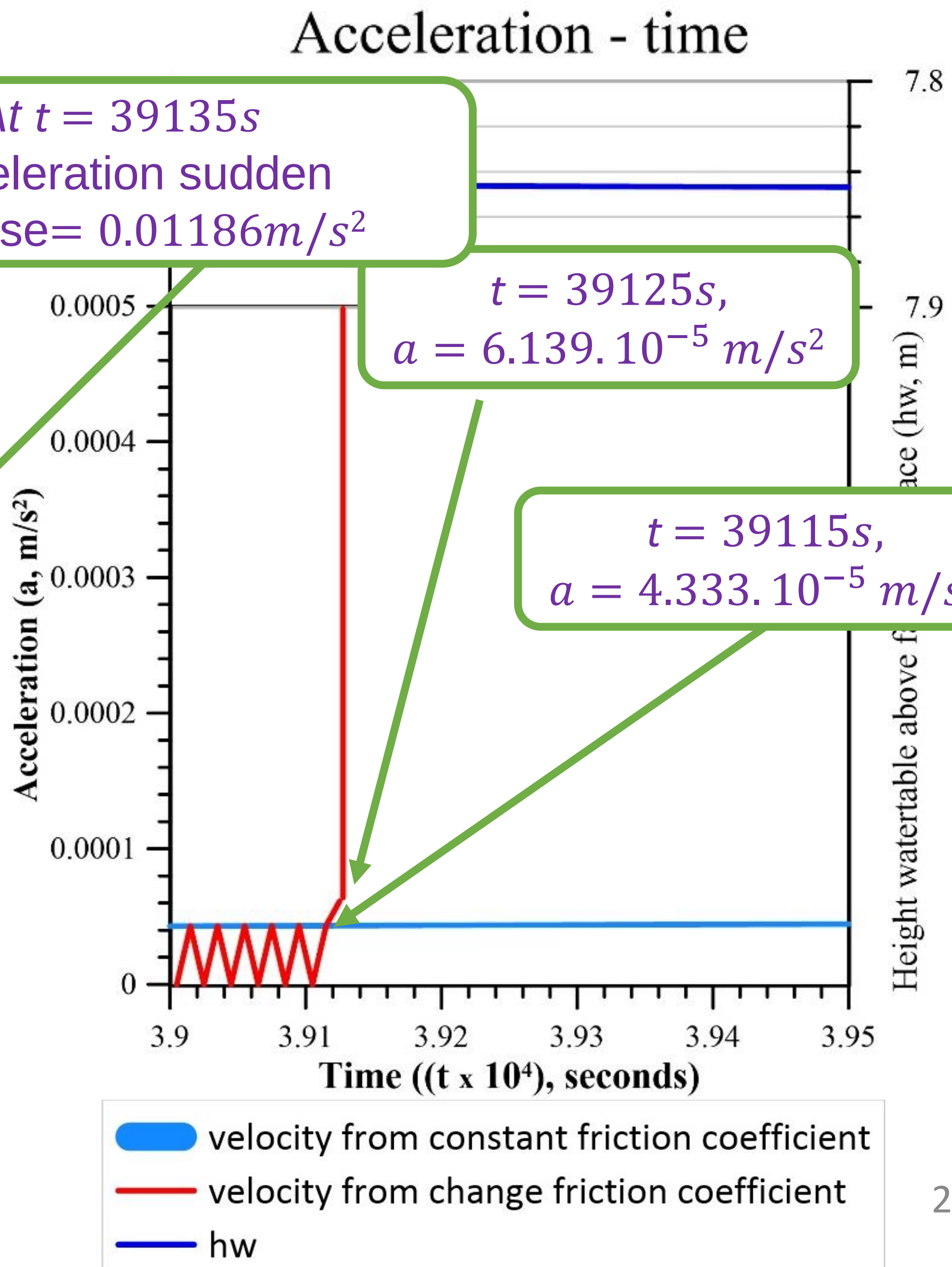
At $\underline{t = 39125s}$ with $\underline{v \geq 0.19\ m/s}$ then $\underline{\mu = 0.11}$ The block slides and no affect by height watertable above failure surface

Sudden acceleration





At t = 39125s *acceleration start increase* $= 0.00006 m/s^2$

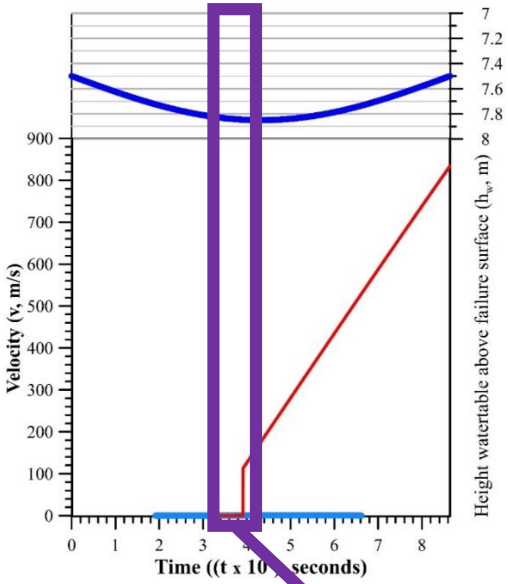


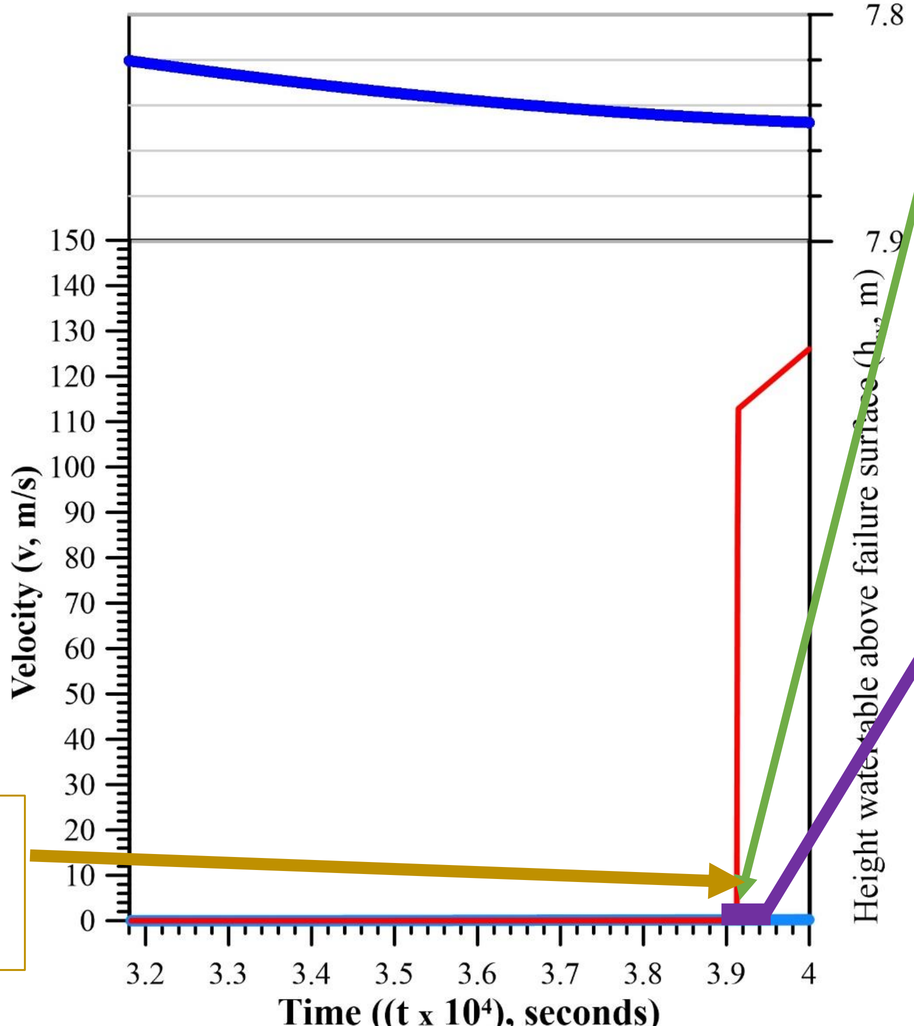
At $t = 39135s$
Acceleration sudden increase= $0.01186 m/s^2$

