Seepage failure of sand in three dimensions -Experiments and numerical analyses-

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2. Three dimensional experiments
3. Experimental results
4. Axisymmetric modeling of three-dimensional seepage flow
5. Conclusions

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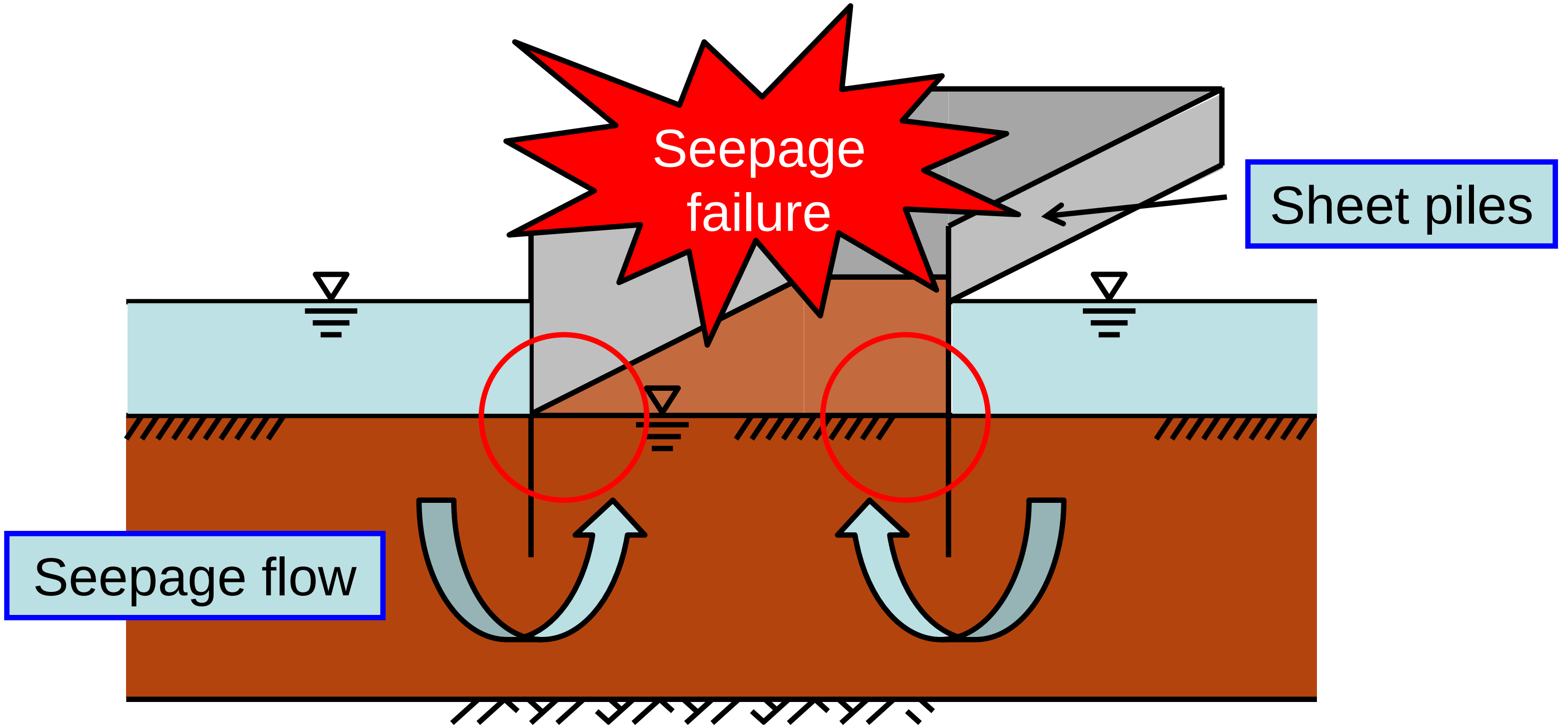
Introduction

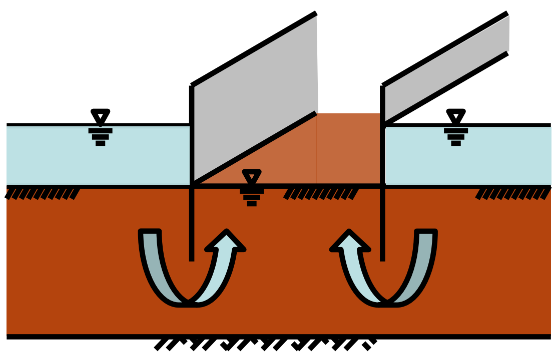
- In excavations of soil with a high ground water level, seepage failure is often a problem.



Introduction

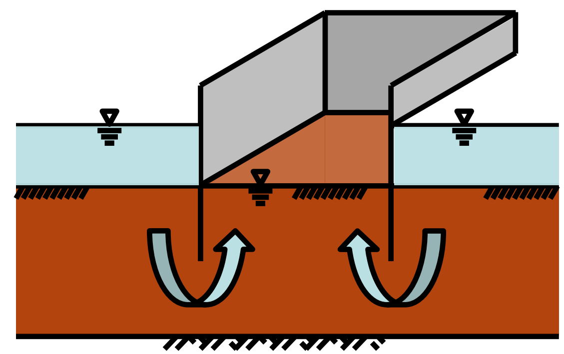
- The three-dimensionally concentrated flow lowers the safety factor for seepage failure more than the two-dimensional condition.

