Strengthening Flood Forecasting in ASEAN Member States through Regional Trainings and Coordination

Module4

Sediment Disasters

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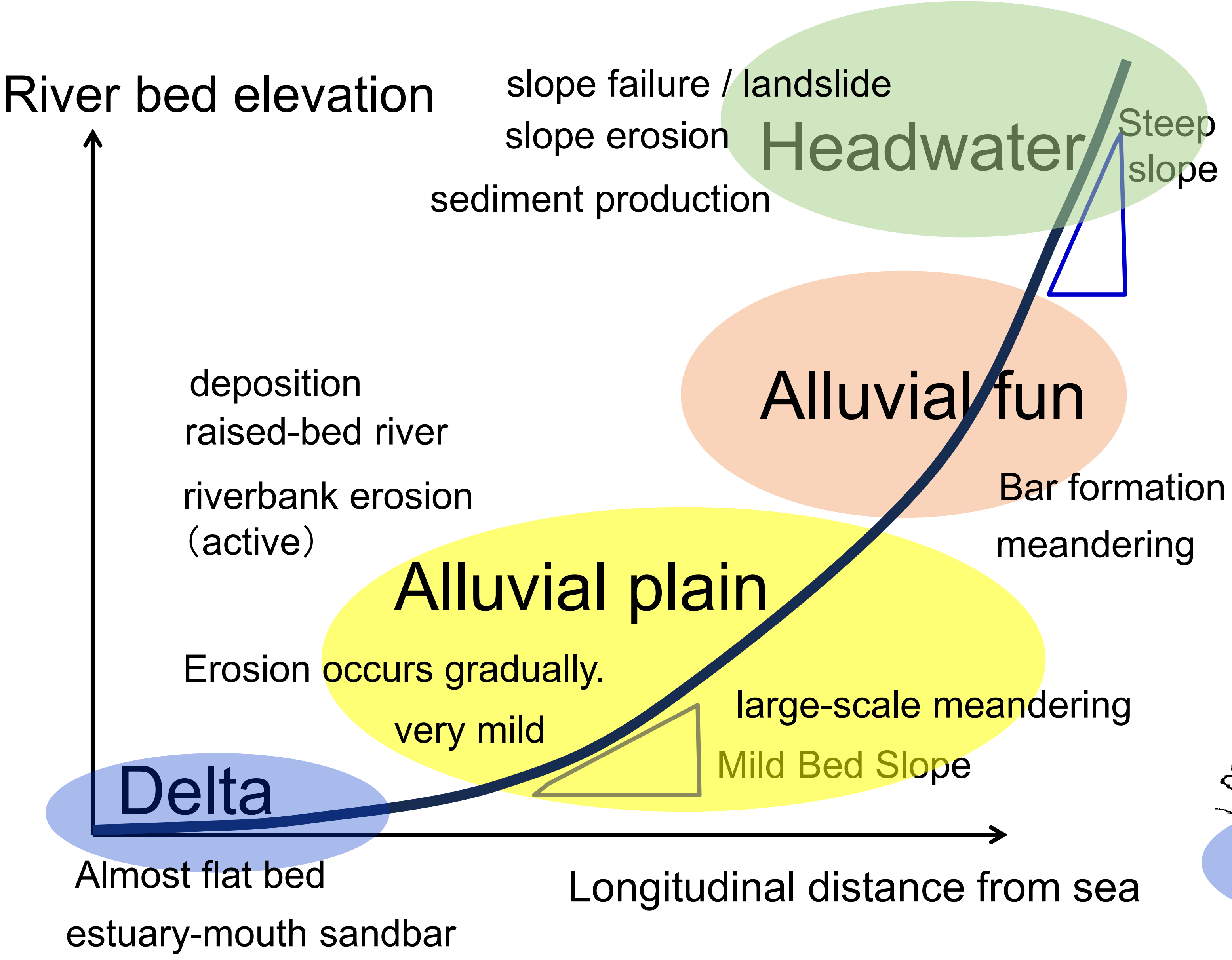
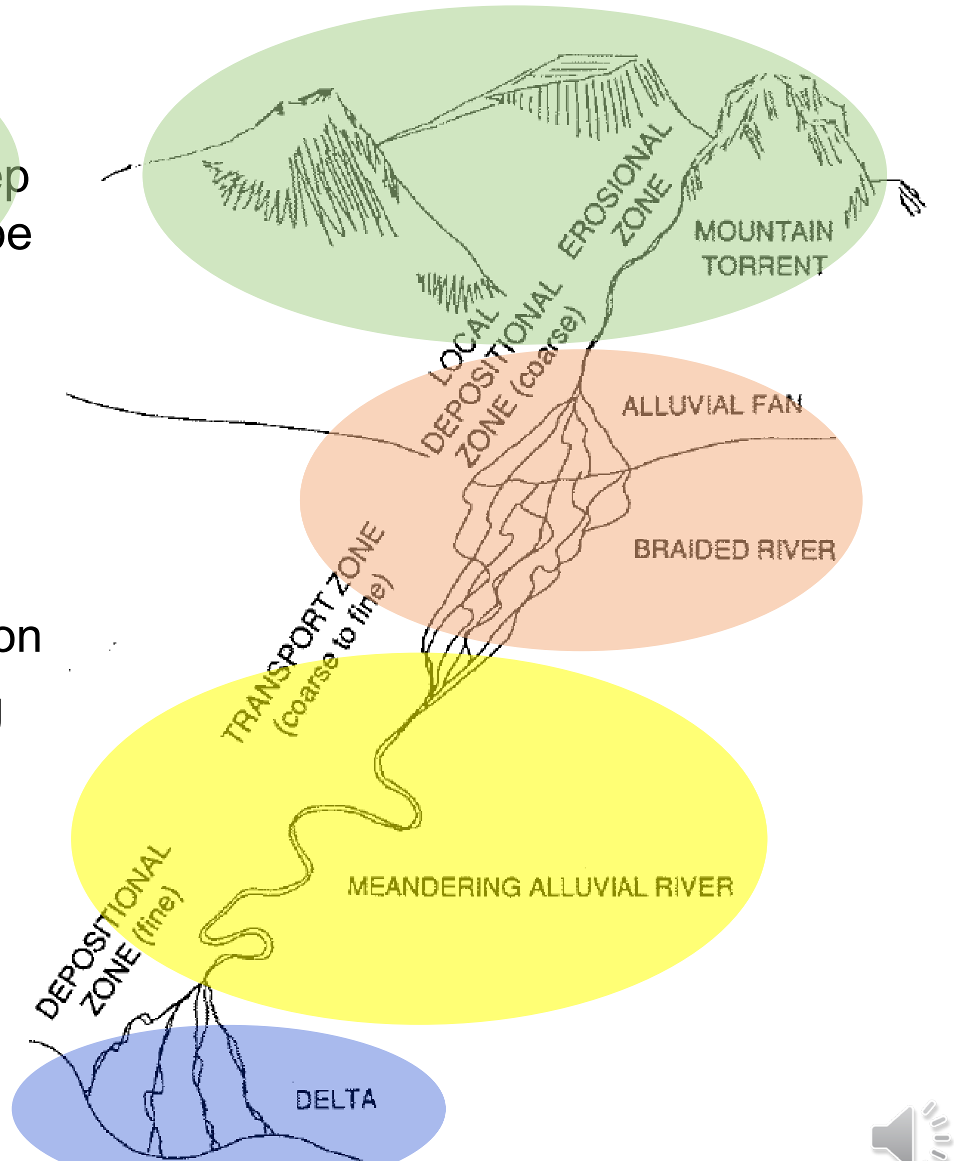
Sediment Disaster

1. Fundamentals of Sediment transport
   1) Landscape River Basin
   2) Introduction to Sediment Transport Dynamics
2. Debris flow disaster
   1) Mechanics of Slope Failure and Debris Flows
   2) Debris Flow Disasters and Countermeasures
3. Flood disasters caused by channel migration
   1) Channel meandering and bank erosion
   2) Alternate bars, low-flow channel meandering, and bank erosion
   3) Bank erosion control measures

1.Fundamentals of Sediment transport
1) Landscape River Basin

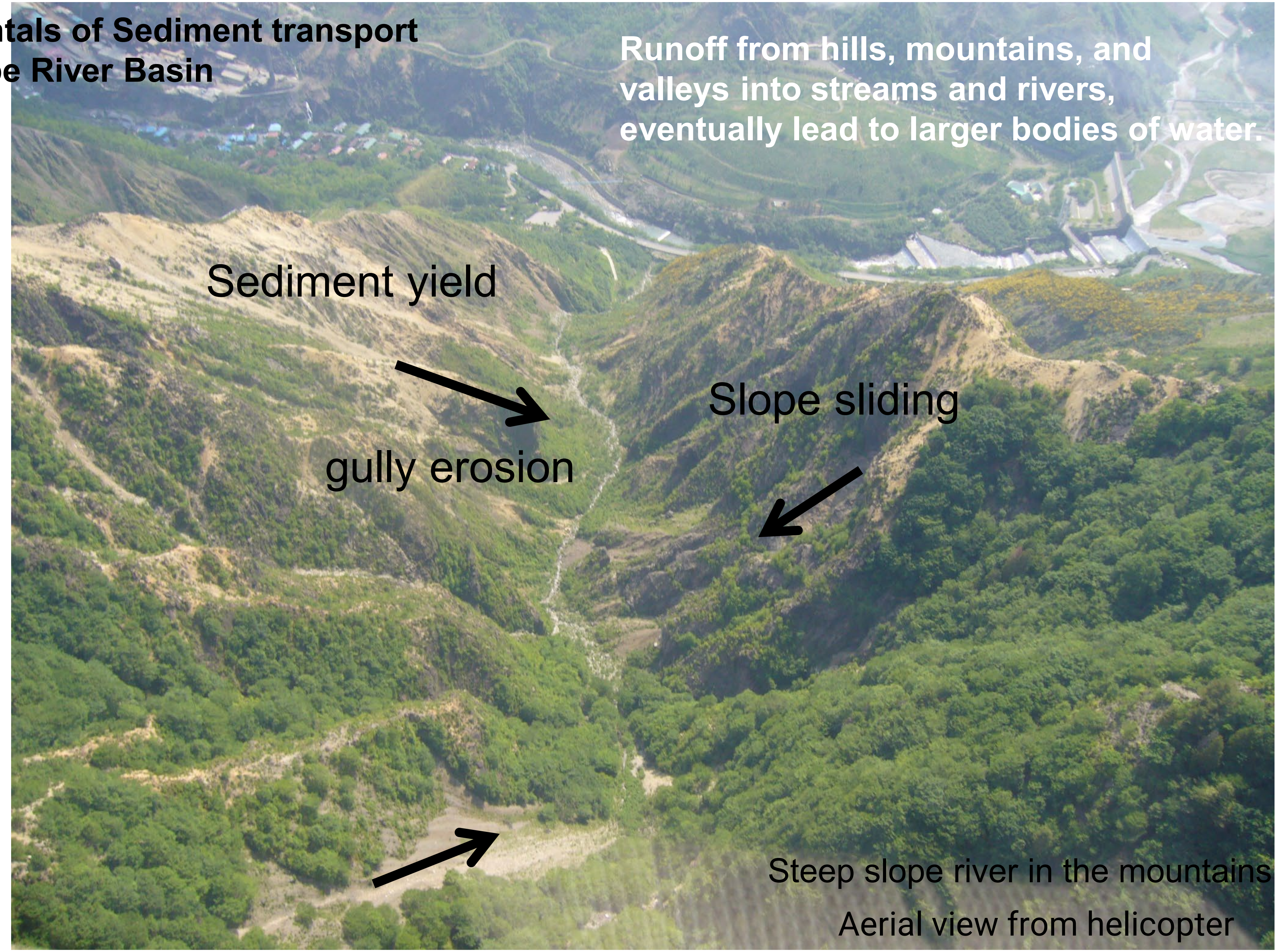
Water flows from high places to low places.





Channel stability assessment
for flood control projects, ASCE, 1997

1.Fundamentals of Sediment transport
1) Landscape River Basin



1.Fundamentals of Sediment transport
1) Landscape River Basin

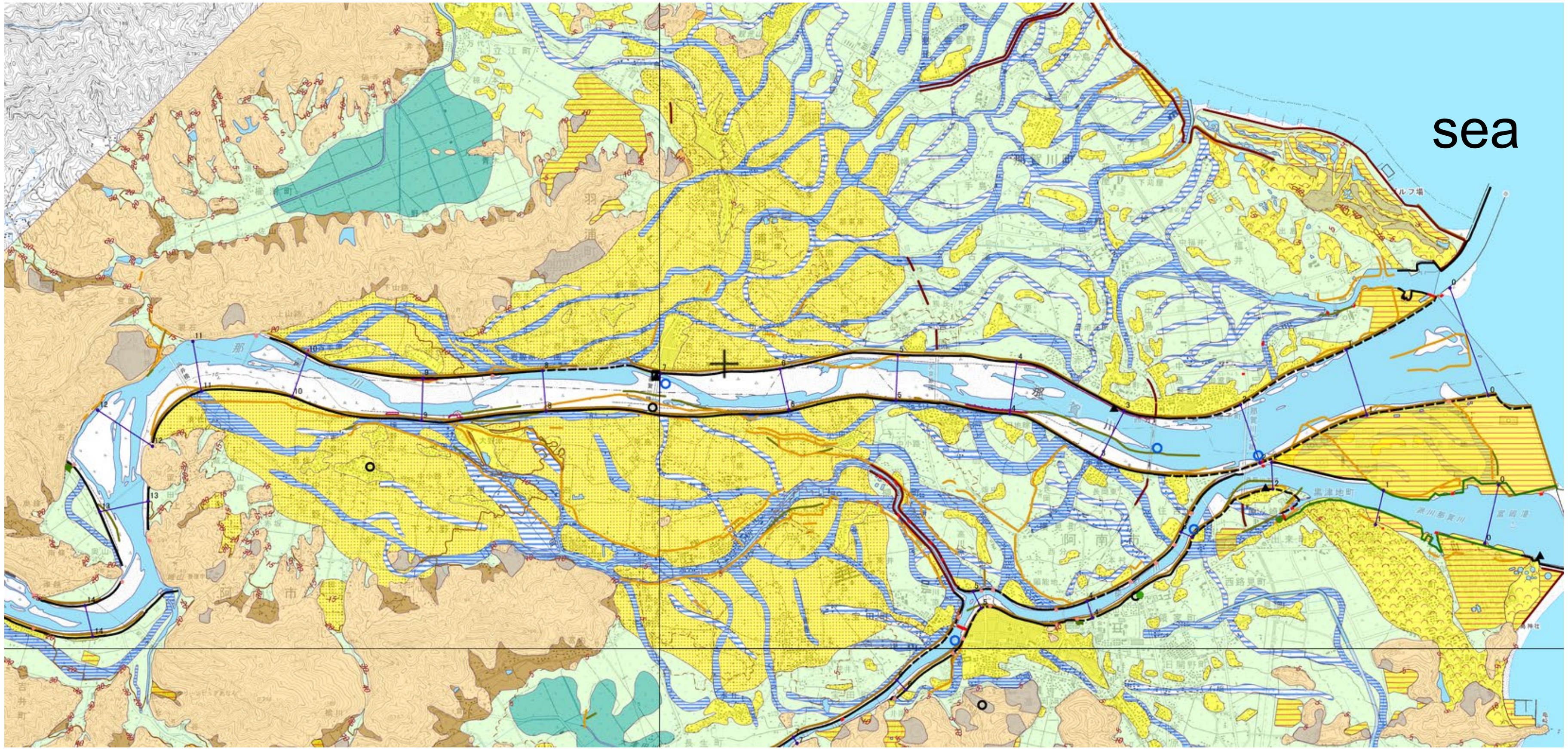
An alluvial fan is a landform where sediment brought from upstream deposit.
As a result, an alluvial fan topography was formed.