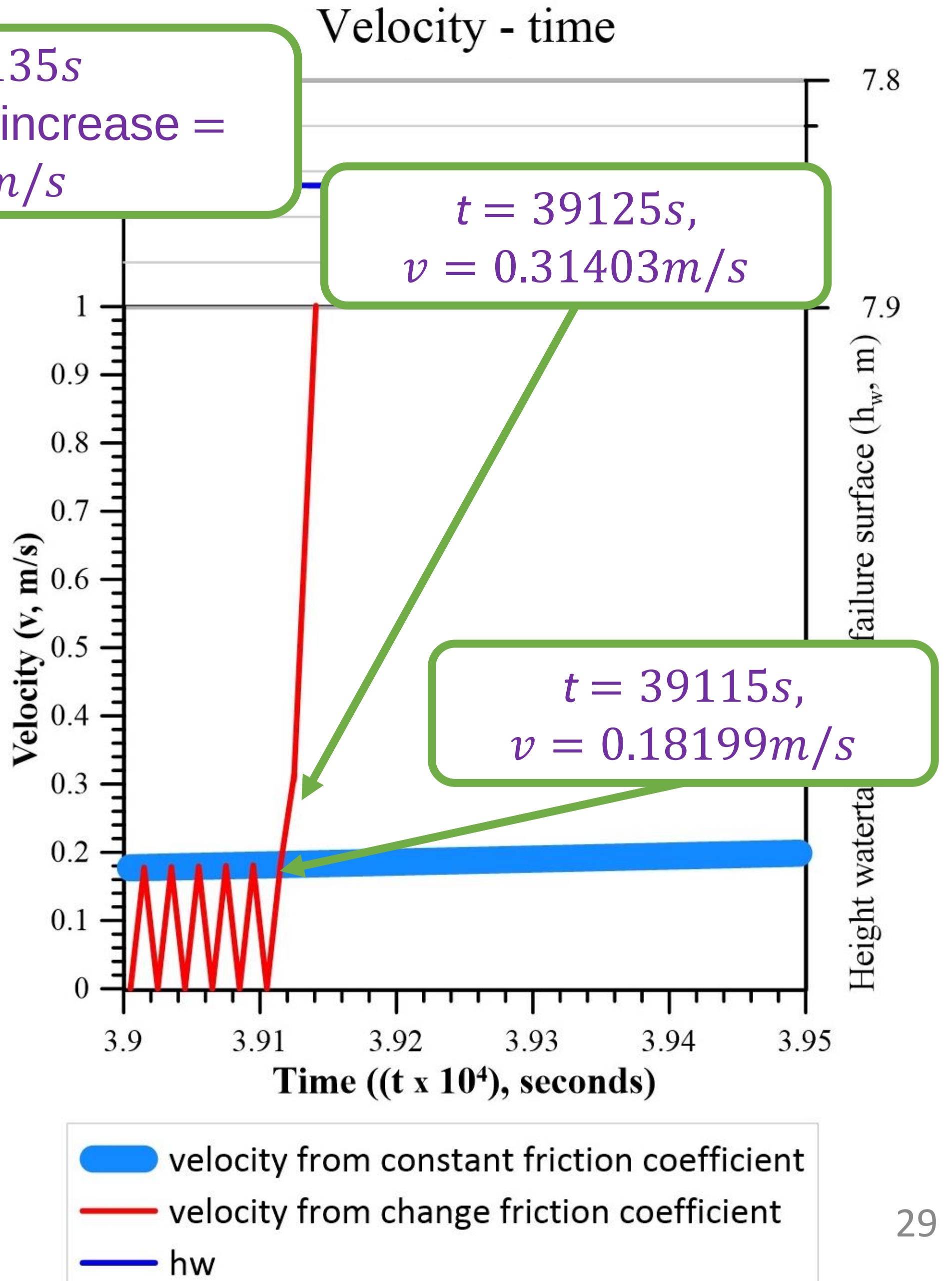
$t = 39125s,$
$a = 6.139.10^{-5}\ m/s^2$

$t = 39115s,$
$a = 4.333.10^{-5}\ m/s^2$

Sudden velocity







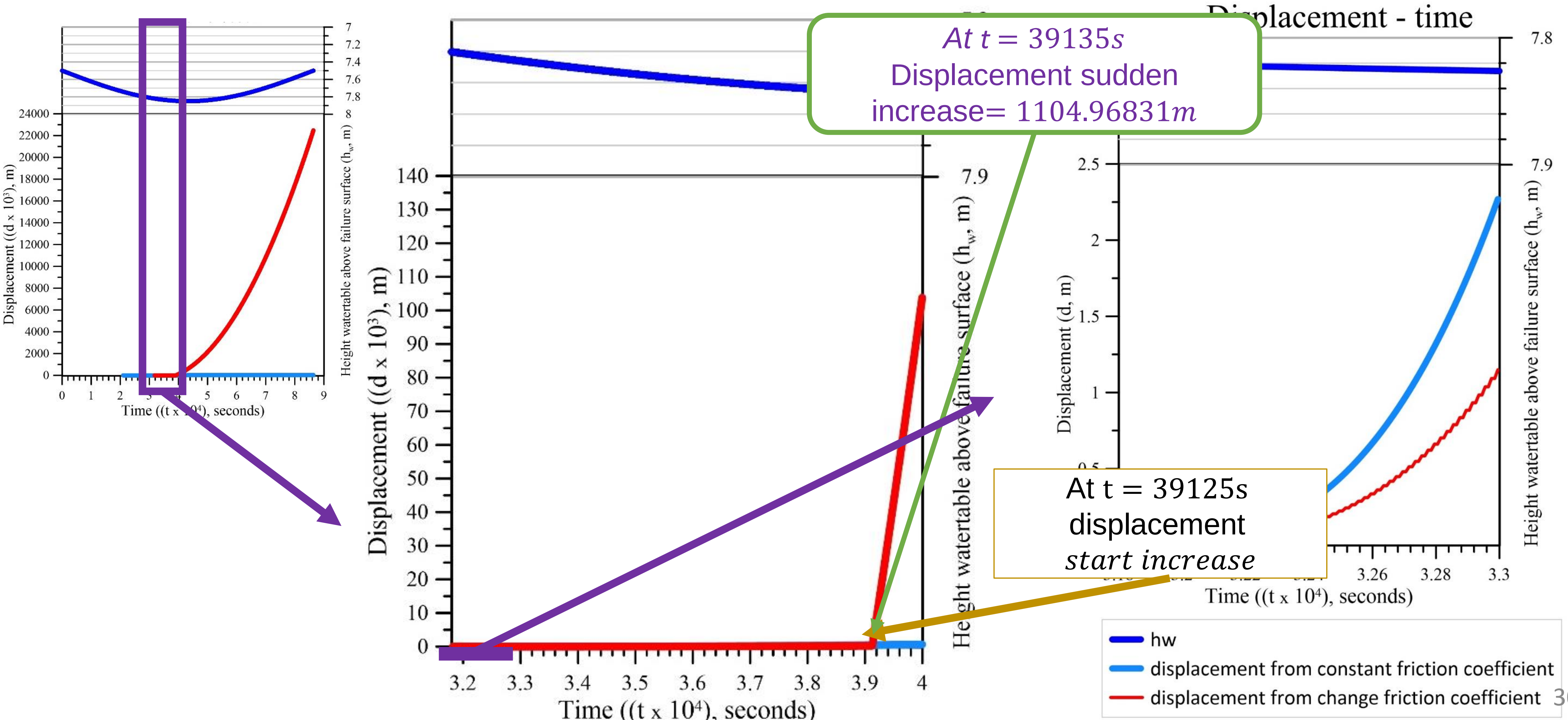
At $t = 39135s$
Velocity sudden increase = $0.31403m/s$