Two-dimensional condition



Depth

Three-dimensional condition



Depth

- The 3D analyses are hard task.

Introduction

- Seepage failure experiments under three dimensional flow conditions

  ⇨ To clarify the seepage failure mechanism.

- The axisymmetric modeling of three-dimensional seepage flow

  ⇨ To analyze easily.

Contents

Test apparatus

Water tank

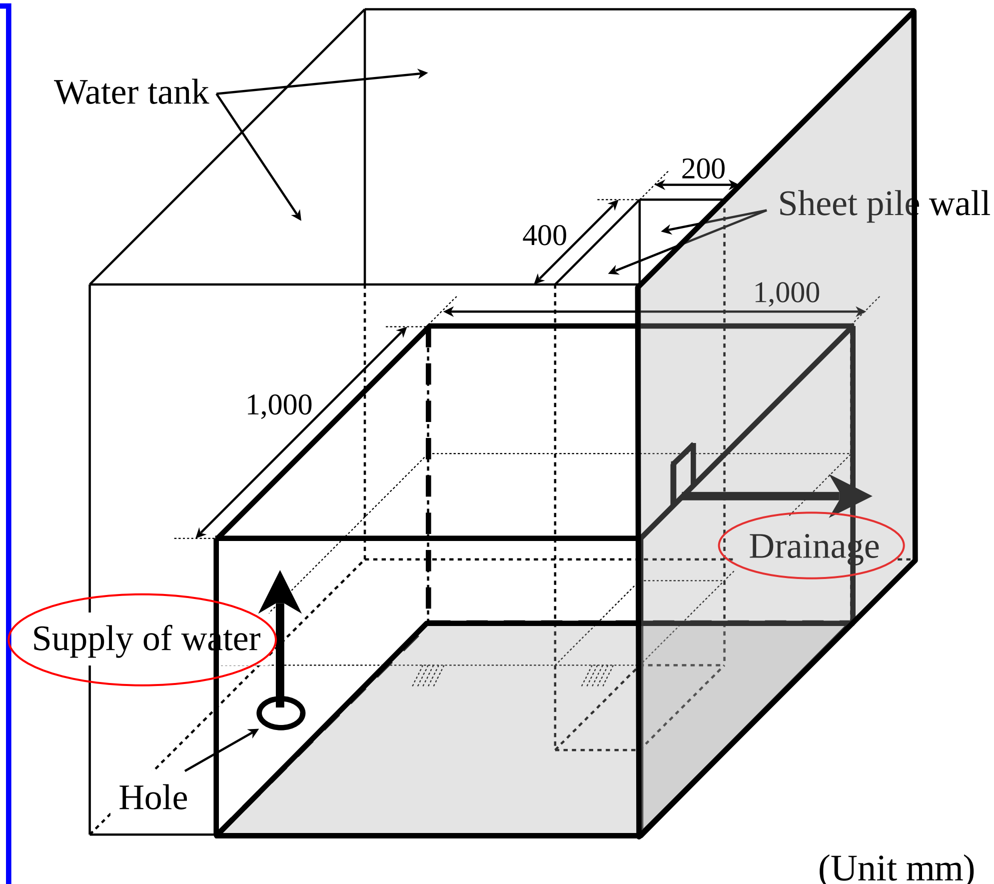
1,000mm wide, 1,300mm high
1,000mm deep

Constant-head device

The upstream water level kept constant by the constant-head device

Open piezometers

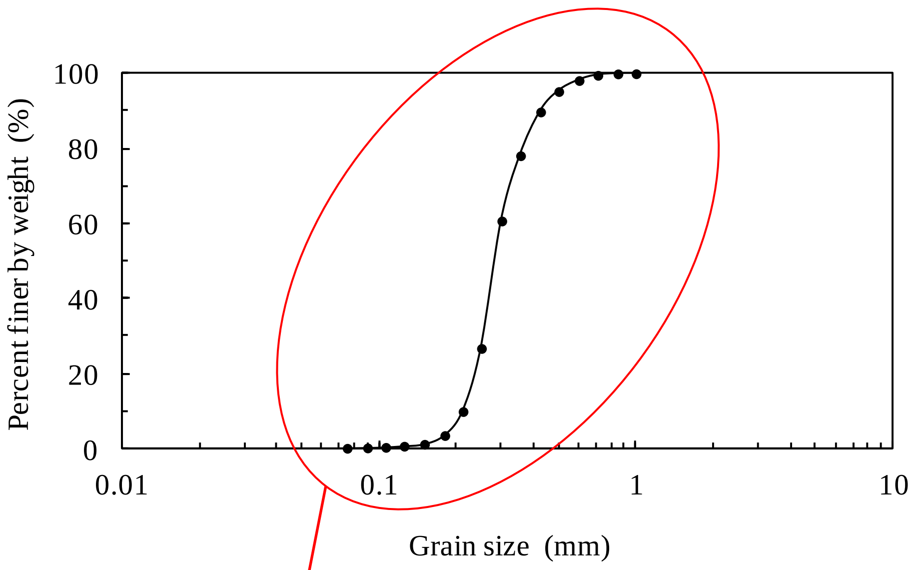
Pore water pressures can be read from 320 open piezometers