1.Fundamentals of Sediment transport
1) Landscape River Basin

1.Fundamentals of Sediment transport
1) Landscape River Basin

Meandering rivers are common in alluvial plains.

Changes in rivers



Naka River

The levee restricts the movement of the river.

Land use can be developed by controlling flooding with levees

1.Fundamentals of Sediment transport

1) Landscape River Basin

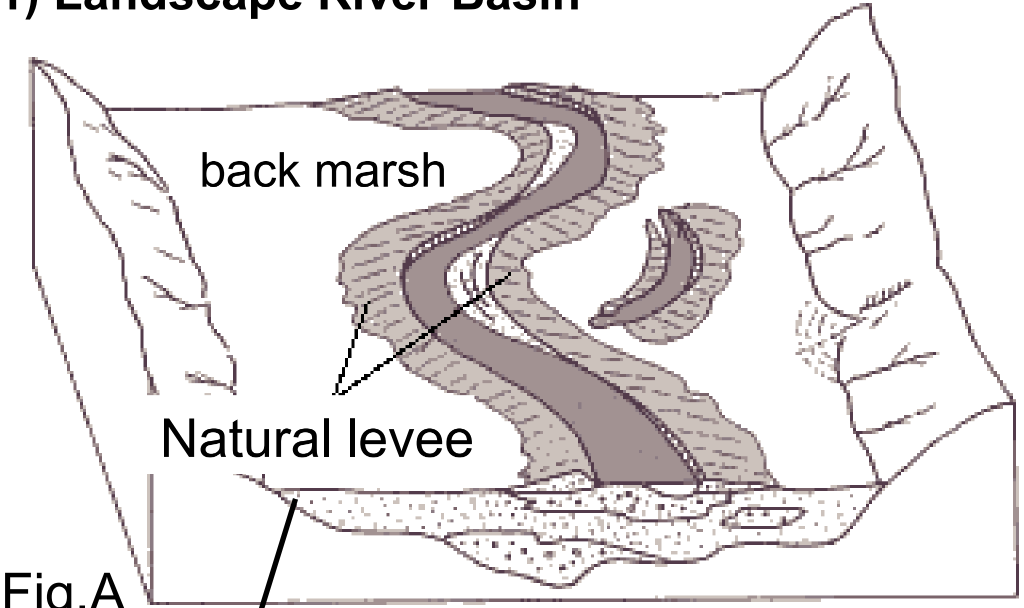
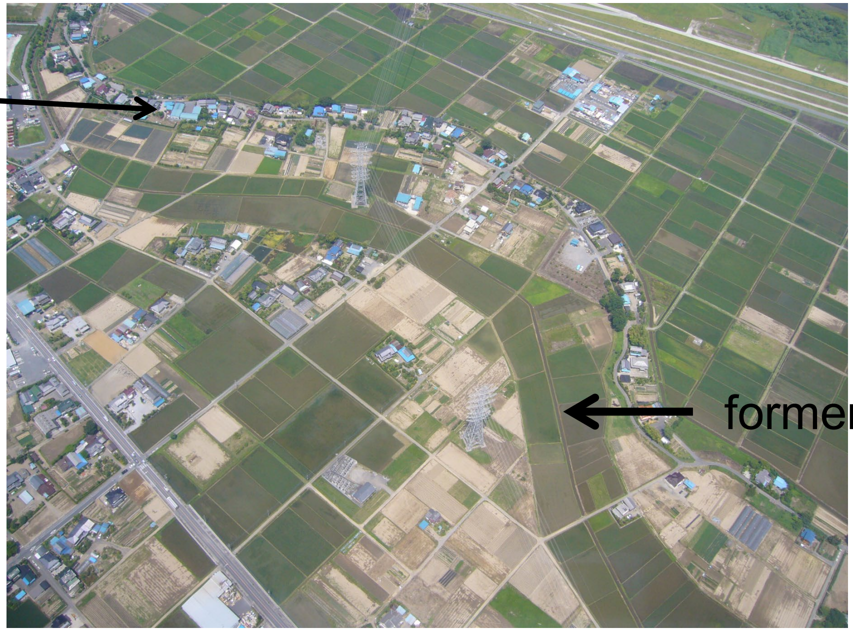


Fig.A

Relatively higher area

Houses built on high areas
are protected from flooding



former river bed

Fig. B

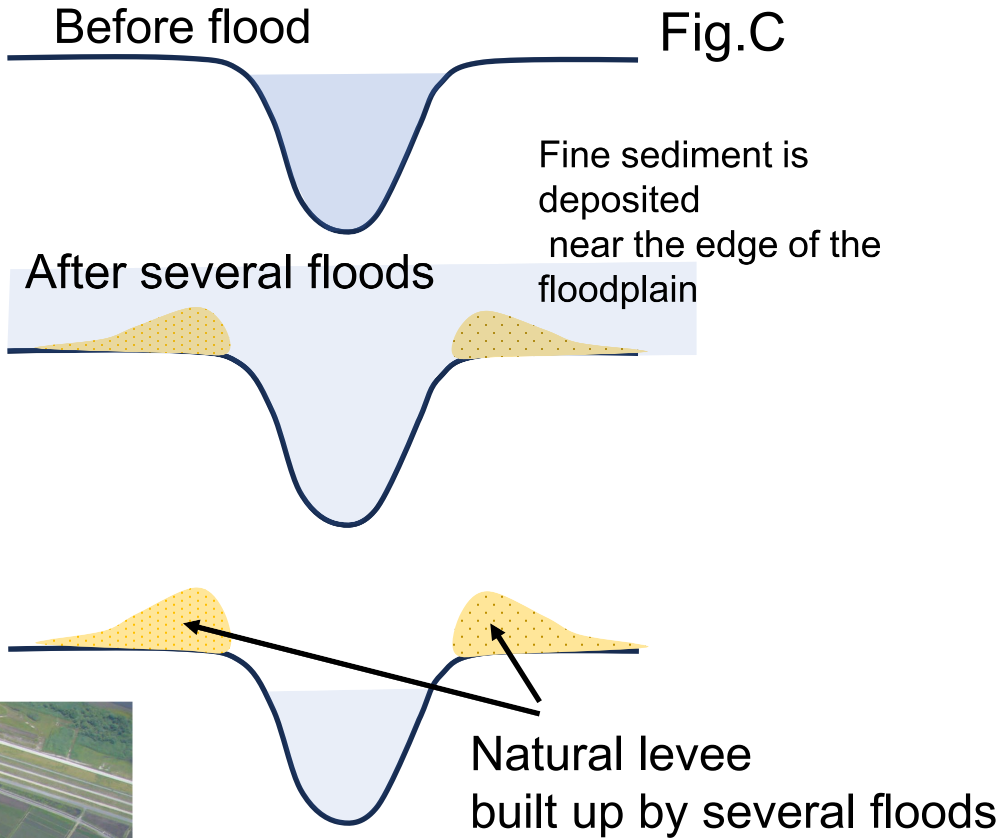
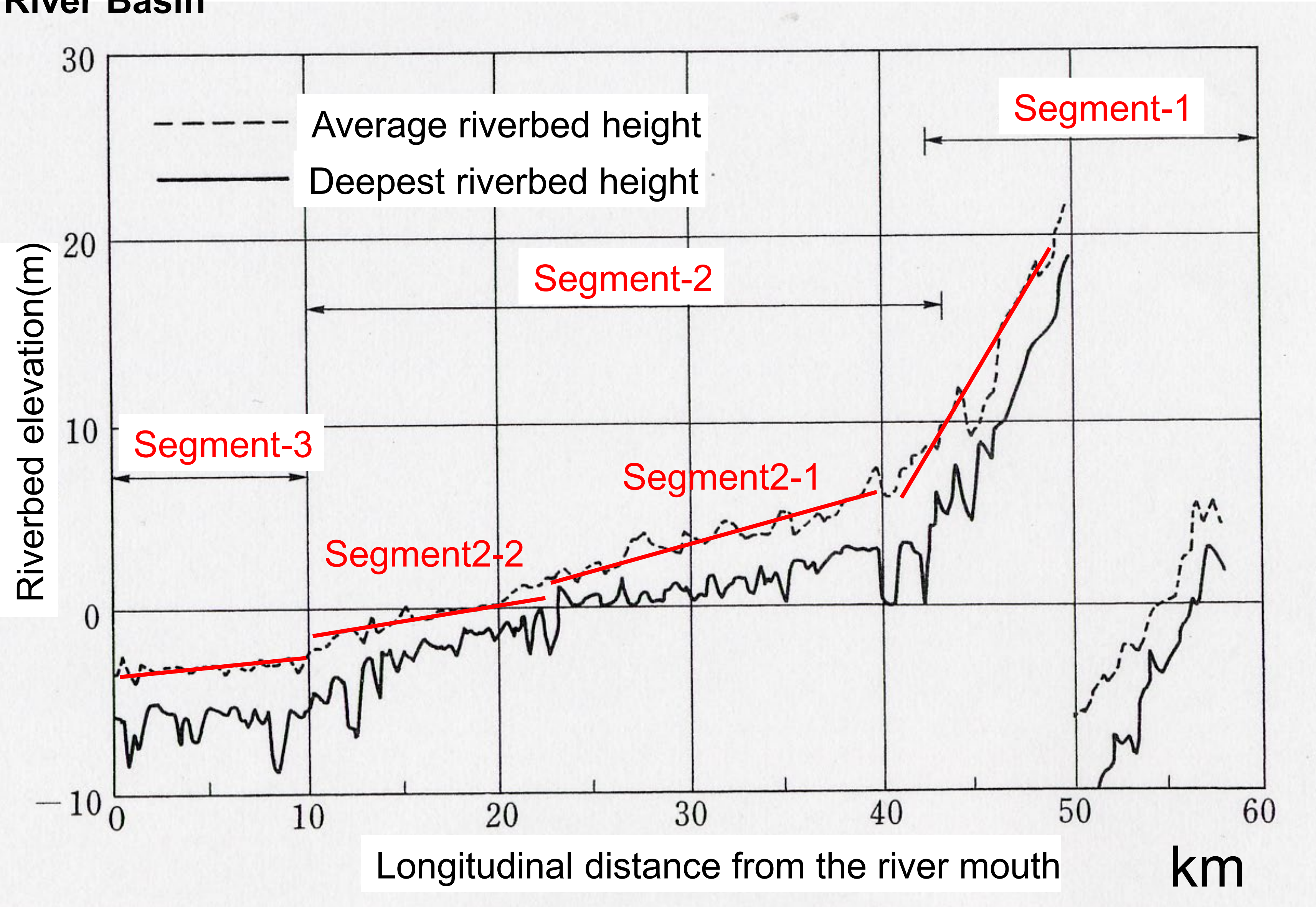


Fig.C

River cross-sectional profile
(formation of natural levees)

1.Fundamentals of Sediment transport
1) Landscape River Basin



Longitudinal section of the Kiso River

(YAMAMOTO Koichi)

Longitudinal bed gradient of an alluvial river is generally made up of a number of sections with roughly the same bed gradient.

1.Fundamentals of Sediment transport
1) Landscape River Basin

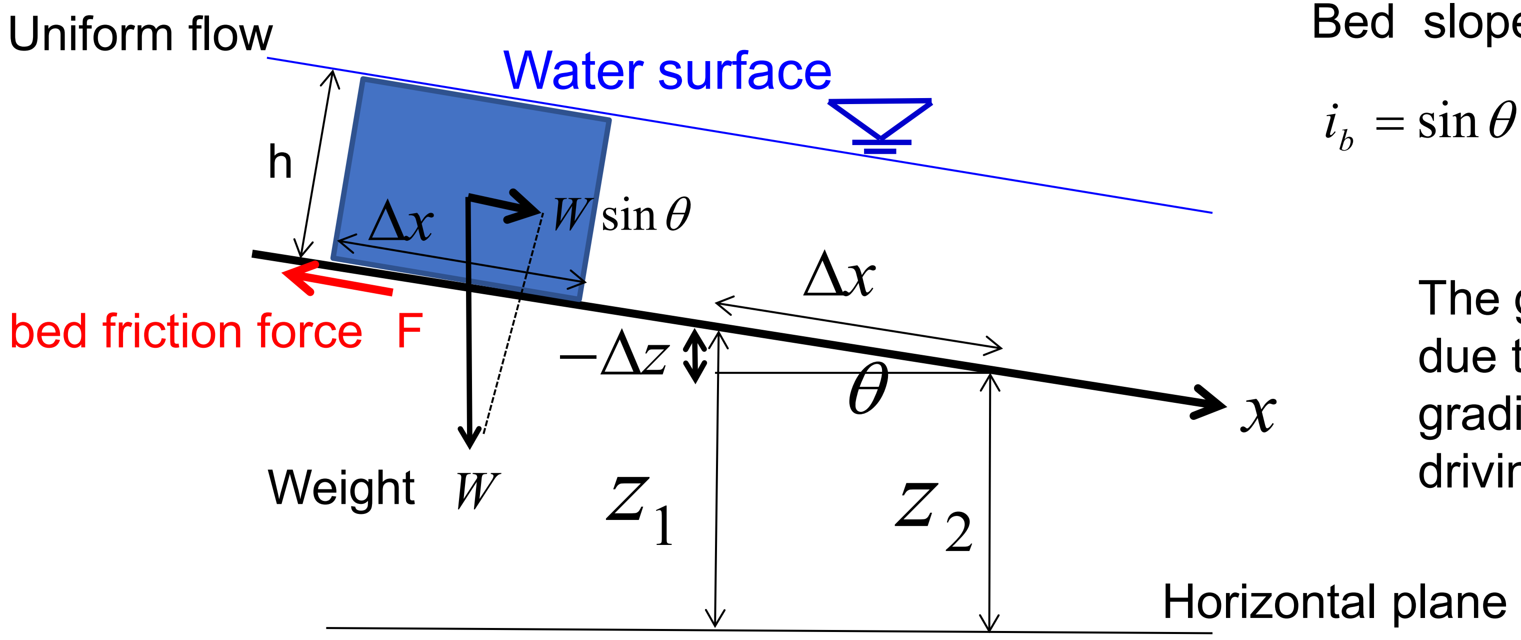
Classification of River Landscapes into Segments

(YAMAMOTO Koichi)

	Segment-M	Segment-1	Segment-2-1	Segment-2-2	Segment-3
Landscape	Mountain	Alluvial fan Valley bottom plain	Natural levee		Delta
Representative particle size	Wide variety	Over 2cm	3cm-1cm	1cm-0.3mm	Less than 0.3mm
Bank materials		Same as bed material with sand ,slit.	Fine sand, Slit, clay (mixture)		Slit, clay
Range of gradient (approximately)	Wide variety	1/60-1/400	1/400-1/5000		Less than 1/5000
Meandering	Wide variety	Degree of bending is weak	Very active		Variety of sizes
Bank erosion	Very active	Very active	Moderate		weak
Depth of low Water channel	Wide variety	0.5m-3m	2m-8m		3m-8m

1.Fundamentals of Sediment transport
2)Introduction to Sediment Transport Dynamics

Water flows from higher elevations to lower elevations.
How can we formulate this mathematically?