$t = 39125s,$
$v = 0.31403m/s$

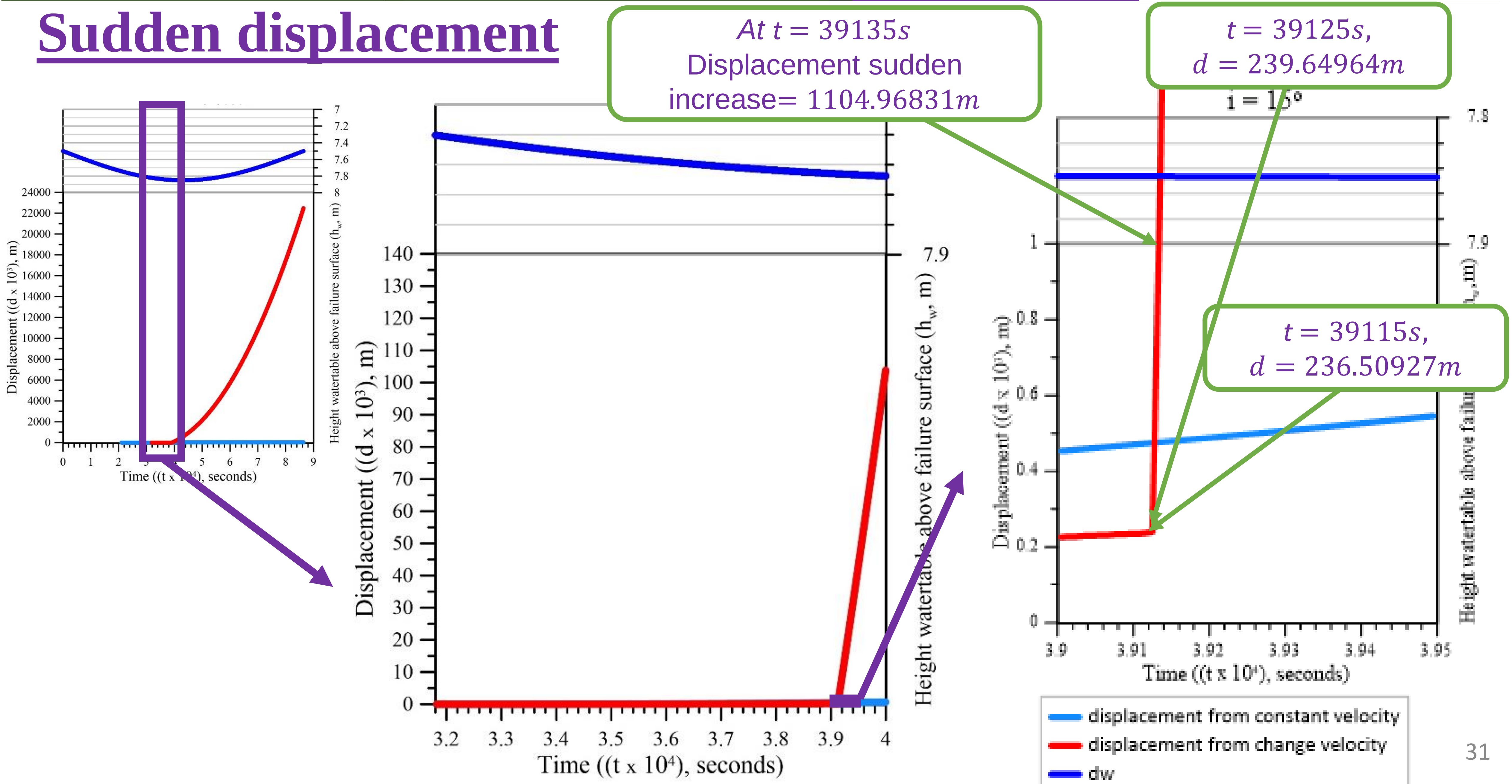
$t = 39115s,$
$v = 0.18199m/s$

At t = 39125s
velocity
start increase

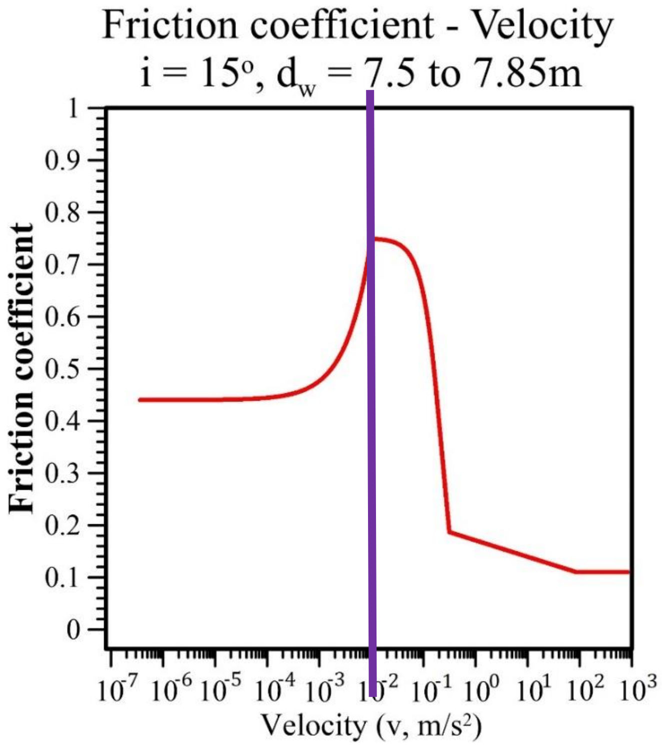
Displacement from change μ< displacement from constant μ