One quarter of three dimensional region

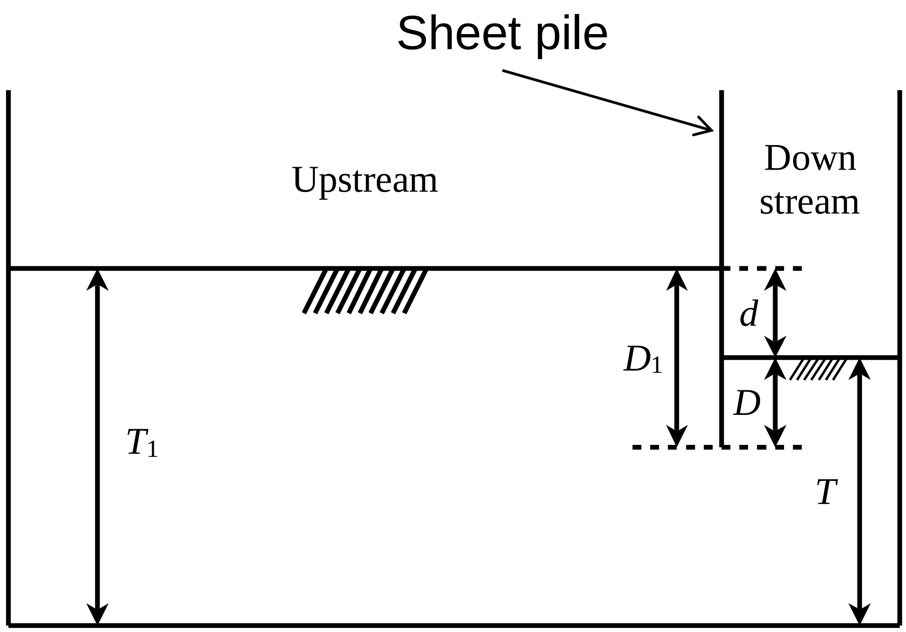
Test materials

Physical properties	Lake Biwa Sand 3
G_s	2.67
U_c	1.40
D_{50}(mm)	0.283
D_{max}(mm)	0.850
e_{max}	1.12
e_{min}	0.761
k_{15}(×10^{-4}m/s)	7.26



Uniform and fine sand

Notation



D , D_1 : Penetration depth of sheet piles on downstream and upstream side

T , T_1 : Depth of soil on downstream and upstream side

D/T : Penetration ratio of sheet piles

Series of test-sand model

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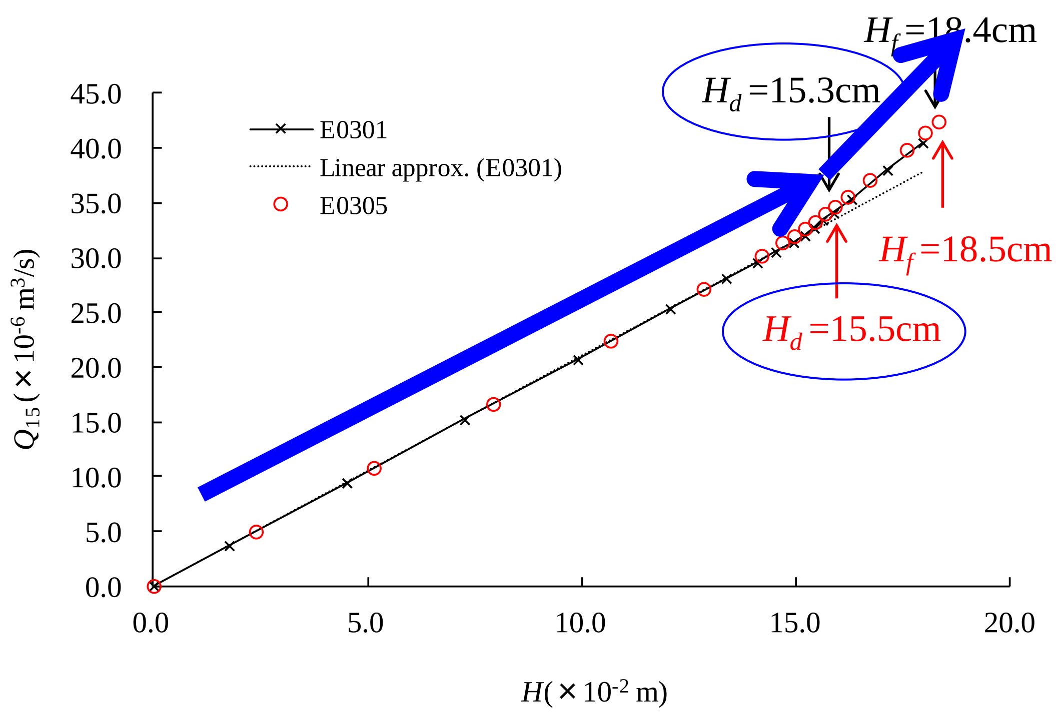
H-Q_{15} curve and reproducibility of experiments