Bed slope

$$i_b = \sin\theta = \frac{-\Delta z}{\Delta x} = -\frac{dz_b}{dx}$$

The gravity component due to the riverbed gradient becomes the driving force of the flow.

$$W \sin\theta - F = 0 \qquad (1)$$

$$W \sin\theta = \rho g V \sin\theta = \rho g B h \Delta x \sin\theta \qquad (2)$$

$$F = \tau_0 \Delta x B \qquad (3)$$

$$\therefore \tau_0 = \rho g h \sin\theta \qquad (4) \qquad \therefore u_* \equiv \sqrt{\frac{\tau_0}{\rho}} = \sqrt{g h \sin\theta} \qquad (5)$$

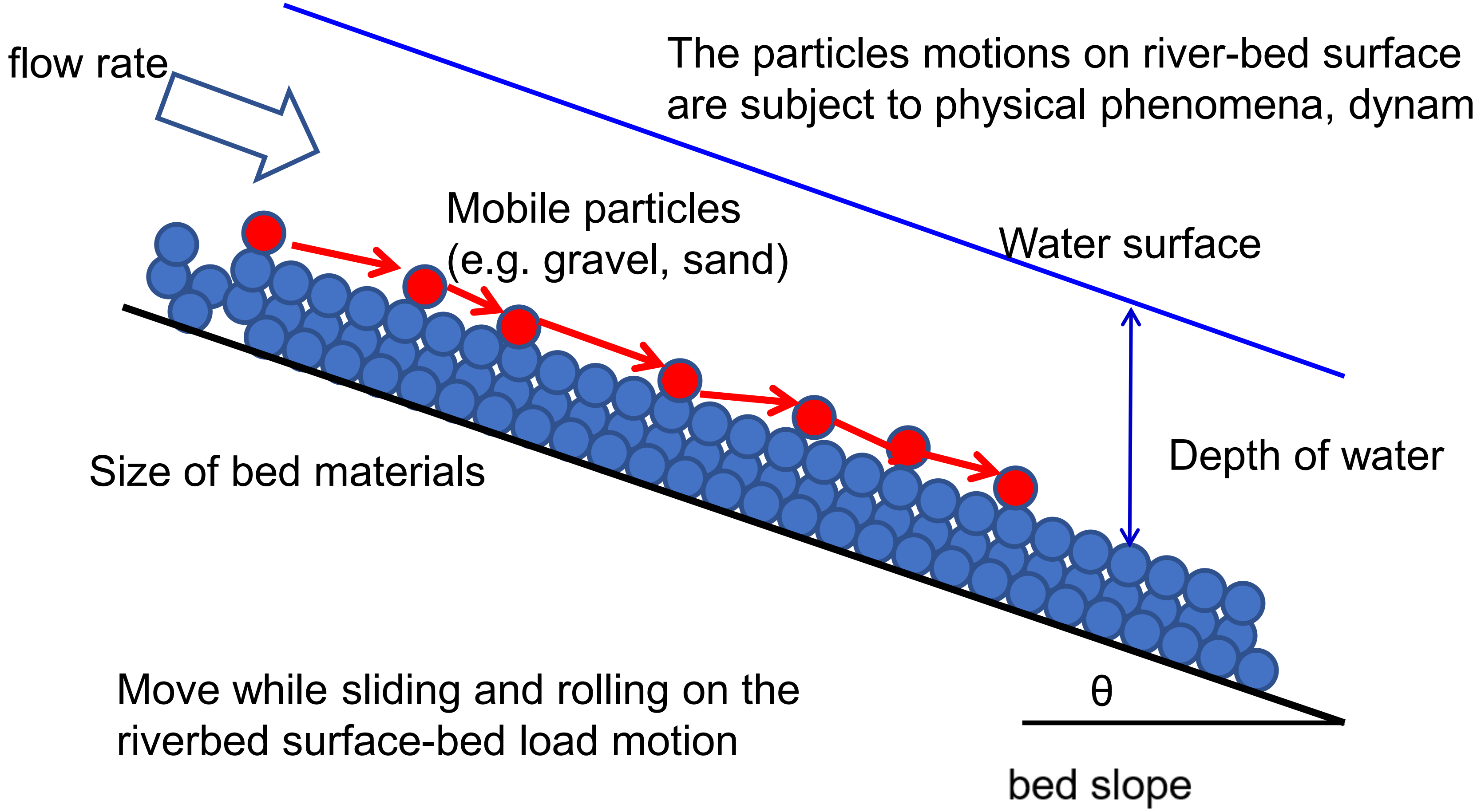
(friction velocity)

A:cross-section area
B:width of channel
h: depth of flow
ρ: density of water
τ_0 : bed shear stress

1.Fundamentals of Sediment transport
2)Introduction to Sediment Transport Dynamics

Motion form of sand, gravel particles

The particles motions on river-bed surface are subject to physical phenomena, dynamics.



1.Fundamentals of Sediment transport
2)Introduction to Sediment Transport Dynamics

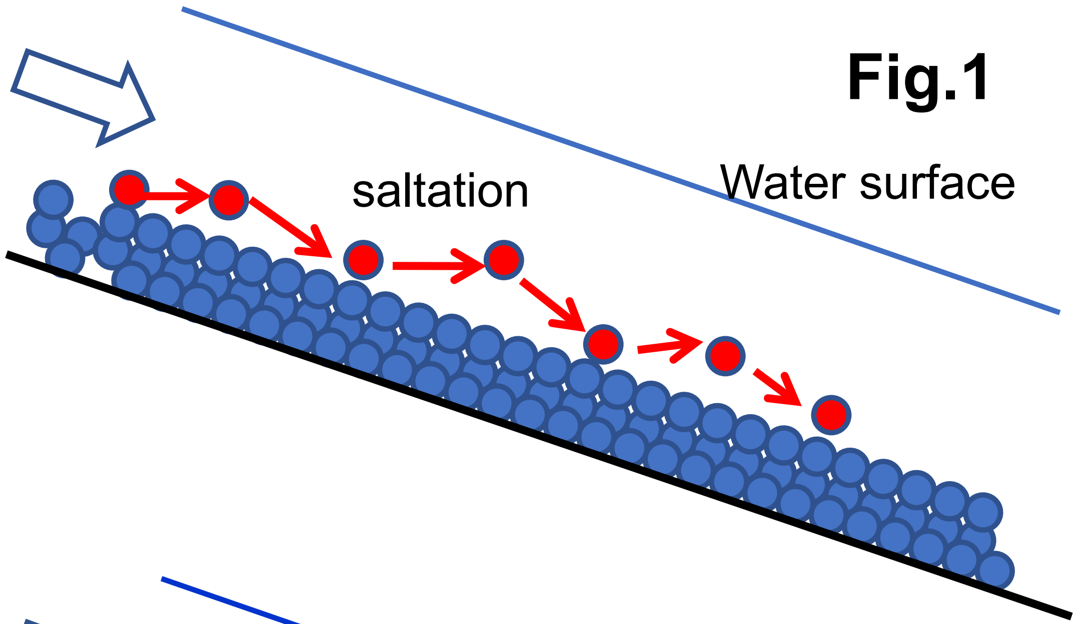


Fig.1

Motion form of gravel particles - saltation

Bed material particle departures from the riverbed and rebounds with the riverbed surface.

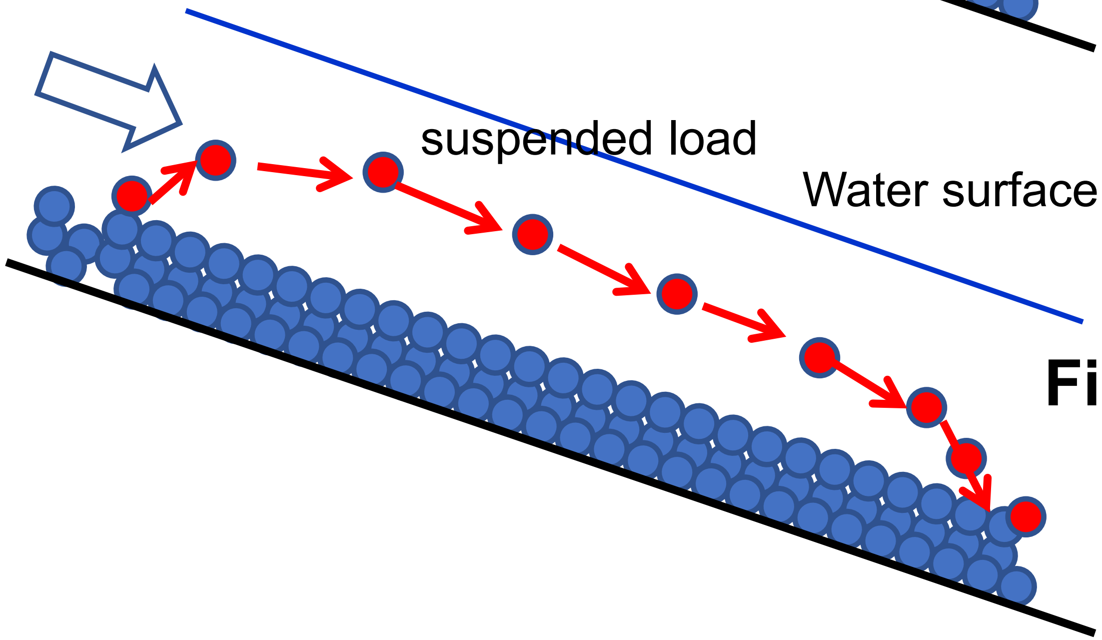


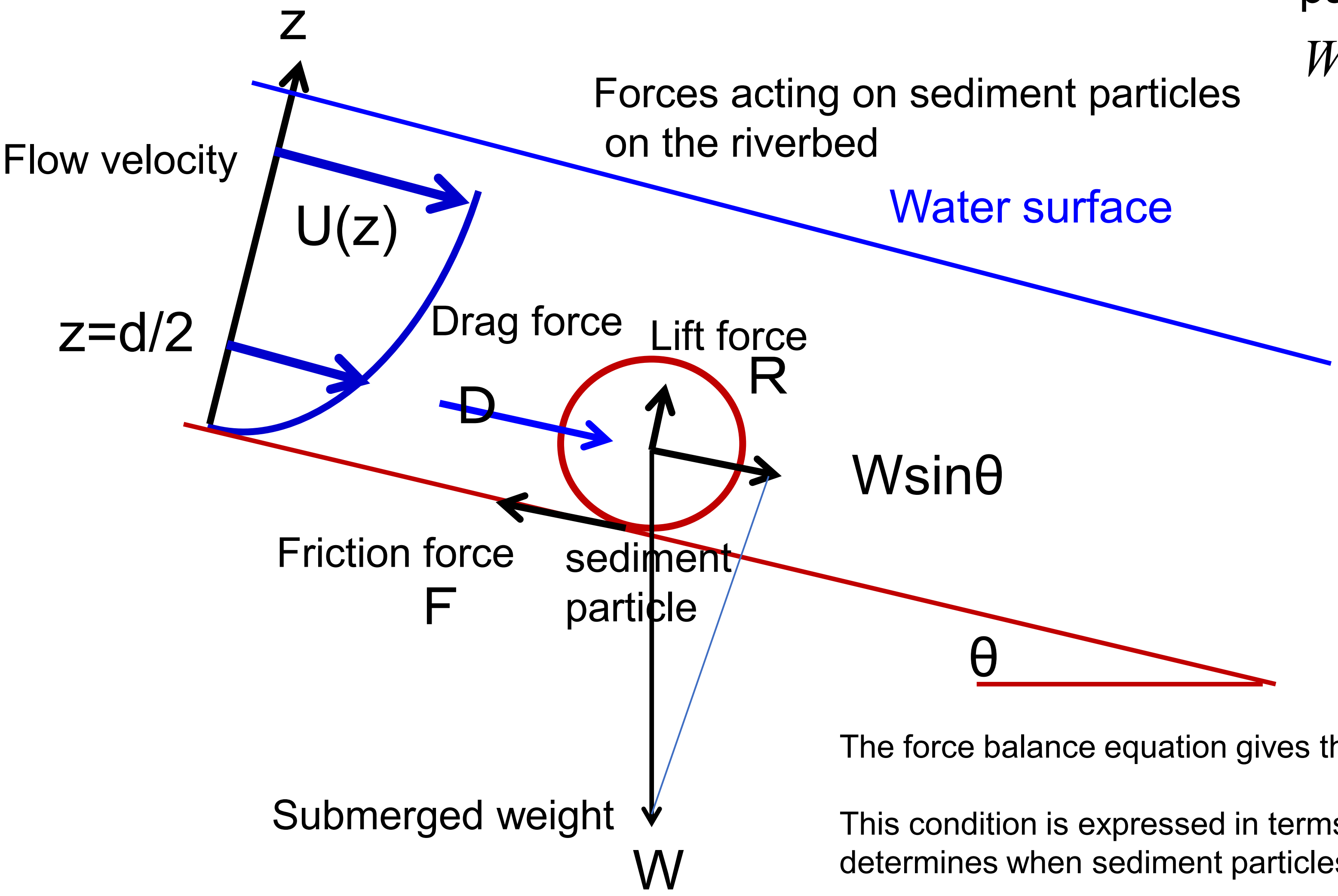
Fig.2

Motion form of gravel particles –suspension

It separates from the riverbed and flows down while being taken into the water.
(Floating sand) and returns to the riverbed.

Repeating this movement acts as a transporter of fine sand.

1.Fundamentals of Sediment transport
2)Introduction to Sediment Transport Dynamics



Balance of forces acting on gravel particles

$$W\sin\theta + D - F = 0 \quad (6)$$

$$W = \rho\left(\sigma/\rho - 1\right)g \cdot A_3 d^3$$

$$F = \mu_s \cdot W\cos\theta$$

$$D = \frac{1}{2} C_D \rho U_{z=d/2}{}^2 \cdot \varepsilon_0 A_2 d^2$$

$$U_{z=d/2} = u_* \cdot A_*$$

ρ: water density
σ: gravel density
d: sediment diameter
A2, A3:Shape coefficient of gravel
(A2 = π / 4, A3 = π / 6)
ε0: shielding coefficient
C_D: drag coefficient

The force balance equation gives the condition for incipient sediment motion.