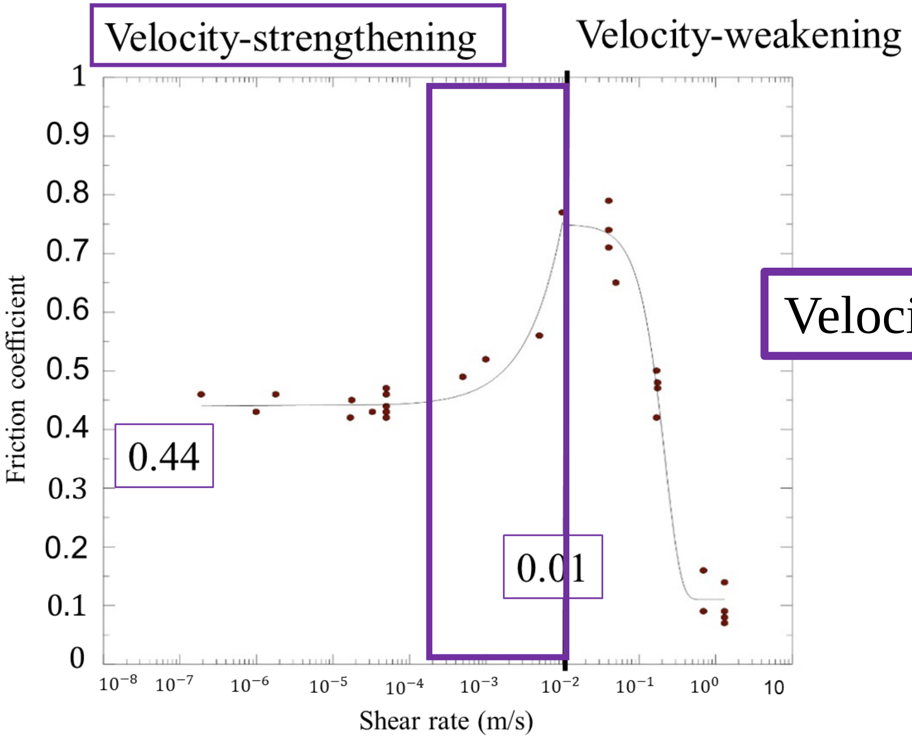


Sudden displacement

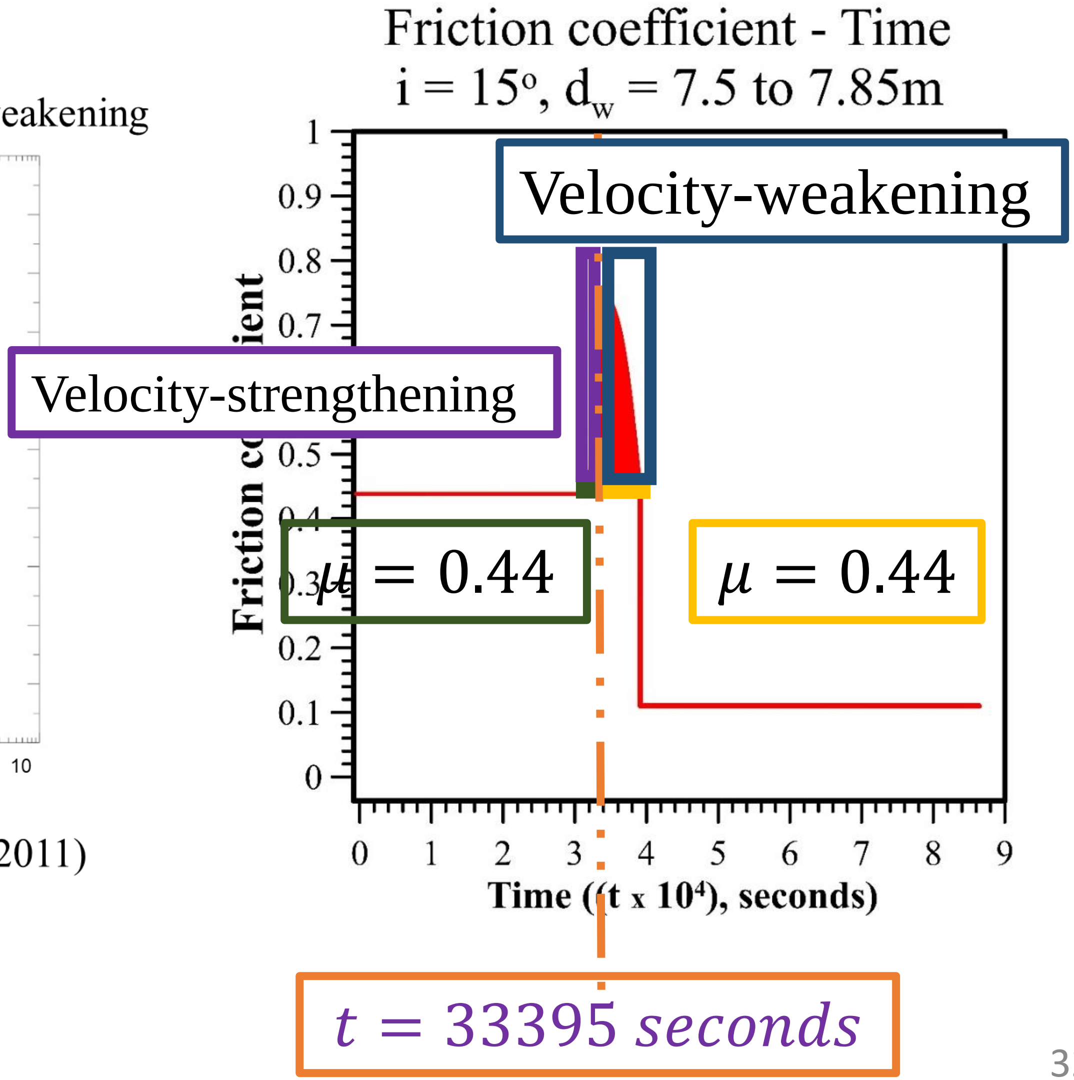


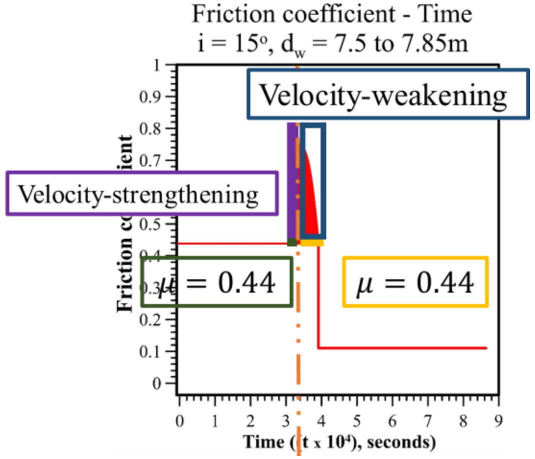
Friction coefficient – Time include 4 part



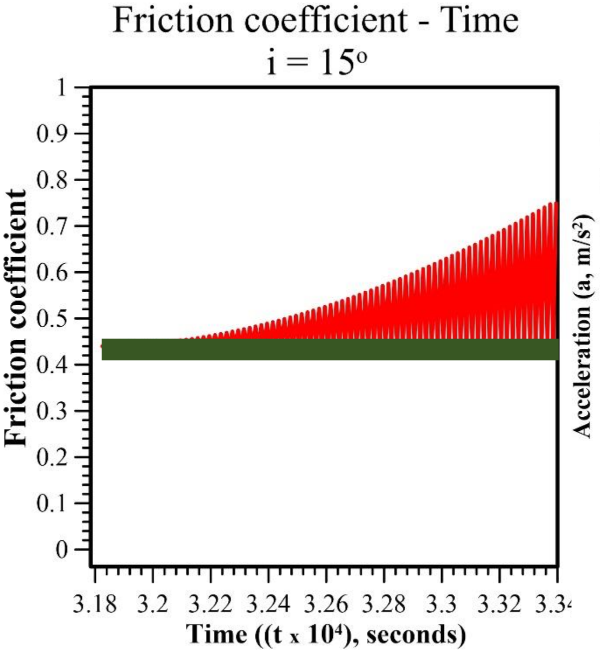


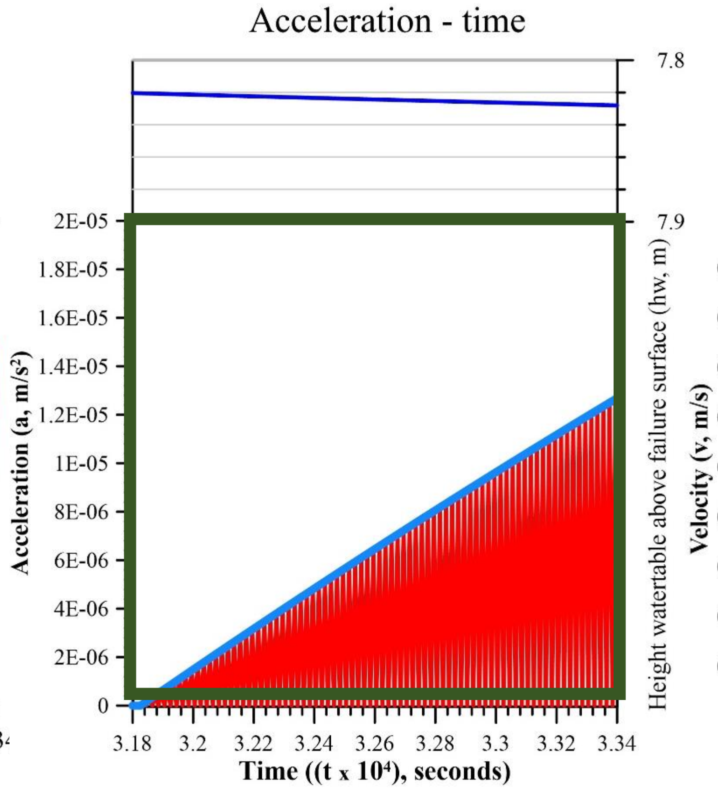
(Ferri et al., 2011)