H_d : Hydraulic head difference at an abrupt change of discharge

H_f : Hydraulic head difference at failure

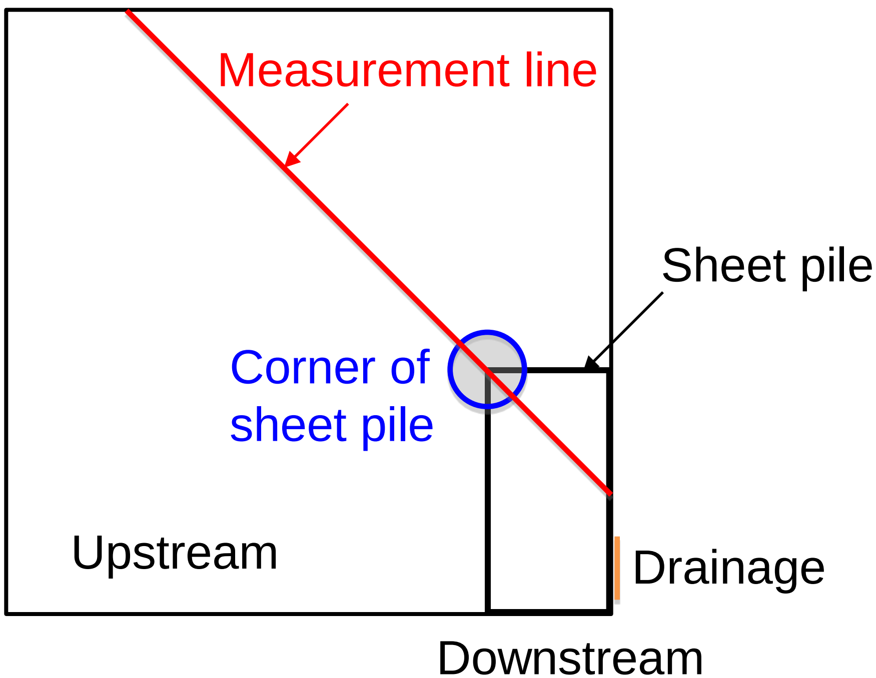
Q_{15} : Discharge

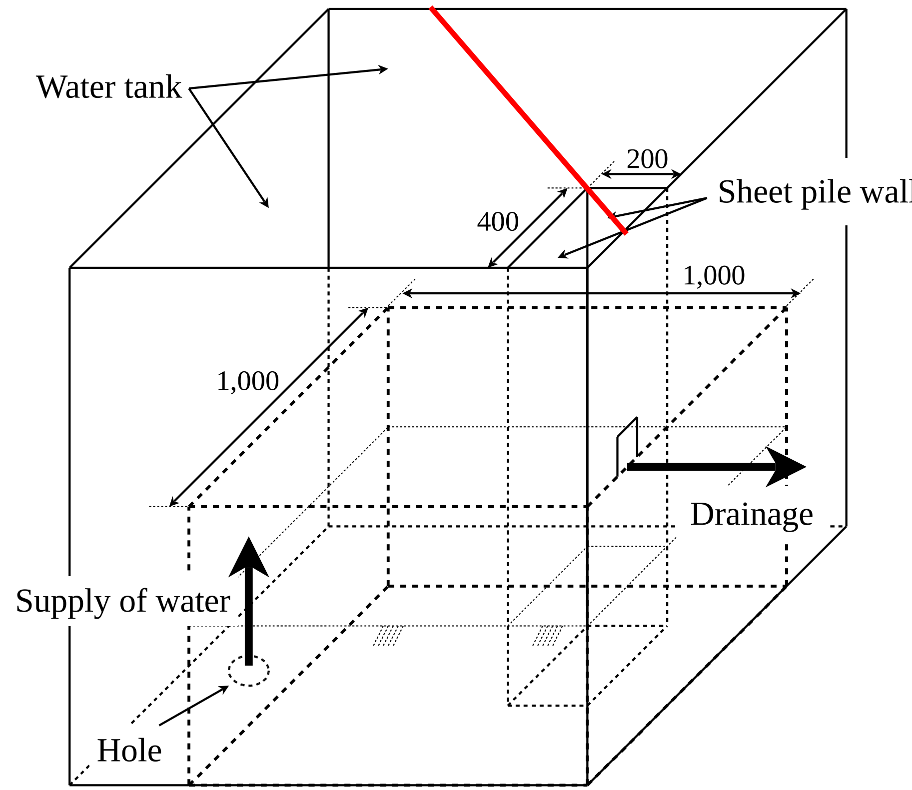
Both test results are best-fitting.

The reproducibility of experiments is verified.

- The soil loosens, the void space enlarges, and permeability of the soil grows larger.