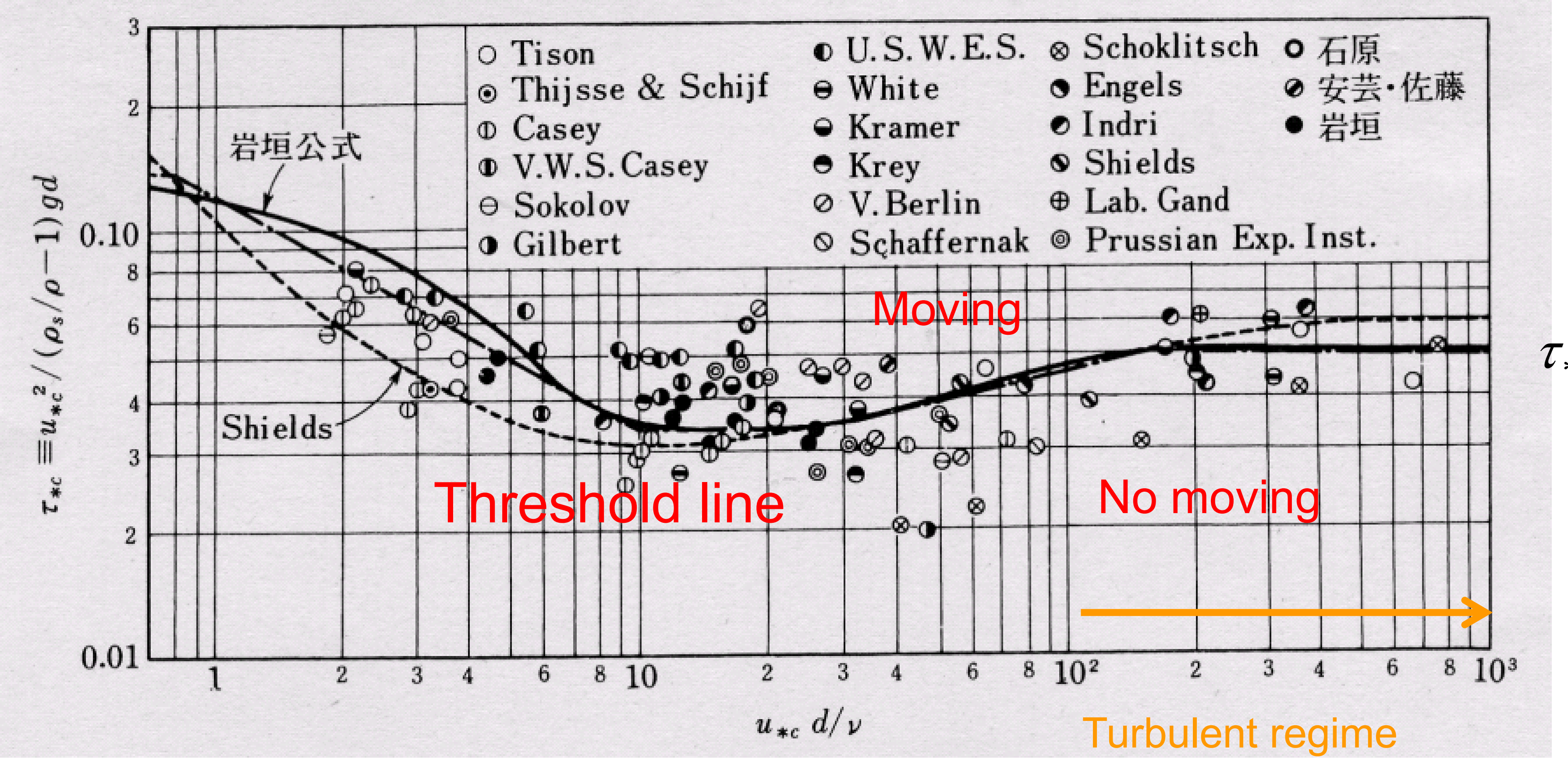
This condition is expressed in terms of the critical dimensionless shear stress, which determines when sediment particles on the riverbed begin to move.

critical dimensionless shear stress,
critical Shields parameter

$$\tau_{*c} \equiv \frac{u_{*c}{}^2}{\left(\sigma/\rho - 1\right)gd} = \frac{4}{3}\frac{\mu_s}{\varepsilon_0}\frac{1}{C_D A_*{}^2}\left(\cos\theta - \frac{1}{\mu_s}\sin\theta\right) = \frac{4}{3}\frac{\mu_s}{\varepsilon_0}\frac{1}{C_D A_*{}^2} \quad (7)$$

(When θ is small)

Shields diagram and Iwagaki's formula for critical tractive force



$\tau_{*c} = 0.05$

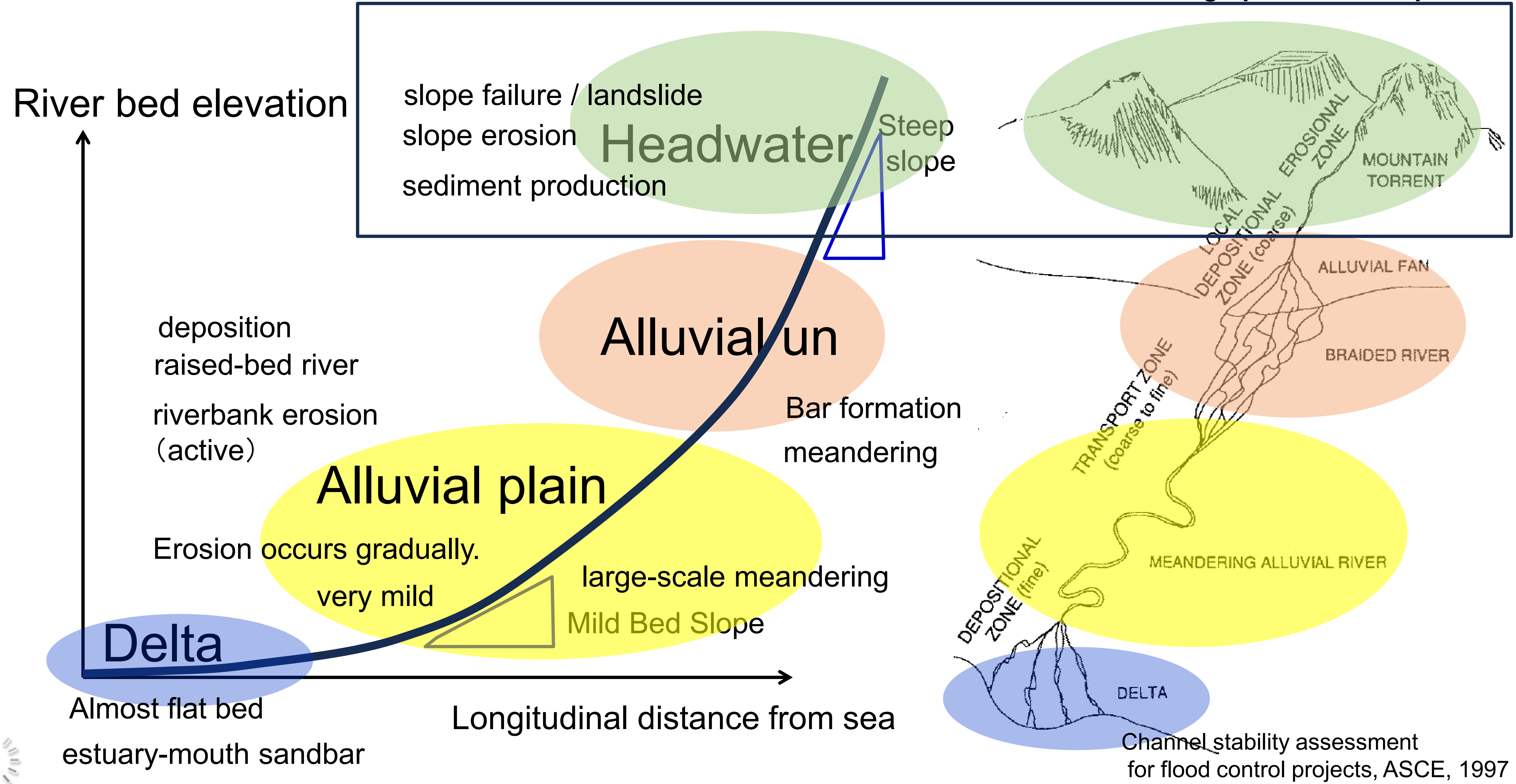
Turbulent regime
(inertia forces dominate)

$$\tau_{*c} \equiv \frac{u_{*c}^{2}}{(\sigma/\rho-1)gd} \cong 0.05 \qquad (8)$$

2.Debris flow disaster

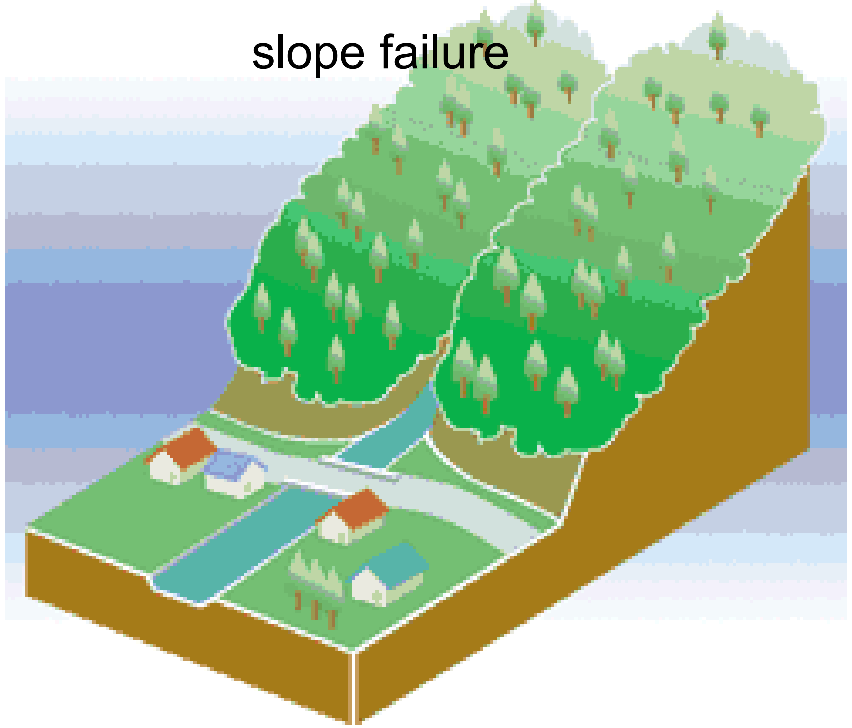
1) Mechanics of Slope Failure and Debris Flows

Water flows from high places to low places.



Channel stability assessment for flood control projects, ASCE, 1997

2.Debris flow disaster
1) Mechanics of Slope Failure and Debris Flows



Debris-flow velocity: 3.8 m/s

August 3, 1976, Mt. Yakedake (DPRI, Kyoto University / Matsumoto Sabo Office, Ministry of Construction)

July 2014, Nagiso Town, Kiso District, Nagano Prefecture, Japan

2.Debris flow disaster
1) Mechanics of Slope Failure and Debris Flows

When the pores between soil particles become saturated with water, buoyancy develops, reducing the effective vertical stress. This is one of the mechanisms that can trigger shallow landslides during heavy rainfall.

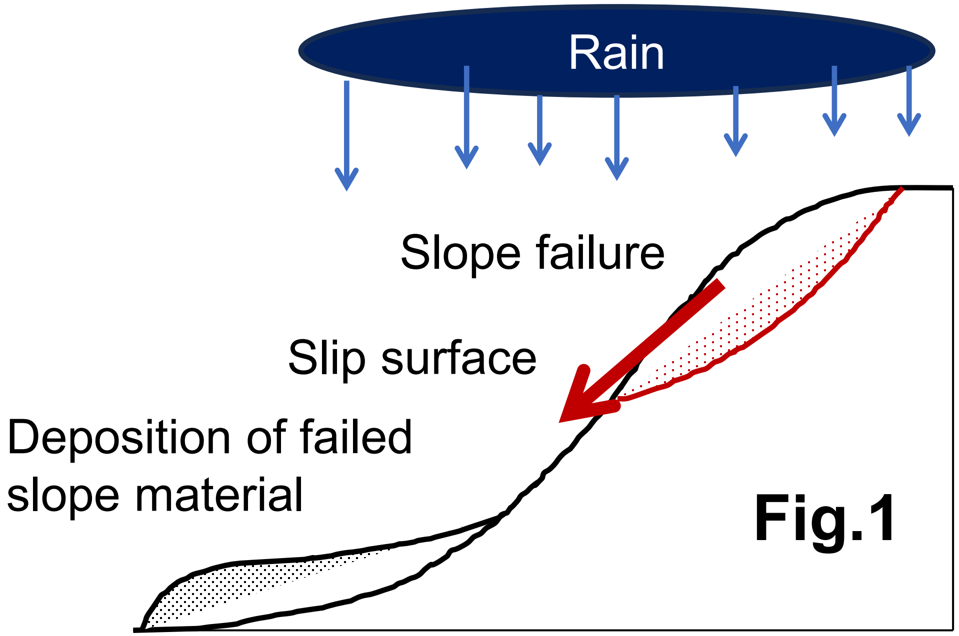


Fig.1

Condition for sliding

$$F = \frac{Resisting\ force}{Driving\ force} = \frac{\mu N + cL}{W \sin\theta} = \frac{\tan\phi \cdot W\cos\theta + cL}{W\sin\theta} < 1 \qquad (9)$$

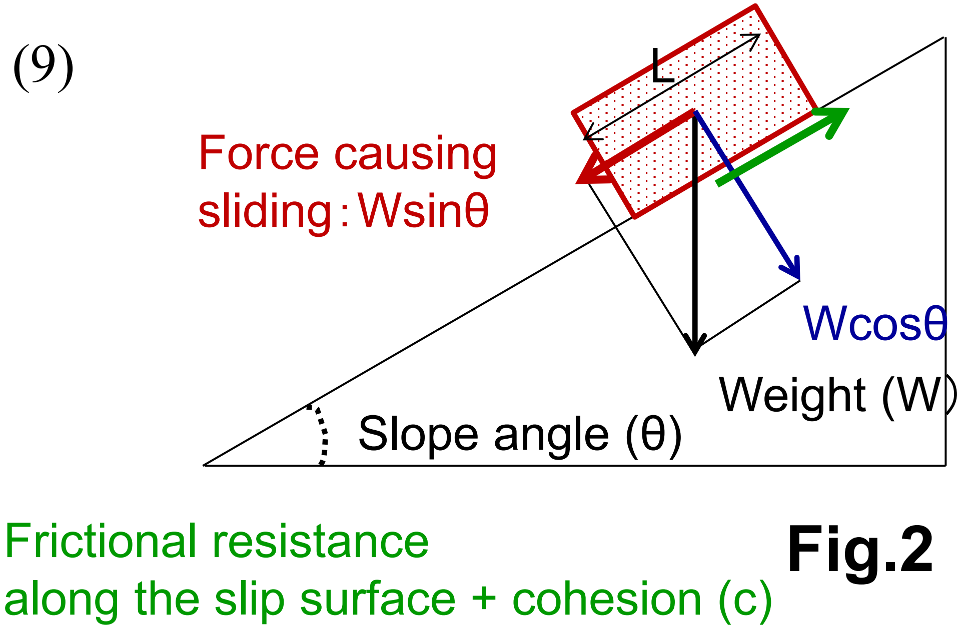
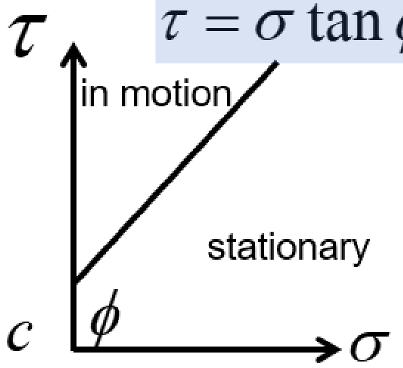