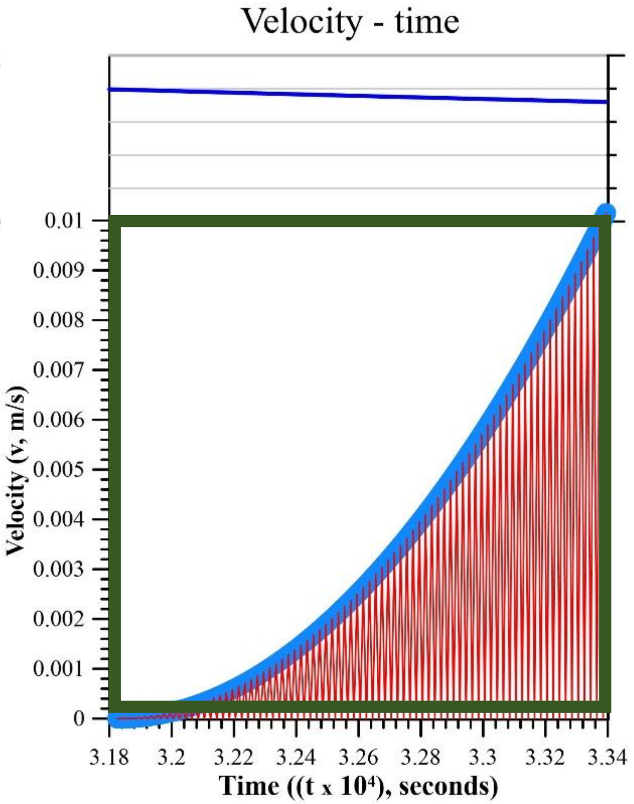


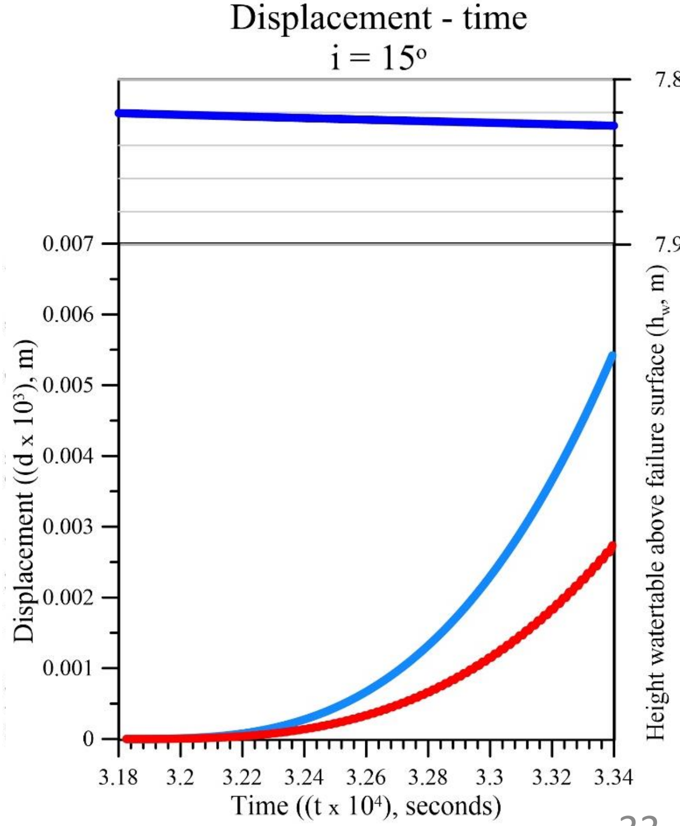


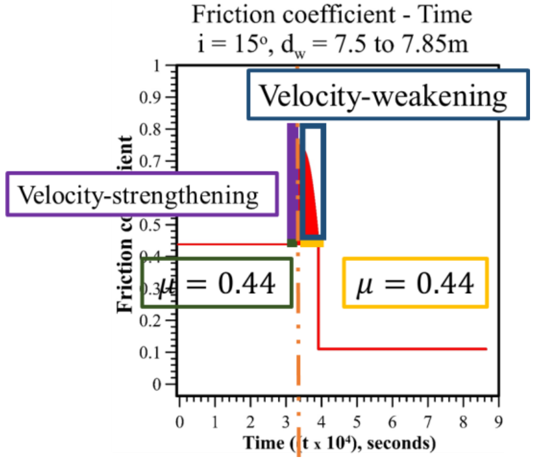
$$\text{If } \mu = 0.44, a > 0 \; and \; v > 0$$





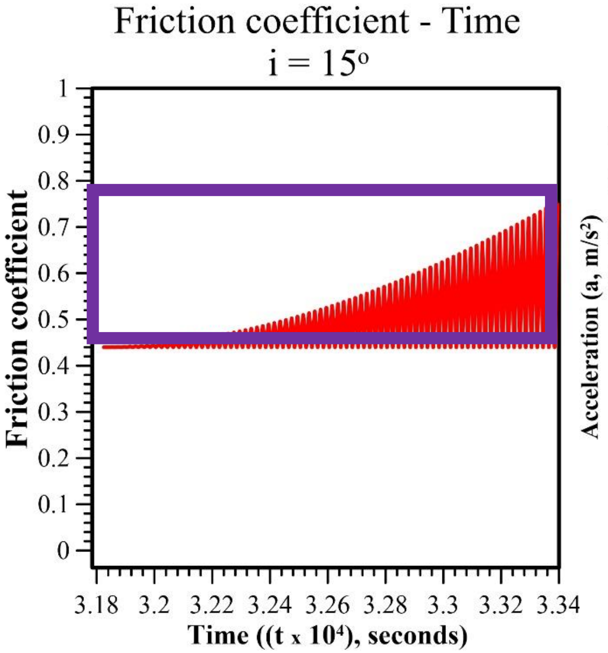


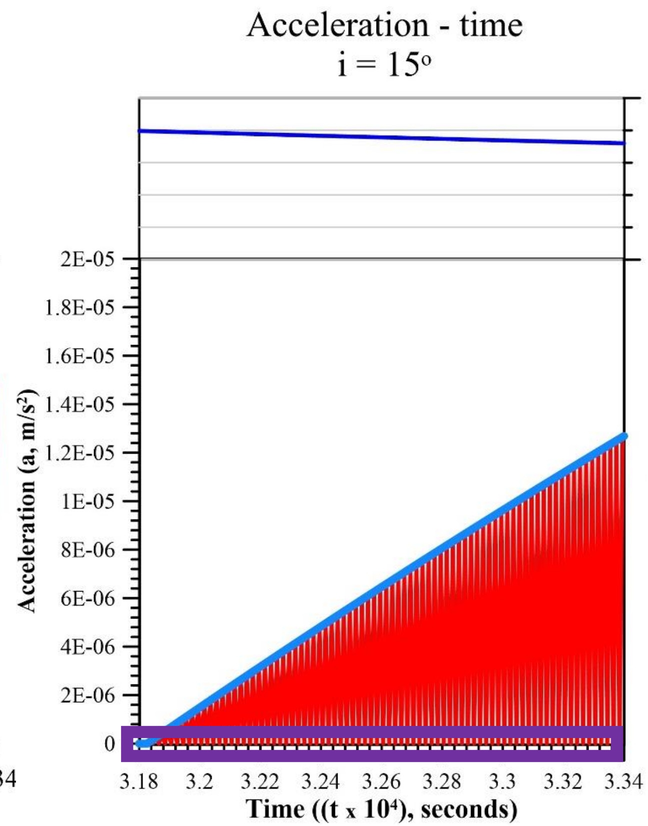


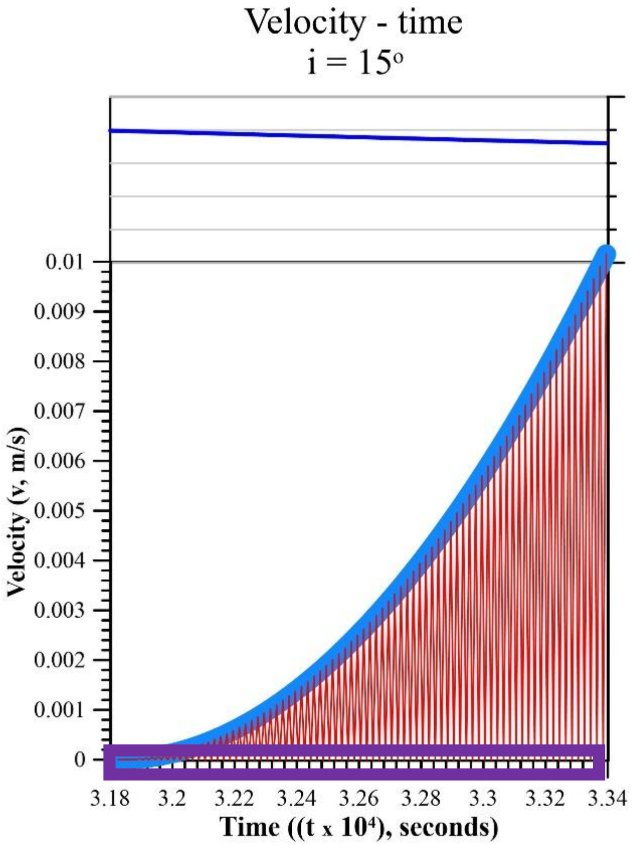


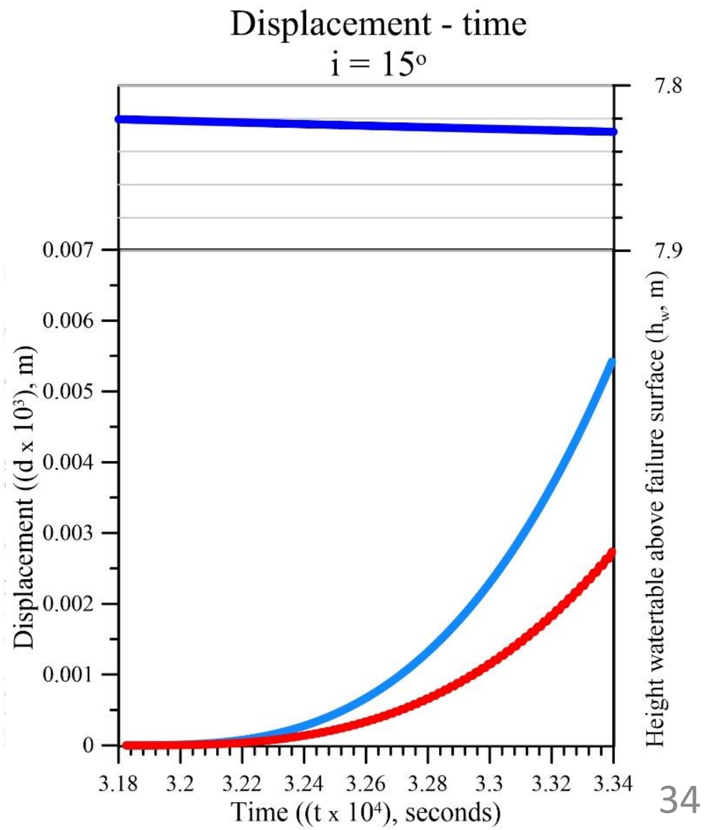
Velocity-strengthening

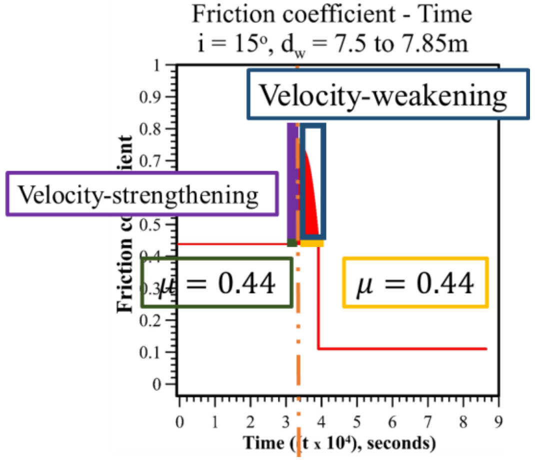
If $0.44 < \mu < 0.75, a = 0\ and\ v = 0$