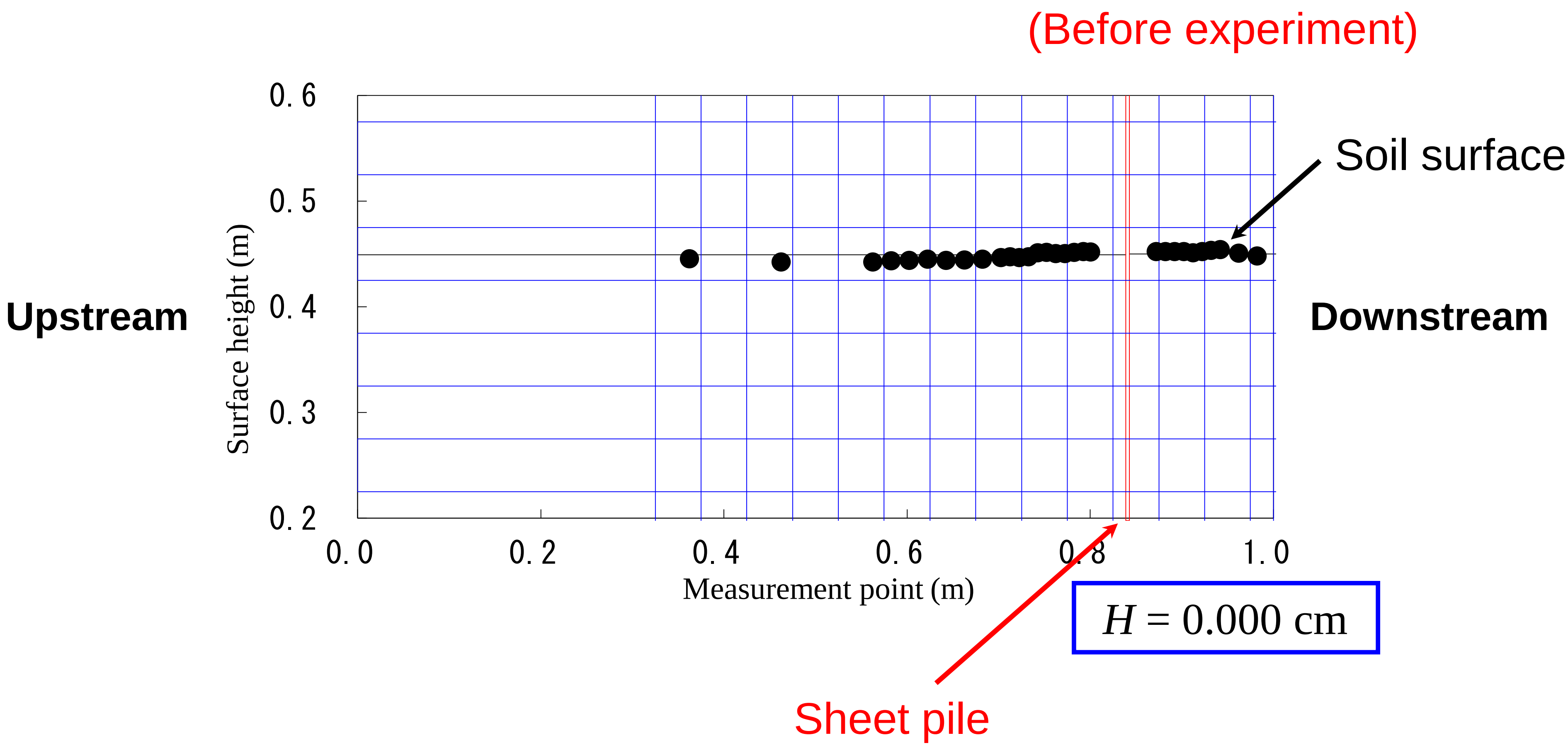
Change in shapes of soil surface



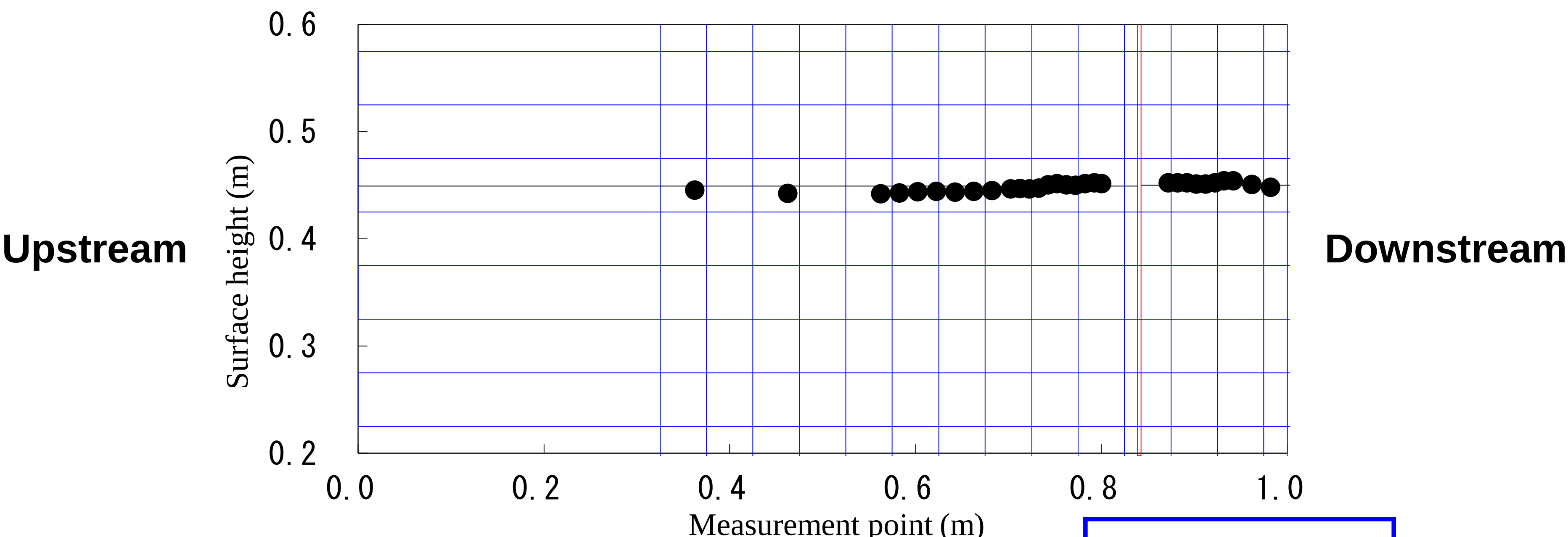


- The heights of the soil surface were measured along the red line. (upstream: ultrasonic, downstream: light wave)