Fig.2

Internal friction angle and cohesion

$$\tau = \sigma \tan\phi + c$$

Fig.3



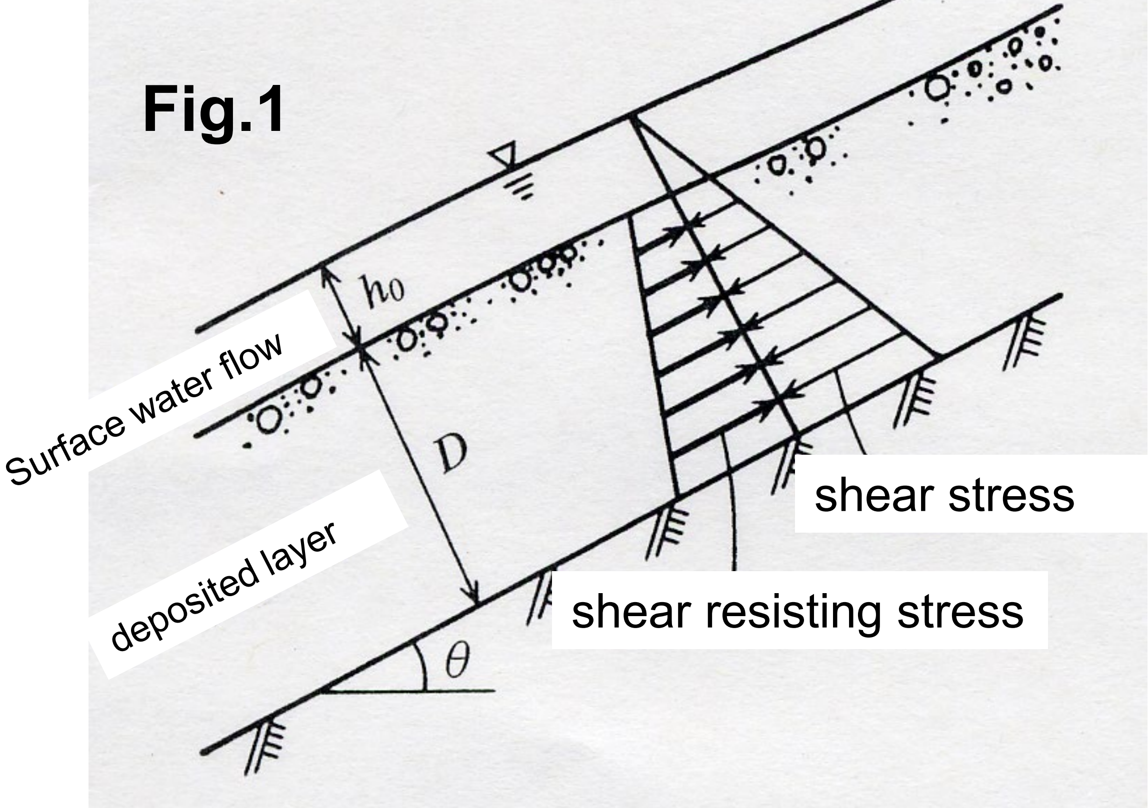
Φ:Internal friction angle

C:cohesion

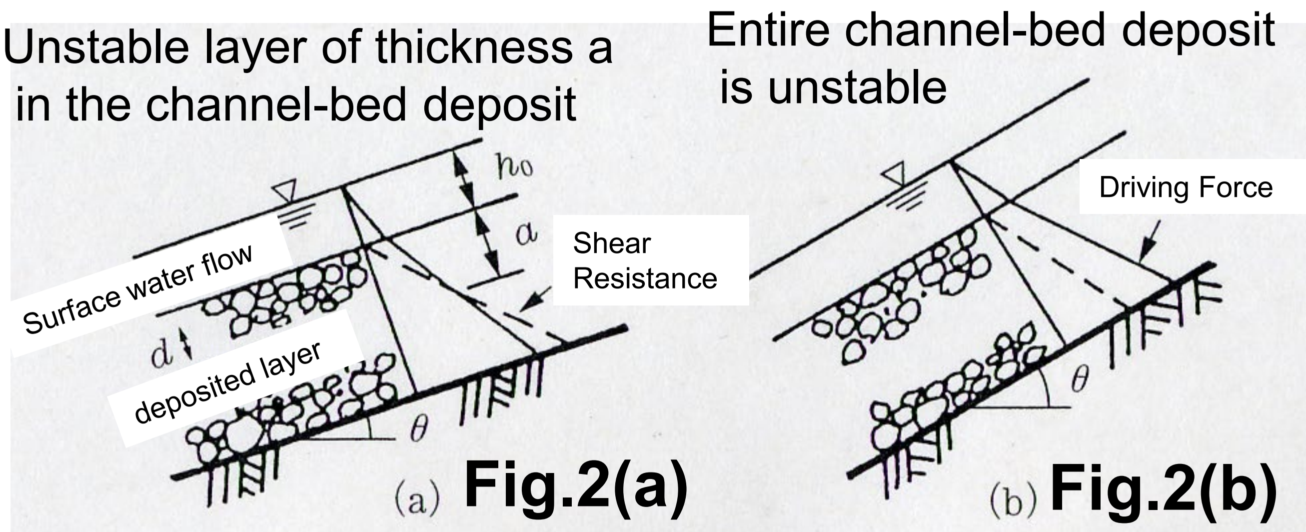
2.Debris flow disaster

1) Mechanics of Slope Failure and Debris Flows

Driving Force and Resisting Force of Debris Flow



Schematic diagram of Distribution of Driving(Shear stress) and Shear Resisting stress within the Bed deposited Layer(D)



Distribution of Driving and Resisting Forces within the Channel Bed deposit Layer

Shear stress at a depth a

$$\tau = g\sin\theta\left[C_*\left(\rho_s-\rho_w\right)a+\rho_w\left(a+h_0\right)\right] \quad (12)$$

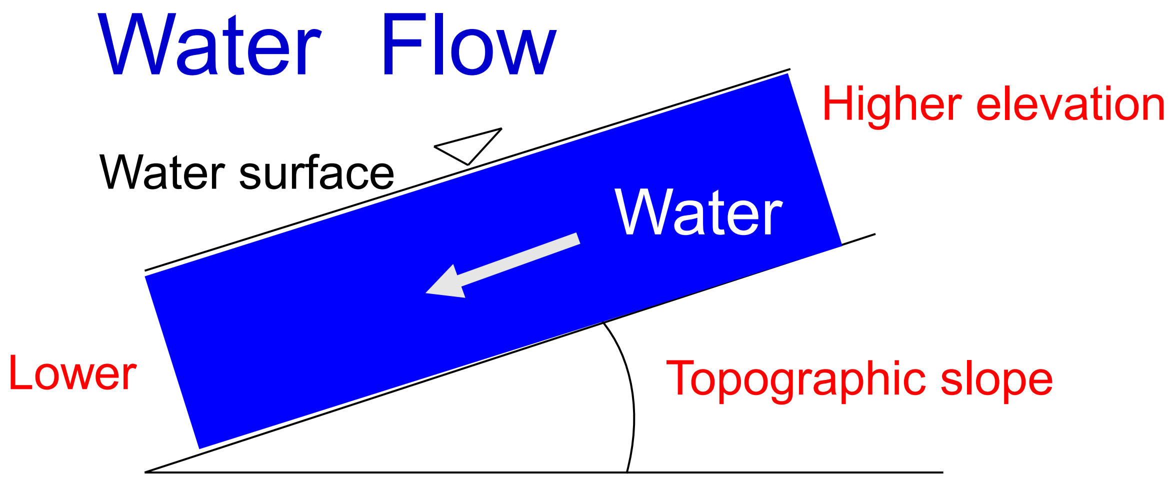
Shear resisting stress at the depth a

$$\tau_L = g\cos\theta\left[C_*\left(\rho_s-\rho_w\right)a\right]\tan\varphi + C \quad (13)$$

C_*:Sediment volume concentration in the deposited layer
Φ:Internal friction angle
C:cohesion
ρw, ρs: density of water and solid

2.Debris flow disaster
1) Mechanics of Slope Failure and Debris Flows

Differences between Water Flow and Debris Flow



Water flows from higher to lower elevations.

Even a slight difference in elevation can cause water to flow.

$$\tau_0 = \frac{1}{2} f \rho U^2 \quad (10)$$ f:Bed friction coefficient

$$U = \sqrt{\frac{2\tau_0}{f\rho}} = \sqrt{\frac{2\rho g h}{f\rho}}\sqrt{\sin\theta} = \sqrt{\frac{2gh}{f}}\sqrt{\sin\theta} \quad (11) \quad \because \tau_0 = \rho g h \sin\theta \quad (4)$$

2.Debris flow disaster

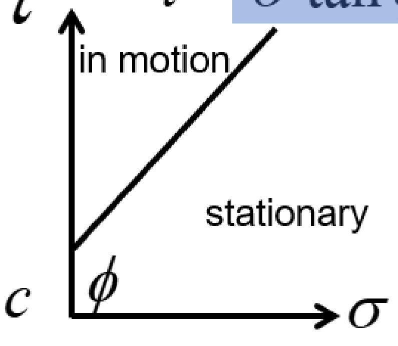
1) Mechanics of Slope Failure and Debris Flows

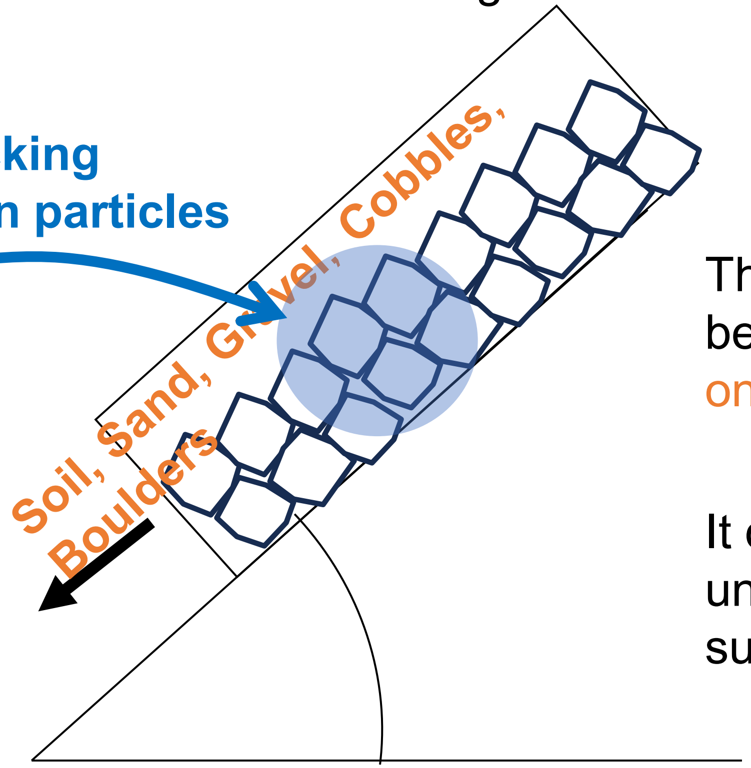
A mass of soil and gravel is more difficult to move than water.

interlocking between particles

Internal friction angle and cohesion

$$\tau = \sigma \tan\phi + c$$





The particles are difficult to move because they are interlocked with one another.

It does not begin to move unless the slope becomes sufficiently steep.

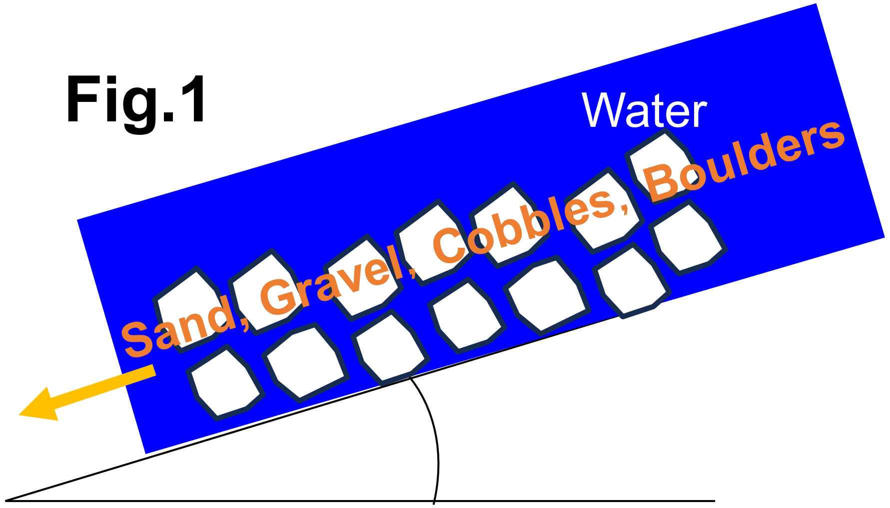
A mass of solid materials remains stationary until the slope reaches a certain critical value.

Downslope component of the weight of the mass > Resisting force of the mass (internal frictional resistance)

2.Debris flow disaster
1) Mechanics of Slope Failure and Debris Flows

Debris flow lies between these two types of flow.

Fig.1



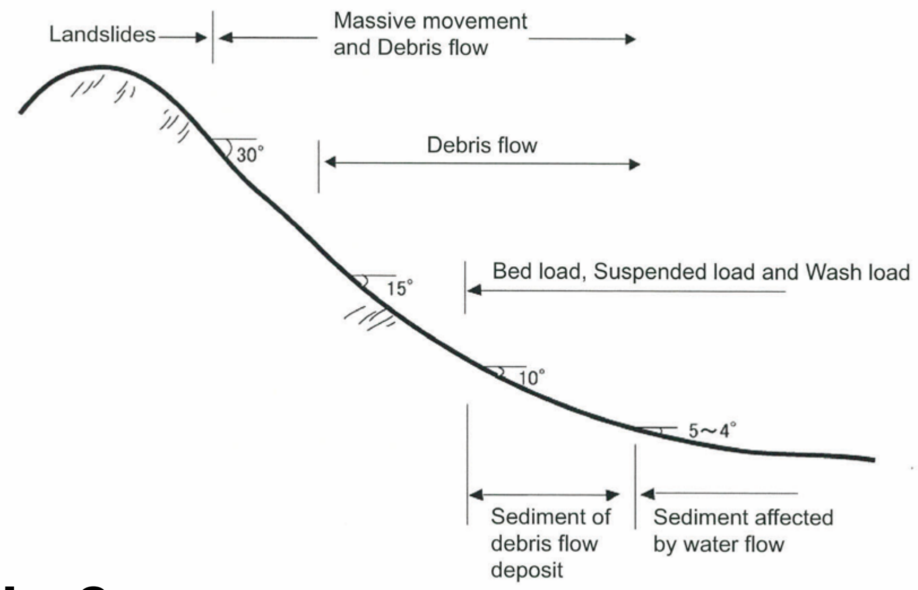


Fig.2

Sediment transport forms in drainage basins

A debris flow does not occur unless the slope exceeds a certain critical value.

These critical slopes depend on the grain-size composition of the sediment.

Mechanical Characteristics of Debris Flows

1. A debris flow is a mixture (continuum) of solid materials, such as soil, sand, gravel, and boulders, and water. It moves downslope under gravity as the driving force.
2. It is a flow phenomenon in which water plays an important role. This differs from slope failures and landslides, where a soil mass itself moves mainly by sliding or rotational motion.
3. However, the motion of a debris flow is quite different from that of water flow alone. Water can flow whenever there is a slope, whereas a debris flow cannot develop or continue to flow unless the slope exceeds a certain critical value.