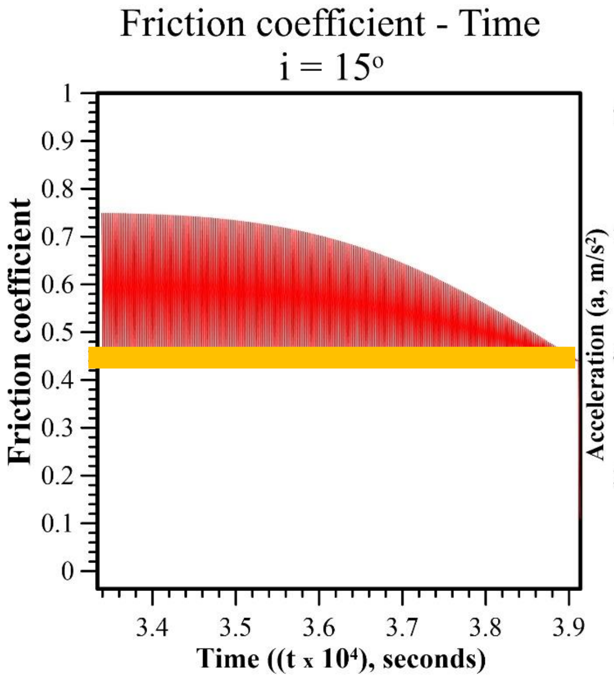


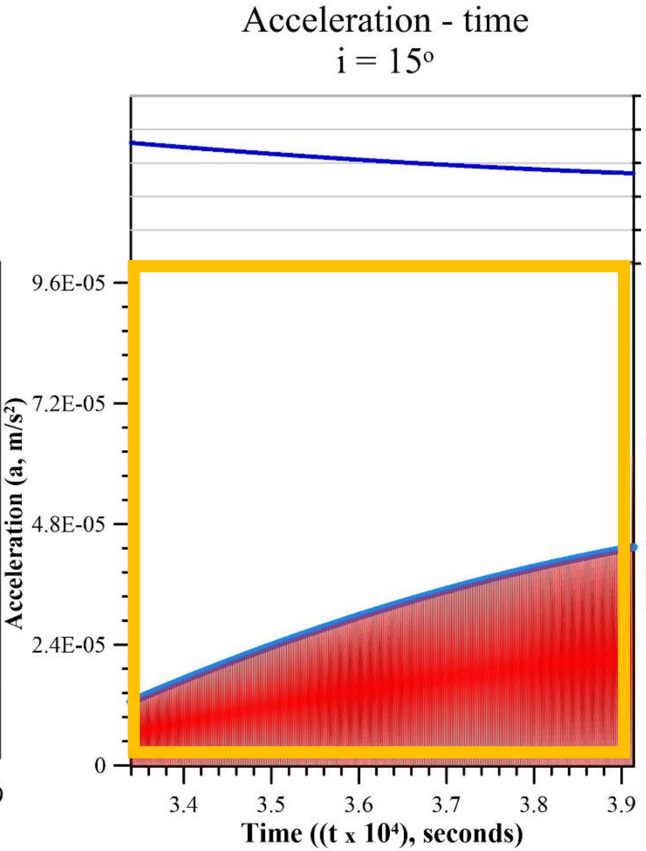


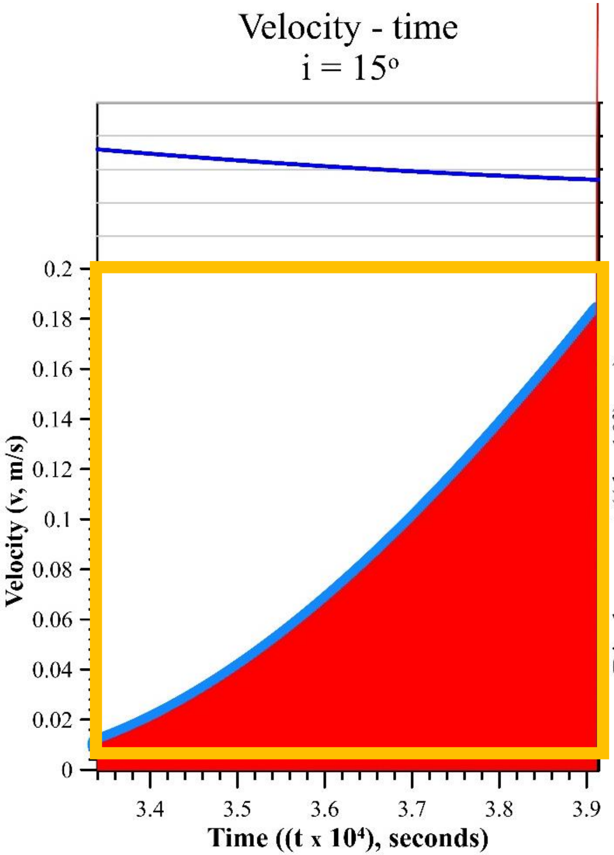


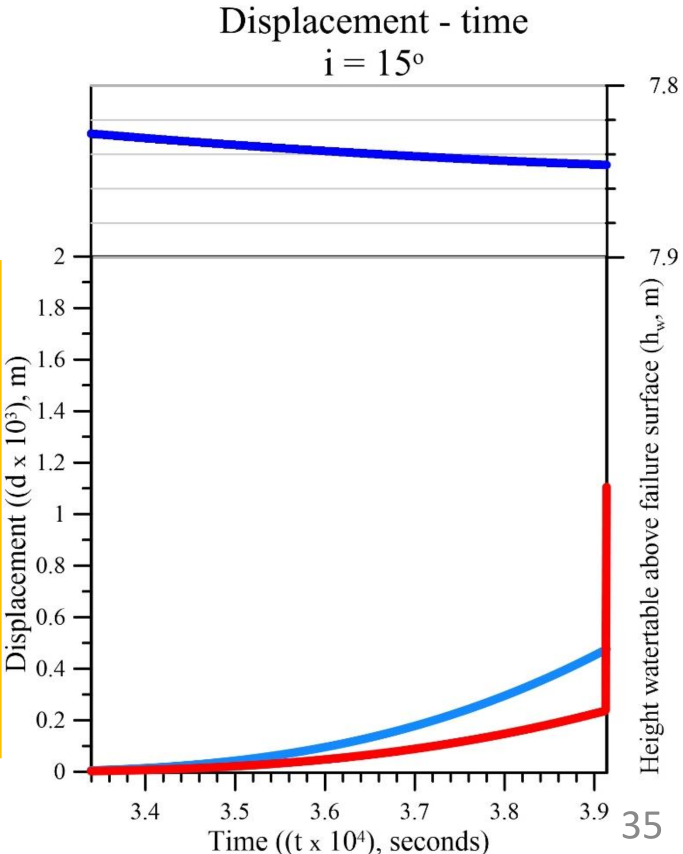


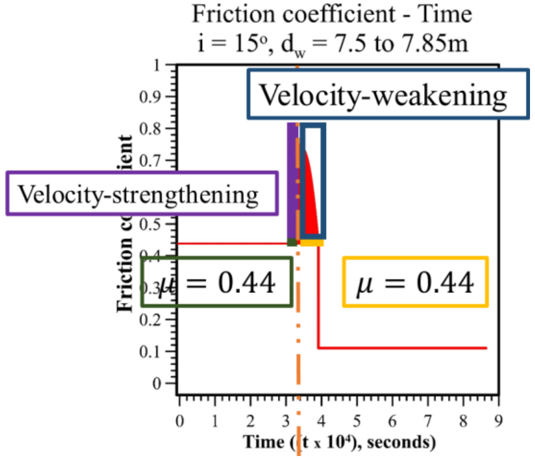
$$\text{If } \mu = 0.44, a > 0 \text{ and } v > 0$$