Change in shapes of soil surface



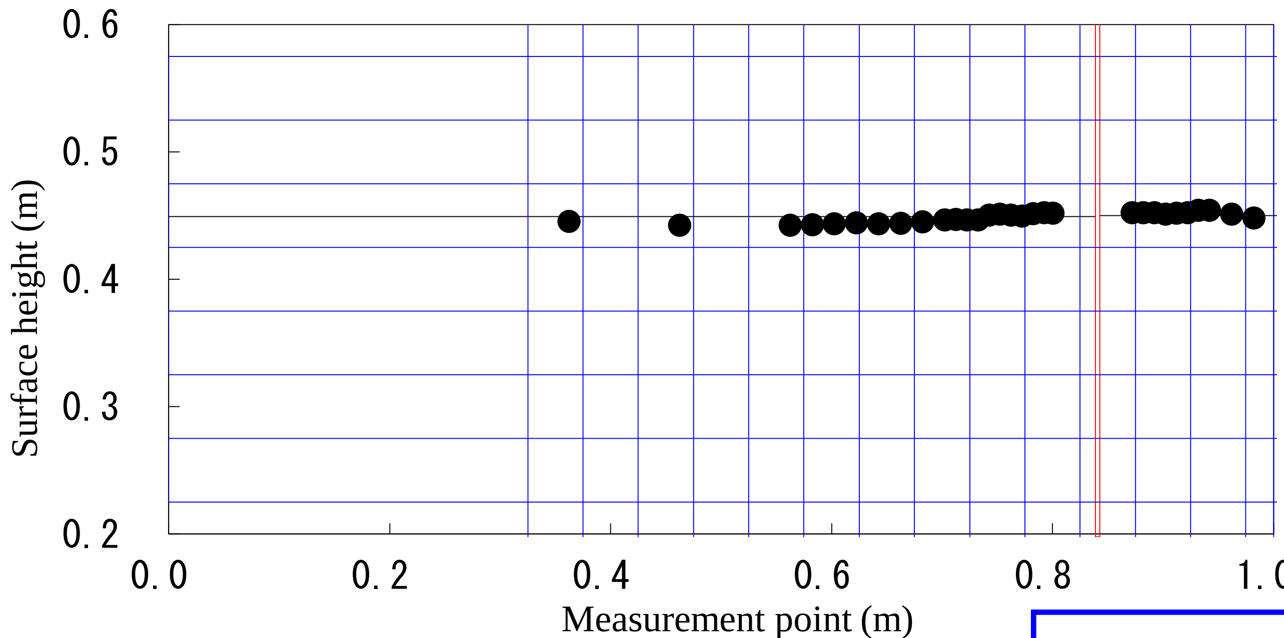
Change in shapes of soil surface



H = 5.922 cm

Change in shapes of soil surface

Upstream

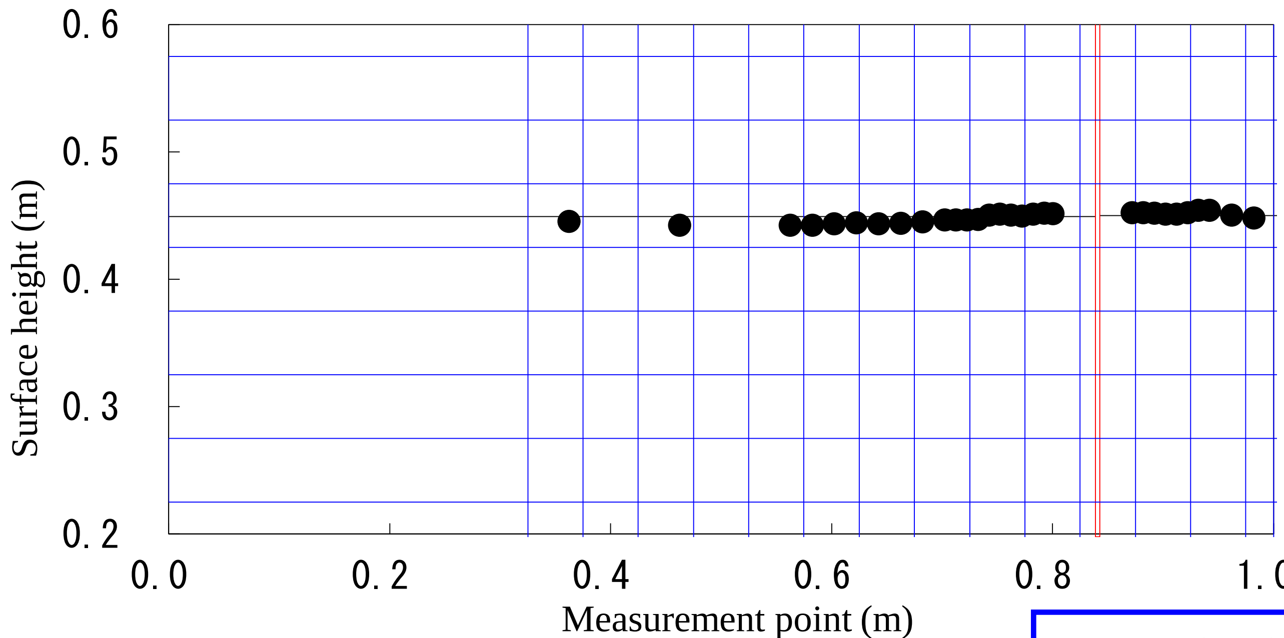