2.Debris flow disaster
1) Mechanics of Slope Failure and Debris Flows

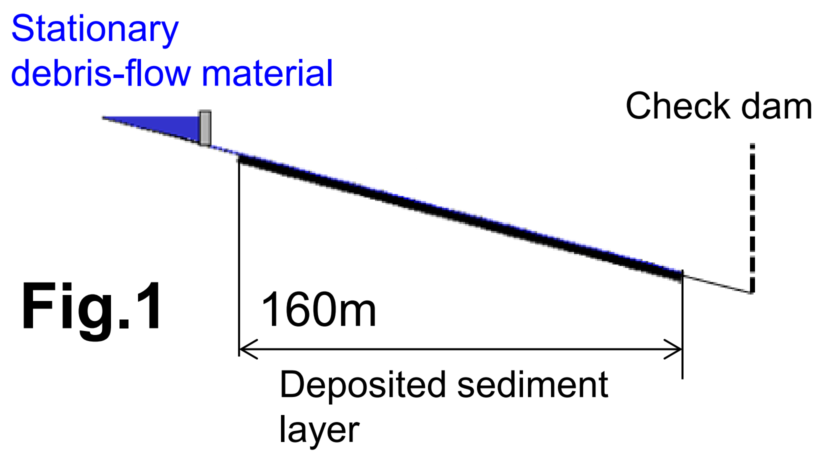


Fig.1

Distinct Element Method coupled with the unsteady 1D flow calculation.

Osada & Shimizu(2006)

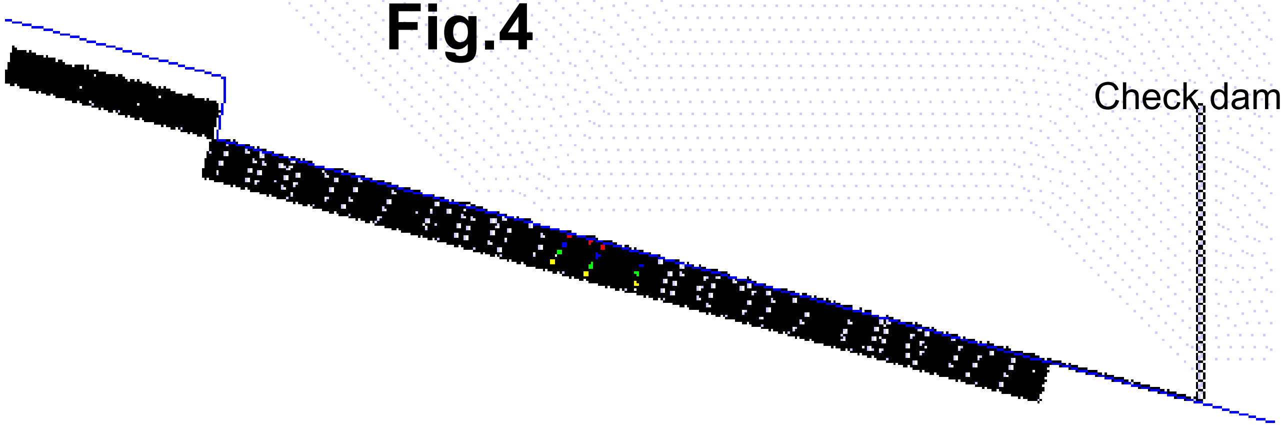


Fig.4

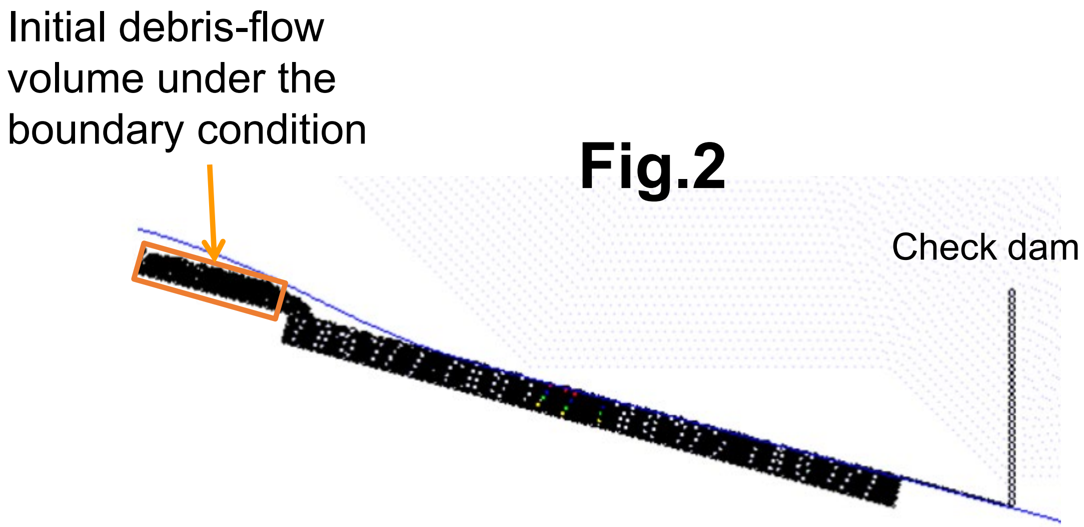


Fig.2

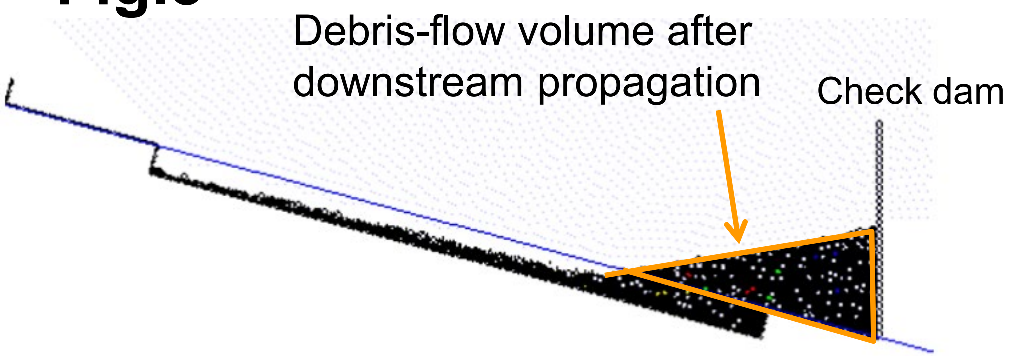


Fig.3

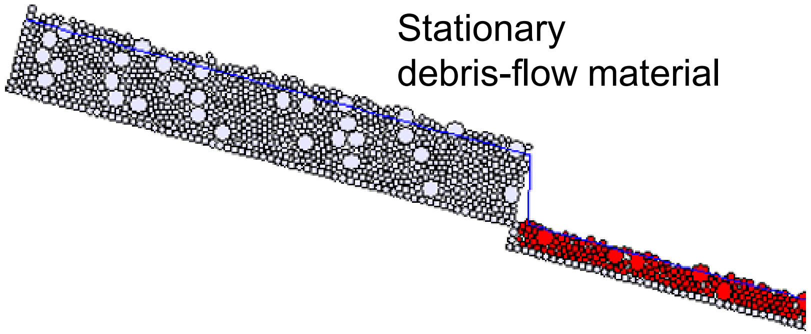
In this study, we focus such a process by using the proposed numerical simulation, which is composed of the particle-fluid multiphase flow analysis by using the Distinct Element Method coupled with the unsteady 1D flow calculation.

Debris flow disaster

1) Mechanics of Slope Failure and Debris Flows

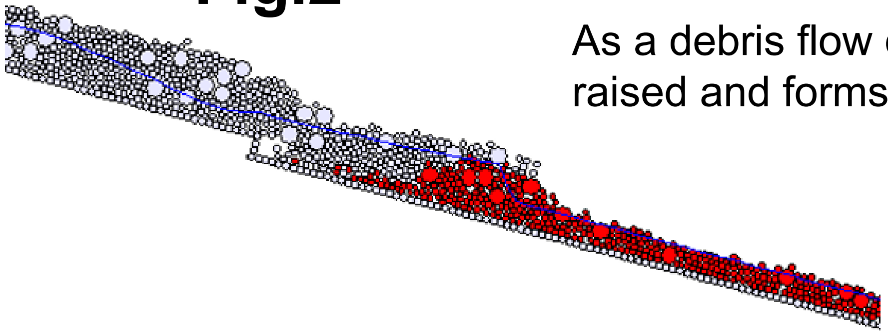
Osada & Shimizu(2006)

Fig.1



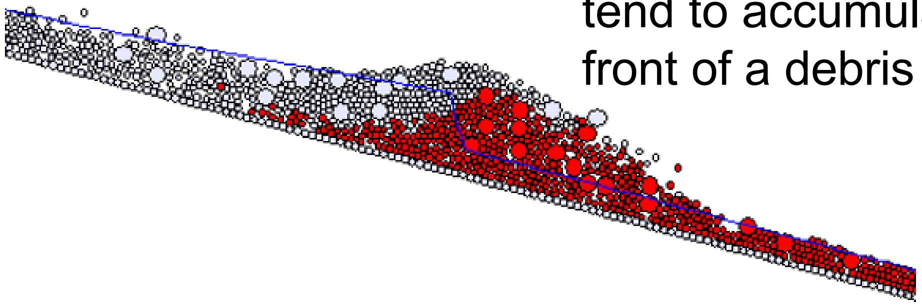
Stationary
debris-flow material

Fig.2



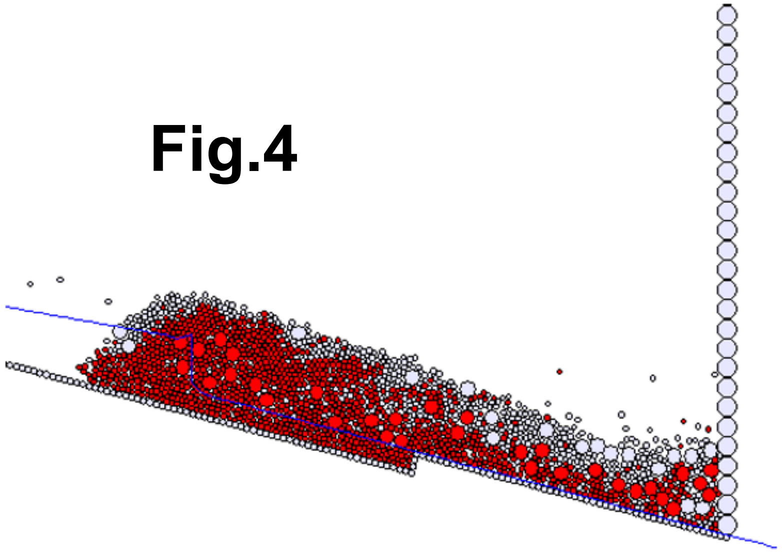
As a debris flow develops, its front becomes increasingly raised and forms a pronounced surge front.

Fig.3



Coarse sediment particles tend to accumulate at the front of a debris flow.

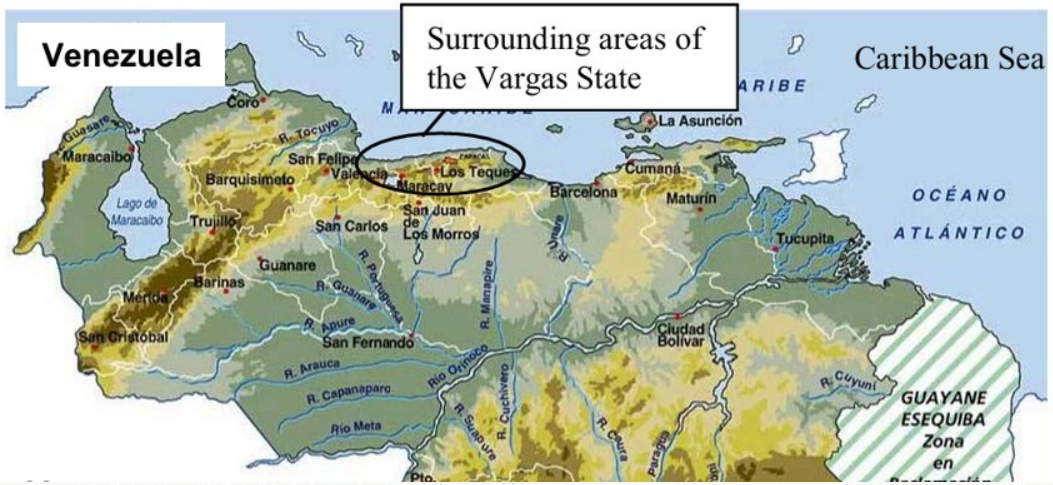
Fig.4

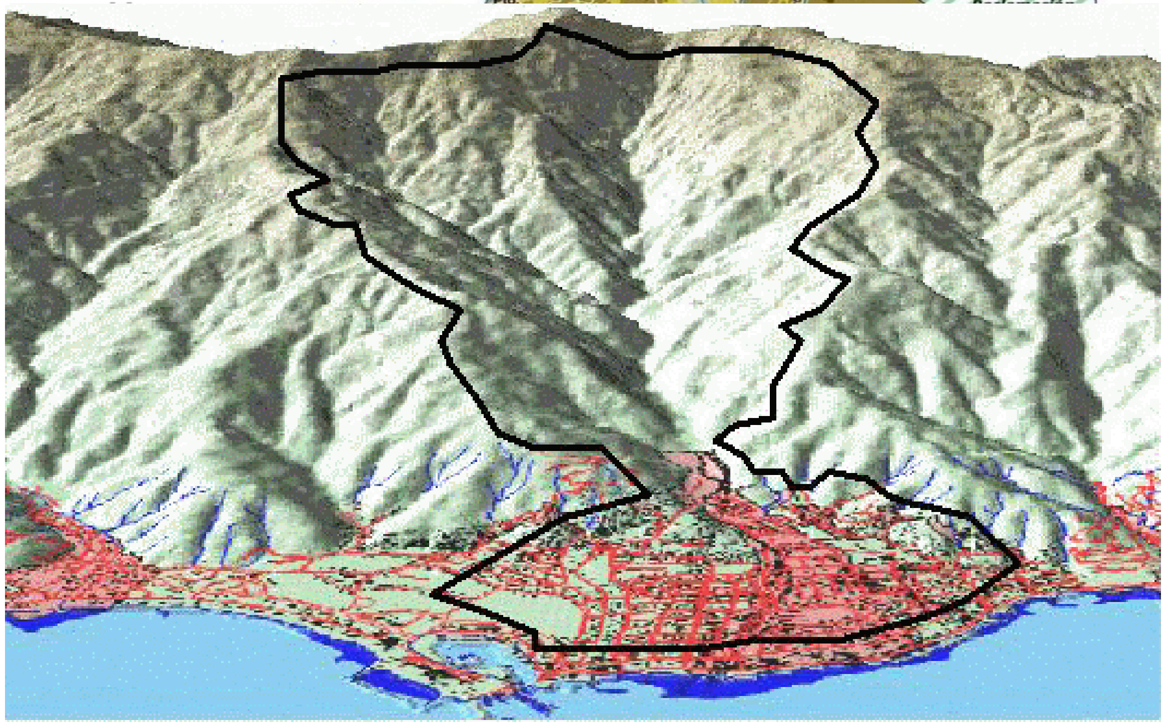


Debris flow disaster

2) Debris Flow Disasters and Countermeasures

December 1999 Venezuela Sediment Disaster
Estimated death toll: approximately 50,000