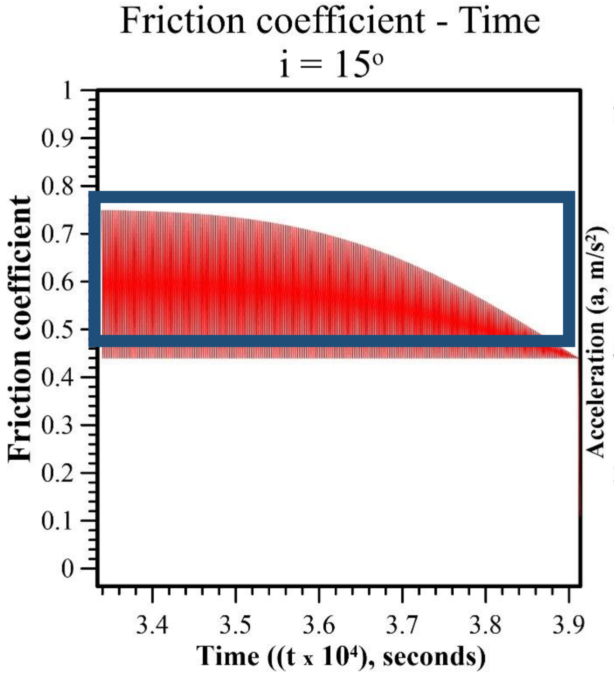


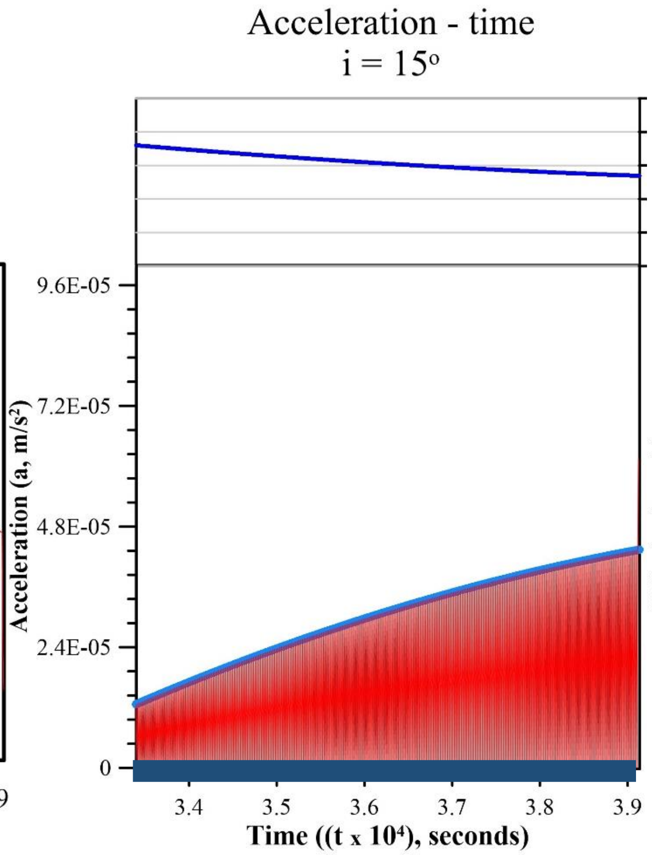


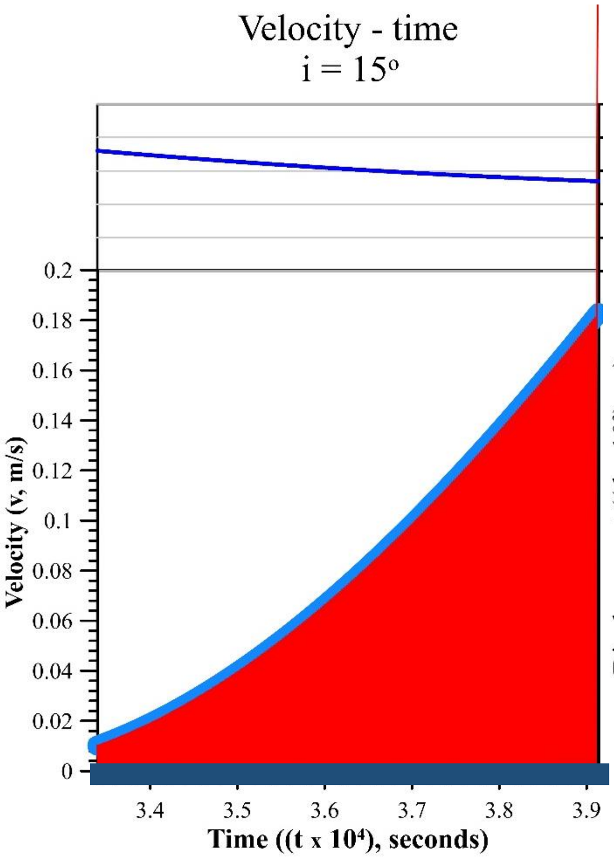


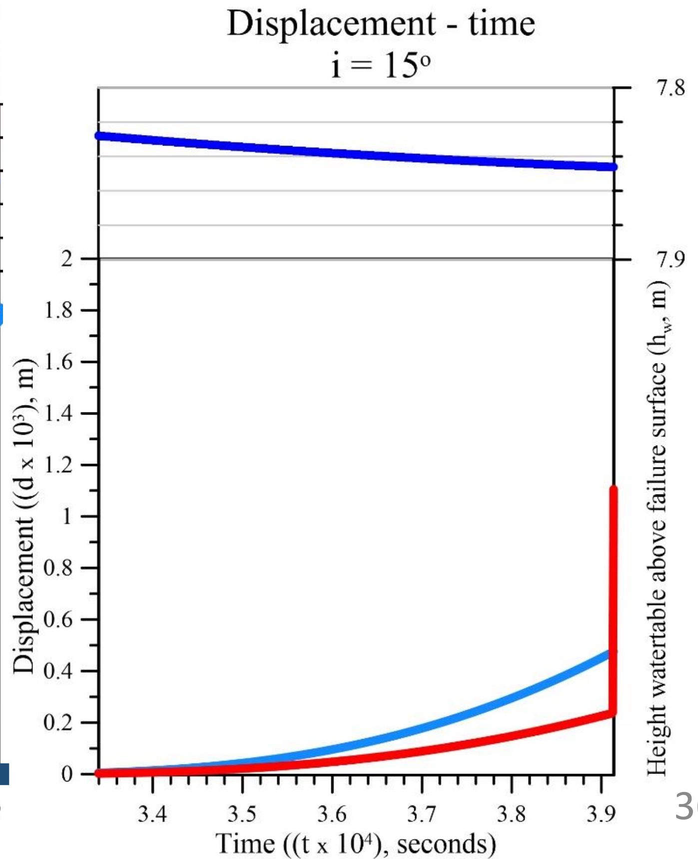
Velocity-weakening

$$0.44 < \mu < 0.75, a = 0 \; and \; v = 0$$



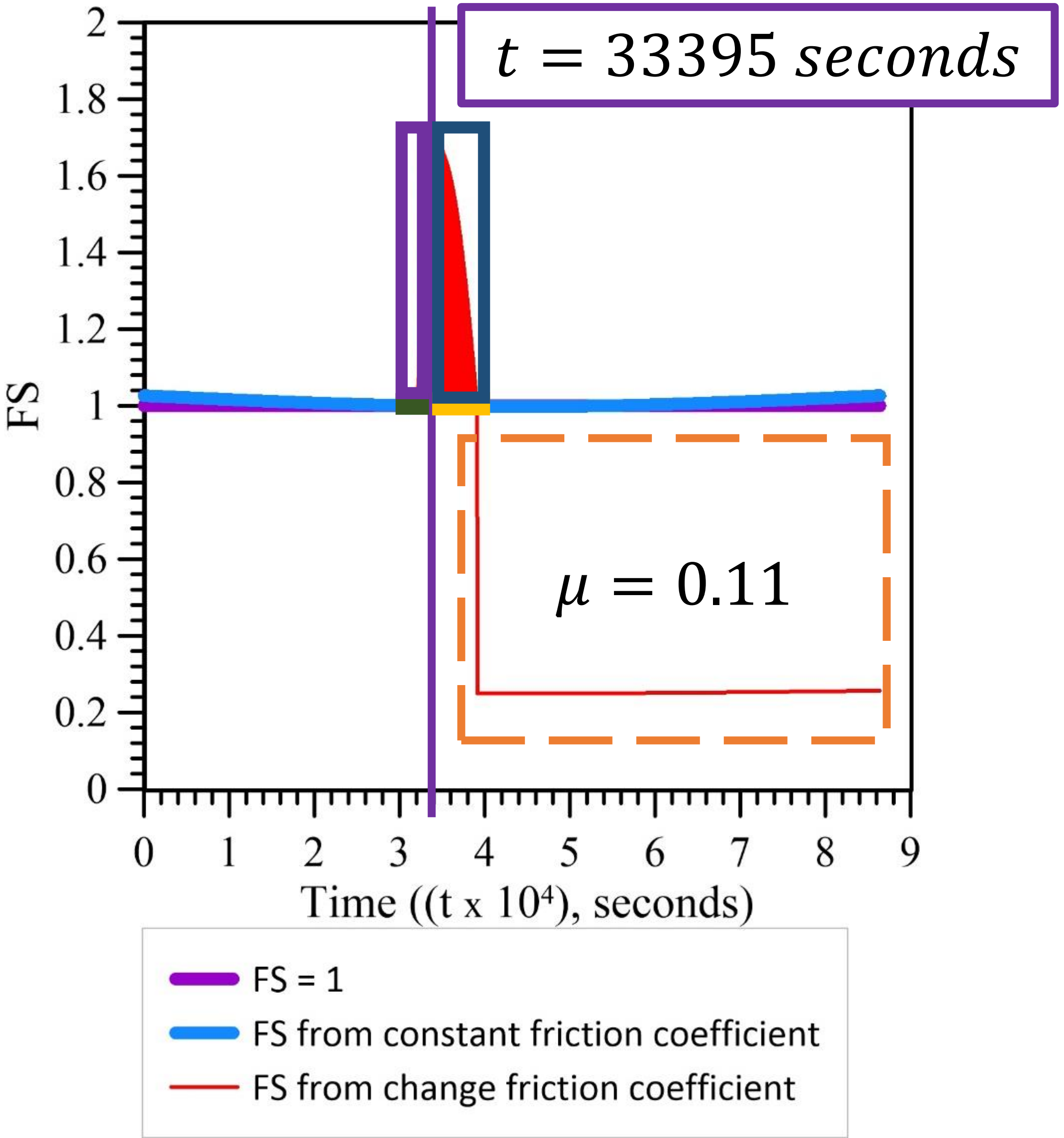






Fs – time similar Friction coefficient - time

Include 4 part



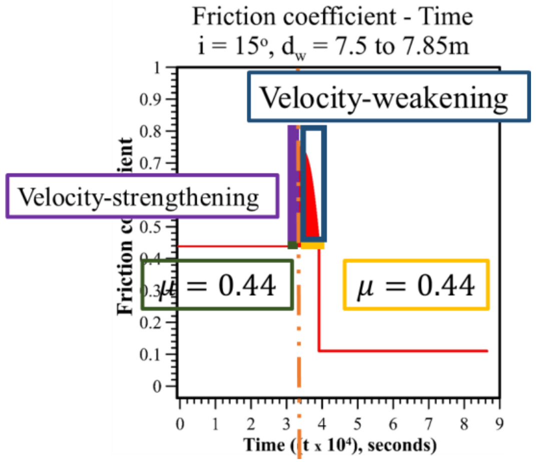
- Most **differences Δt** have **similar results** (both acceleration, velocity increase and decrease as shown in figure Zigzag and are limited by acceleration and velocity from constant friction coefficient)
- However, at t with $v \geq 0.19\ m/s$ then $\mu = 0.11$ so **acceleration, velocity, displacement sudden increase**. The block slides and no affect by height watertable above failure surface