Downstream

H = 12.16 cm

Change in shapes of soil surface

Upstream

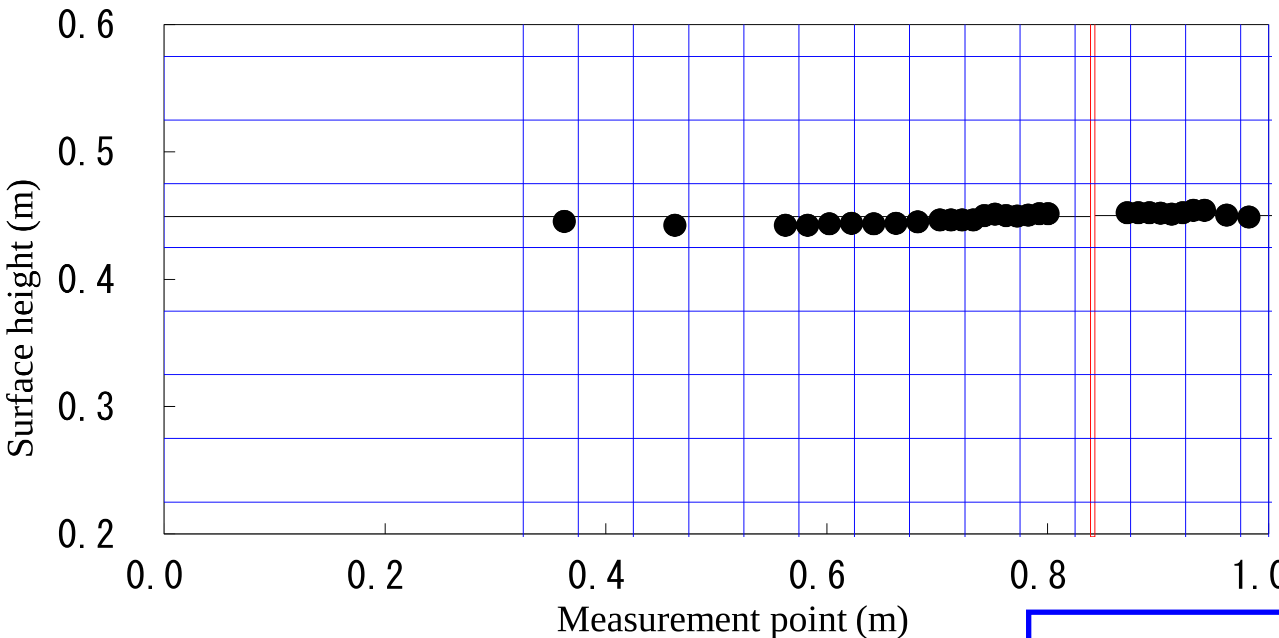


Downstream

H = 18.18 cm

Change in shapes of soil surface

Upstream