Topography and Land Use of the El Ávila Mountains and the San Julián Watershed, Vargas State, Venezuela

Debris flow disaster

2) Debris Flow Disasters and Countermeasures

Approximately 330,000 people affected

2.Debris flow disaster
2) Debris Flow Disasters and Countermeasures

Fig.1

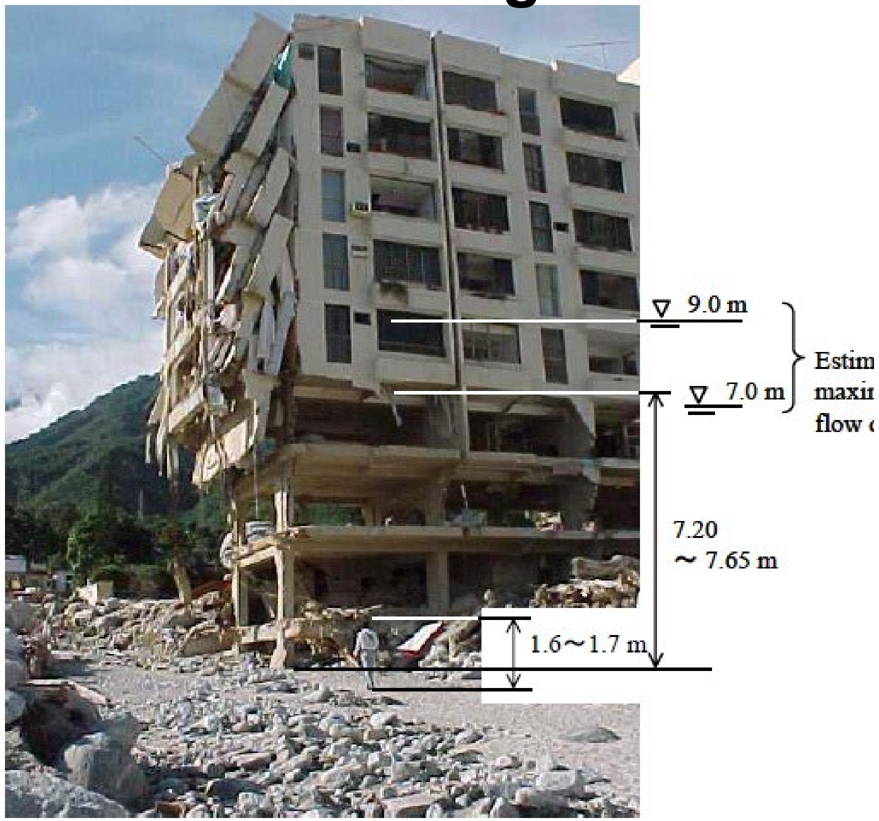


Photo 3 The damaged building and estimated maximum flow depth

Fig.2

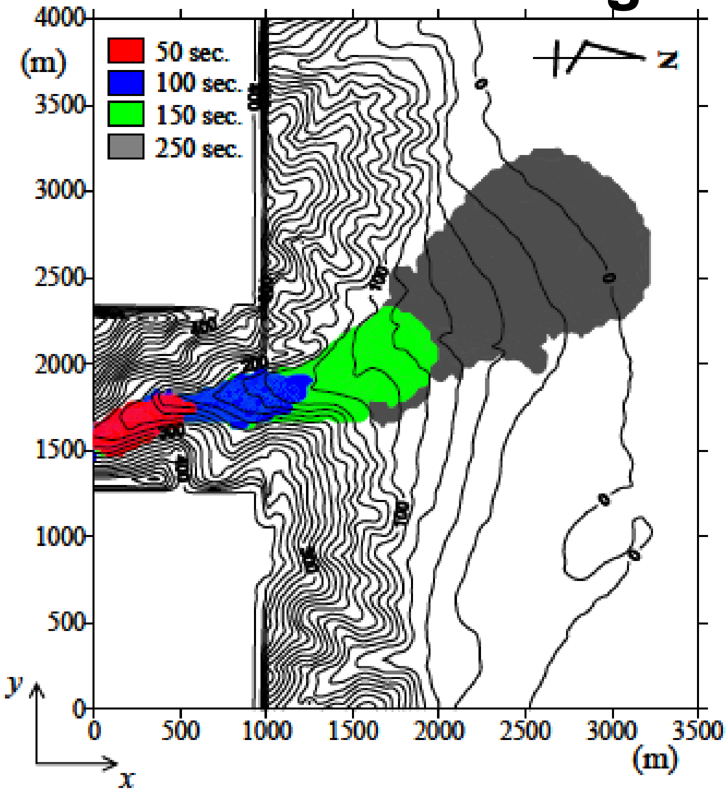


Fig. 5 Temporal spreading of debris flow at the alluvial fan

Fig.3

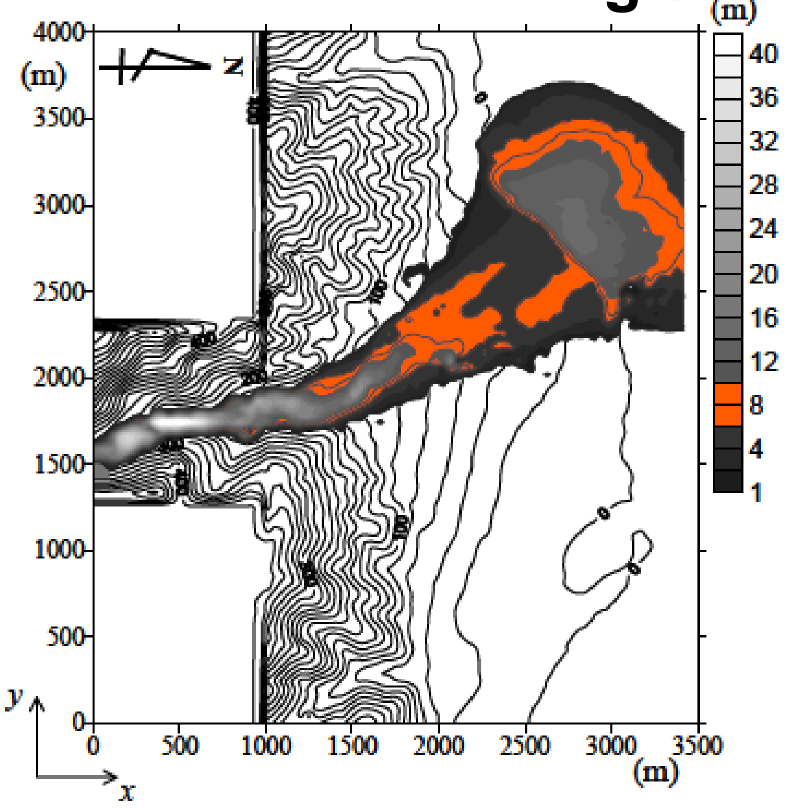


Fig. 6 Distribution of maximum flow depth in San Julian fan

Shinji Egashira and Takahiro Itoh(2004)

2.Debris flow disaster
2) Debris Flow Disasters and Countermeasures

Fig.1

https://www.kyosei-kk.co.jp/dcms_media/image/cbbo_26.jpg https://www.yomiuri.co.jp/bosai-nippon/biz-article/10608

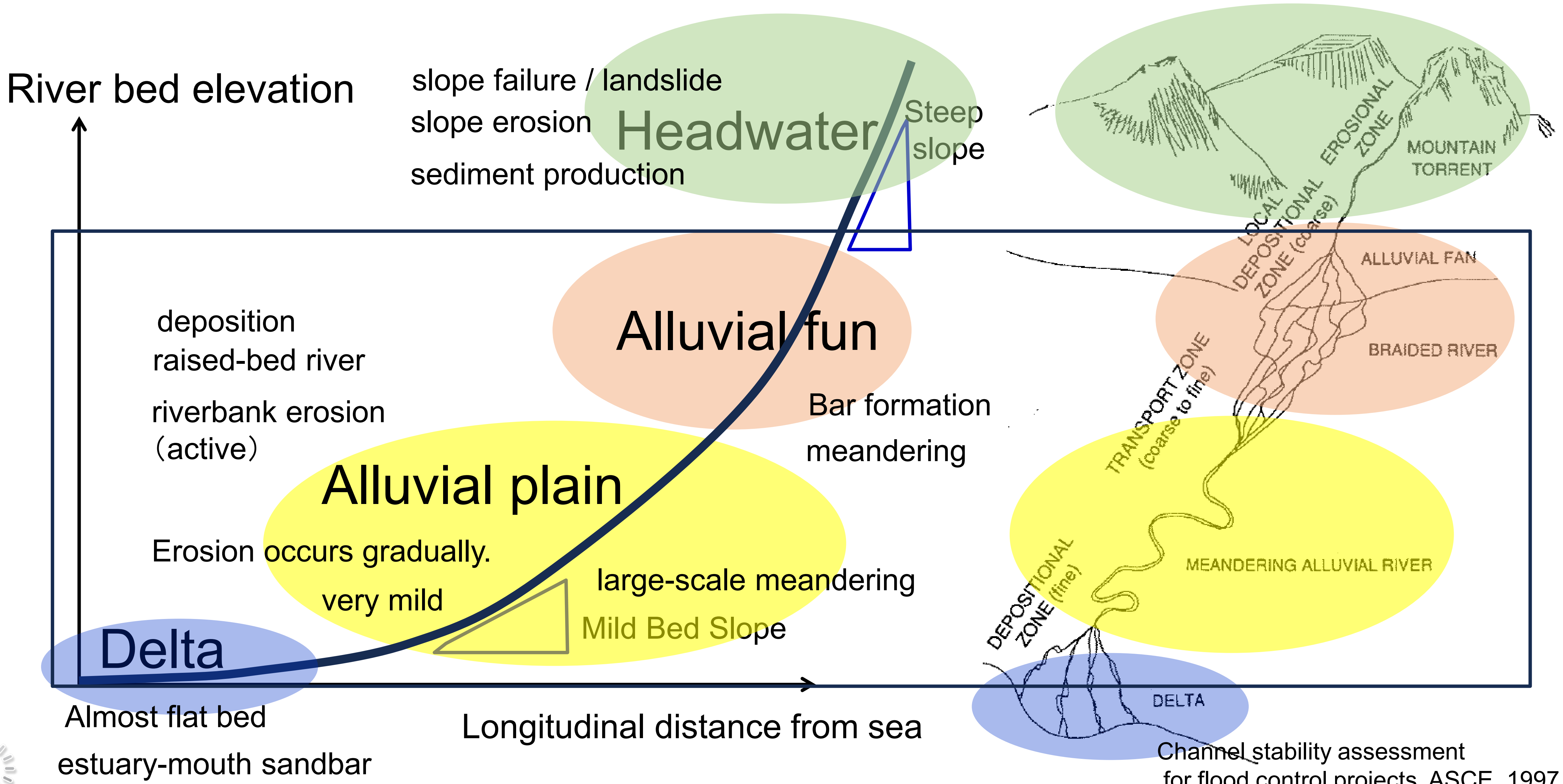
Fig.2a

Open-type Sabo dam

Allows water flow to pass through while trapping debris flows and driftwood.

3.Flood disasters caused by channel migration

Water flows from high places to low places.



Channel stability assessment
for flood control projects, ASCE, 1997

3.Flood disasters caused by channel migration
1) Channel meandering and bank erosion

Fig.2 Flood and sediment disaster in Hokkaido (2016)

Fig.1a,b
Flood and sediment disaster of River Seki in 1995

3.Flood disasters caused by channel migration

2) Alternate bars, low-flow channel meandering, and bank erosion

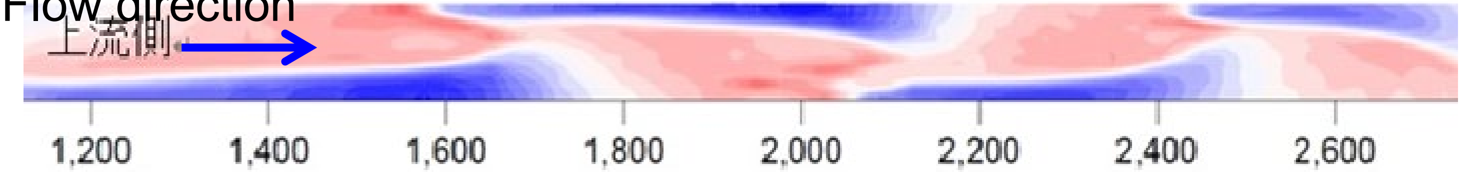
Alternate bars

The river topography where sand bars are alternately formed along the left and right banks is called alternate sand bars.

Fig.1

Difference in height of bed revel

Fig.2



Alternate sand bar topography from computer simulation

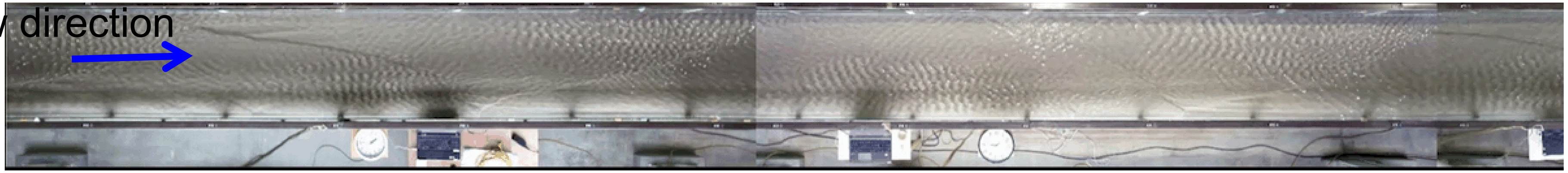


Fig.3

https://i-ric.org/yasu/nbook2/06_Chapt06.html

3.Flood disasters caused by channel migration
2) Alternate bars, low-flow channel meandering, and bank erosion

Alternate bars develop in a channel of constant width. The topography of the alternate bars induces a meandering flow pattern, which causes bank erosion.