- when **velocity increases**, then **stops**, **displacement** will **increase** then **horizontal**
- In the process of h_w increasing the sinusoid with time, μ also changes continuously according to the figure Zigzag divided into **4 parts:**

✓If $\mu = 0.44, a > 0\ and\ v > 0$

✓Velocity-strengthening. If $0.44 < \mu < 0.75, a = 0\ and\ v = 0$

✓If $\mu = 0.44, a > 0\ and\ v > 0$

✓Velocity-weakening. If $0.44 < \mu < 0.75, a = 0\ and\ v = 0$



Future works

$v < 0.01m/s$

Origin condition

Test more conditions

h_w

i

Time (2-3 days)

Decrease final velocity

Results of experiment

Velocity-dependent friction

Test again

Simulate Newmark displacement

Thank you for listening

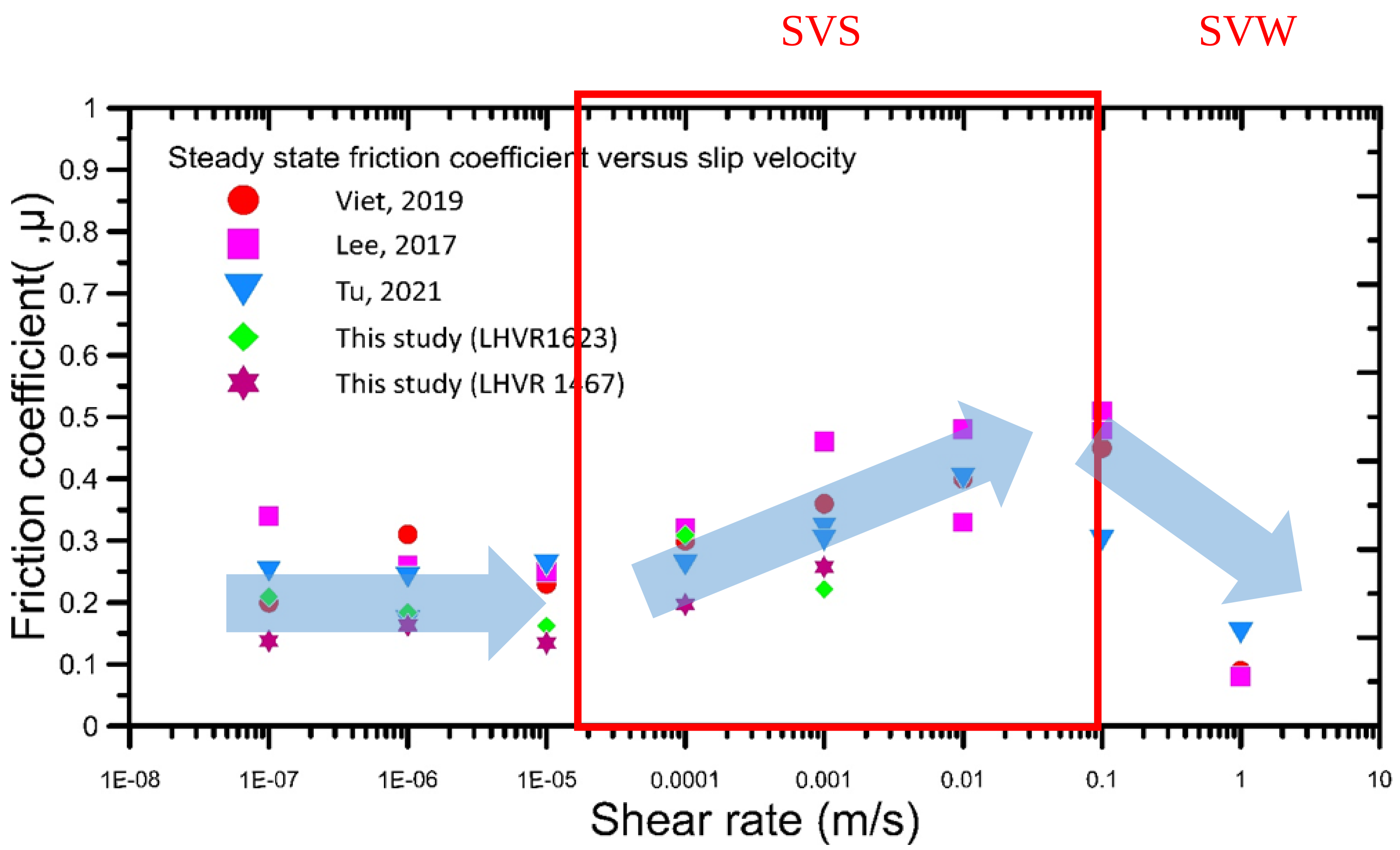


Figure . The steady-state apparent friction coefficients under different slip rates