Formation of alternate bars → Meandering flow → Bank erosion

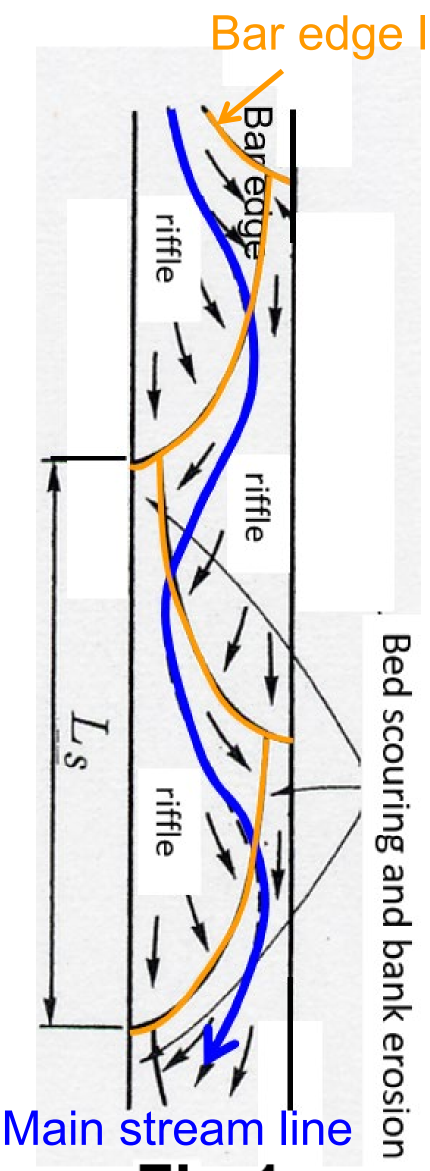


Fig.1

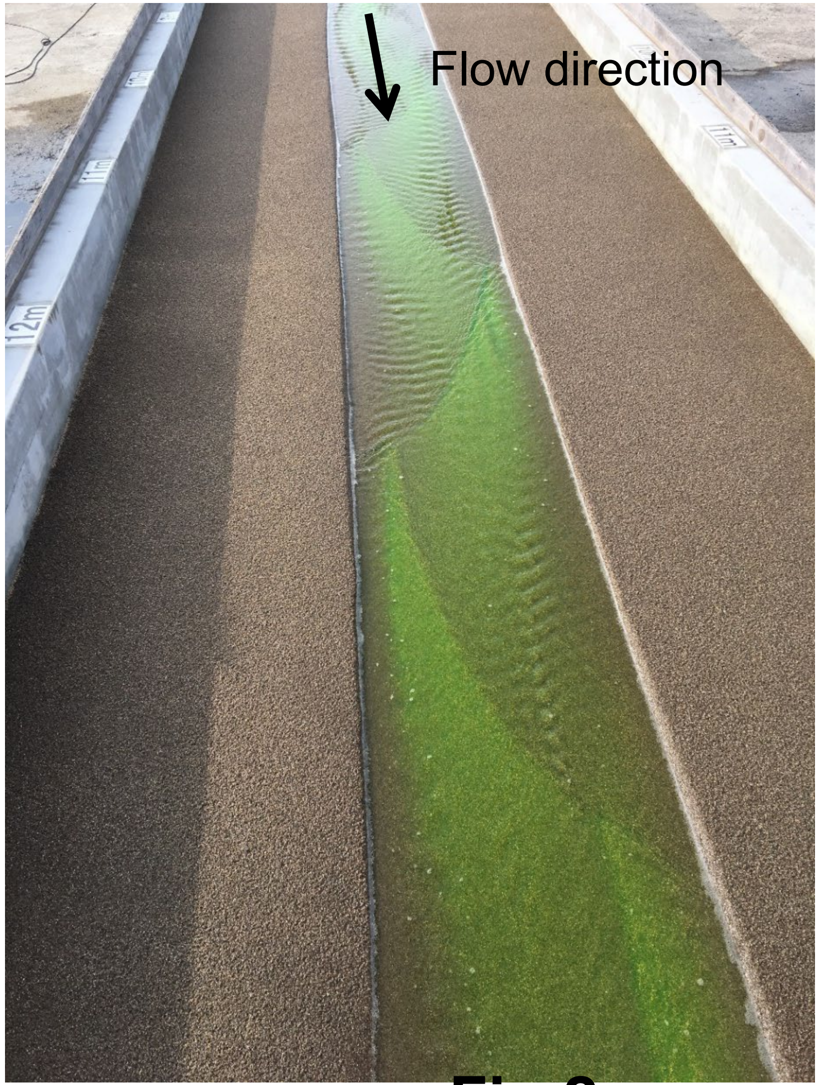


Fig.2

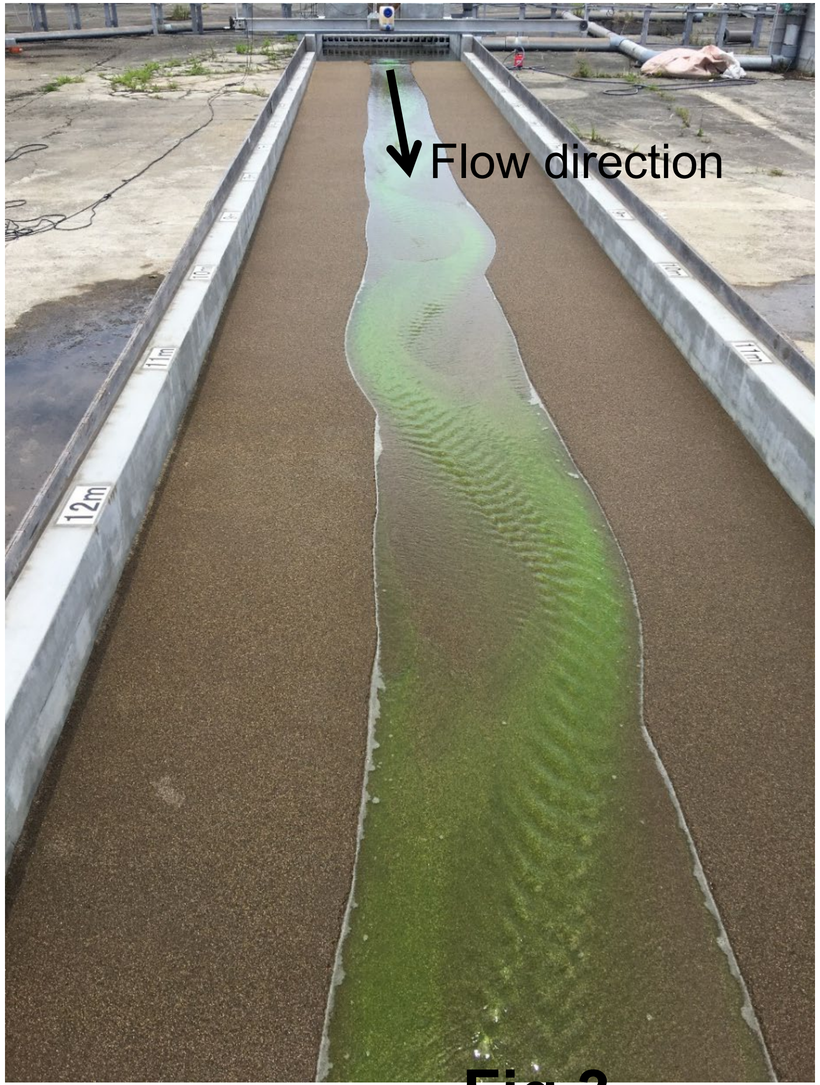


Fig.3

3.Flood disasters caused by channel migration
2) Alternate bars, low-flow channel meandering, and bank erosion

Development of a meandering channel investigated by experiments

3.Flood disasters caused by channel migration
3) Bank erosion control measures

How to control river bank erosion?

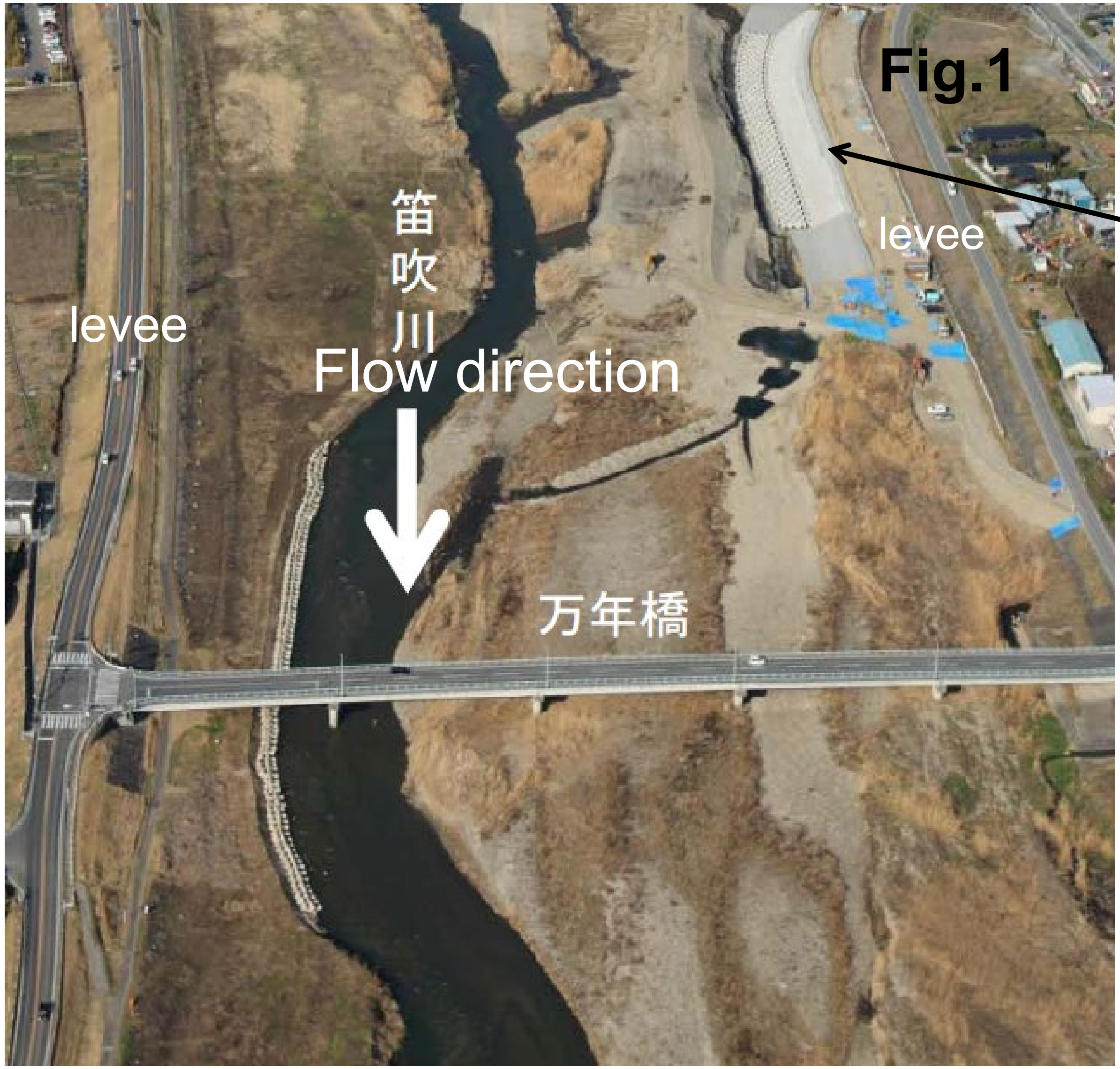


Fig.1

Meandering formation originated by Alternate bars

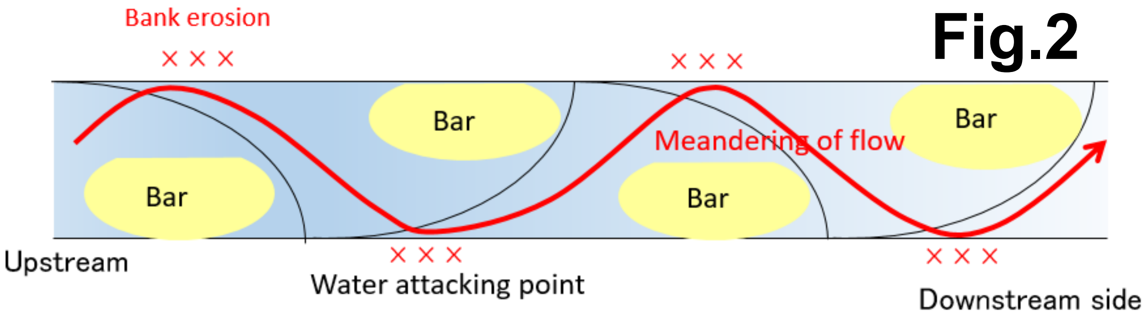


Fig.2

Protection of riverbank erosion areas

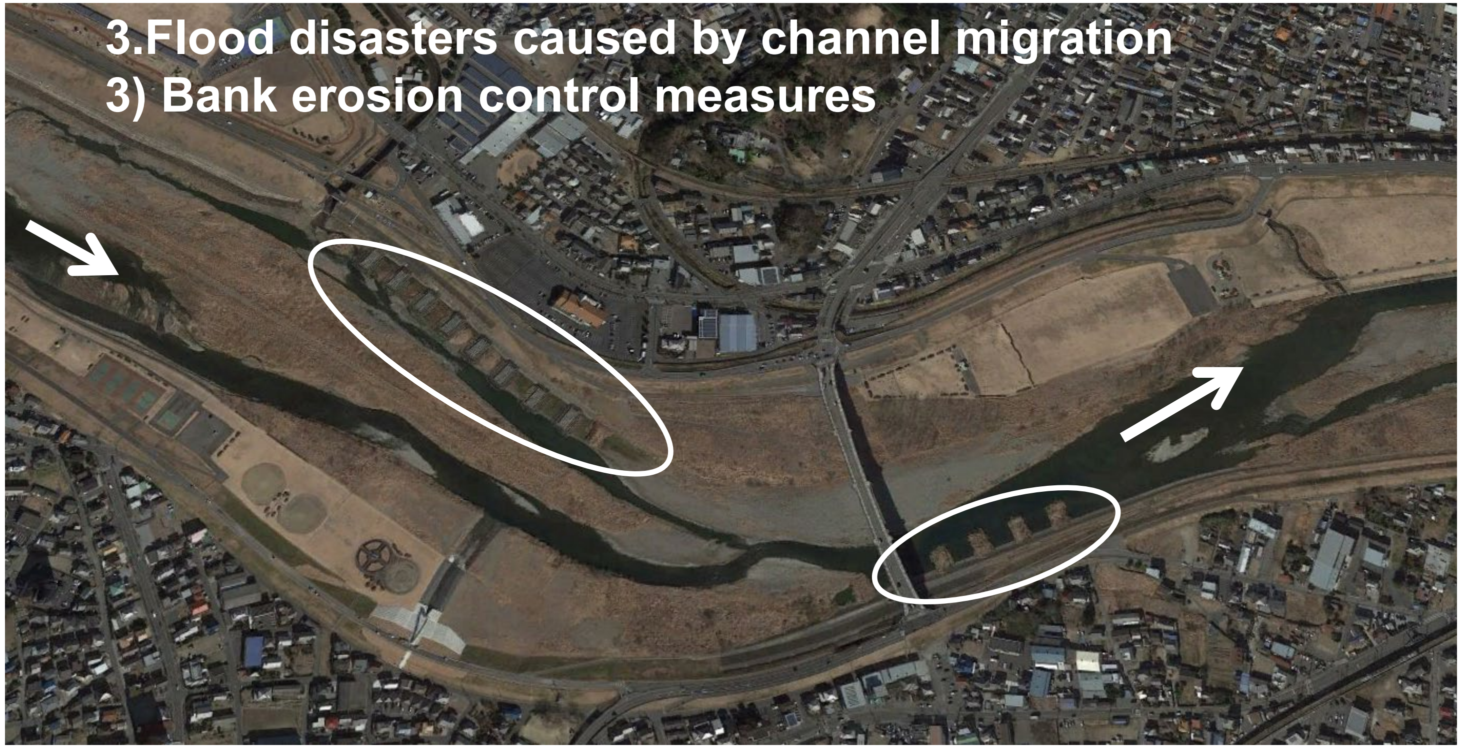

Fig.3a


Fig.3b

3.Flood disasters caused by channel migration
3) Bank erosion control measures

A groyne is a structure that projects into a river at an angle from the riverbank to control the flow of water.

3.Flood disasters caused by channel migration
3) Bank erosion control measures



Effects of dike: Roughness effect that creates an obstacle to the water flow, and "splash effect" that changes the water flow direction