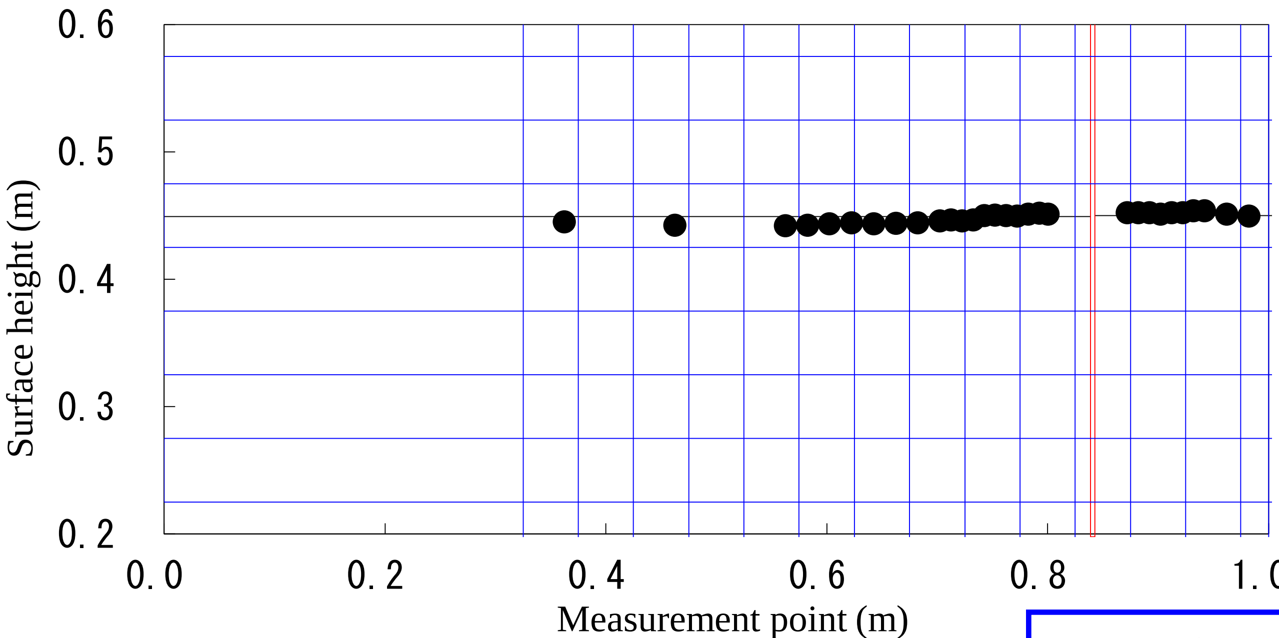


Downstream

H = 23.44 cm

Change in shapes of soil surface

Upstream

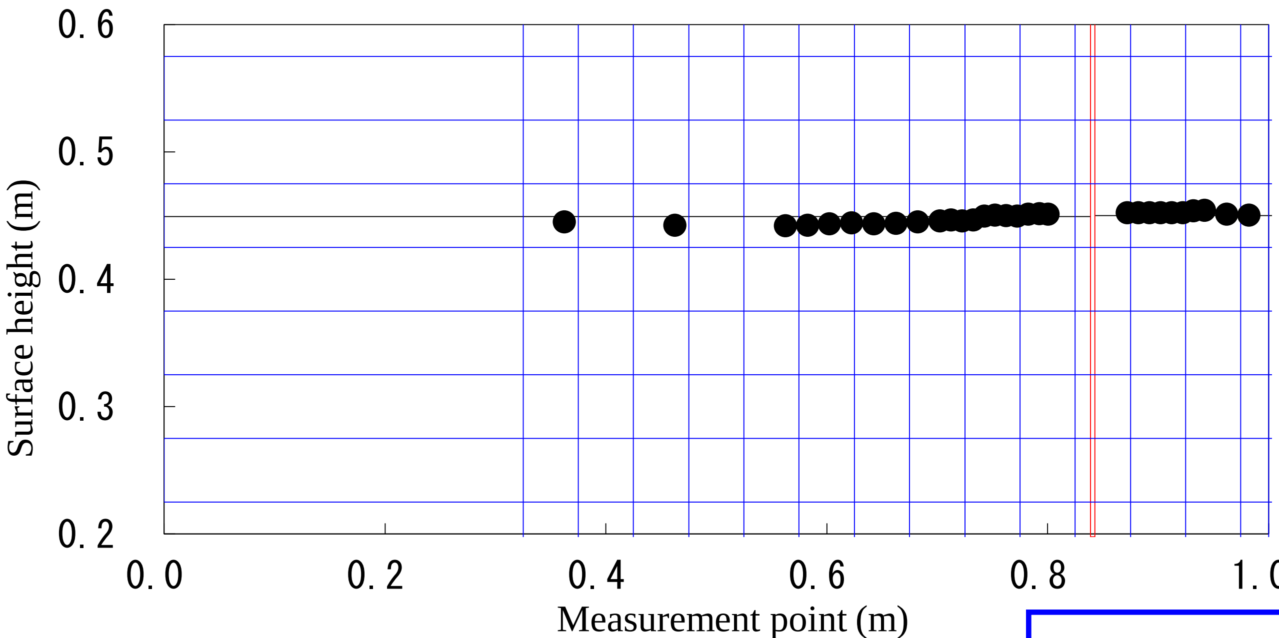


Downstream

H = 28.69 cm

Change in shapes of soil surface

Upstream

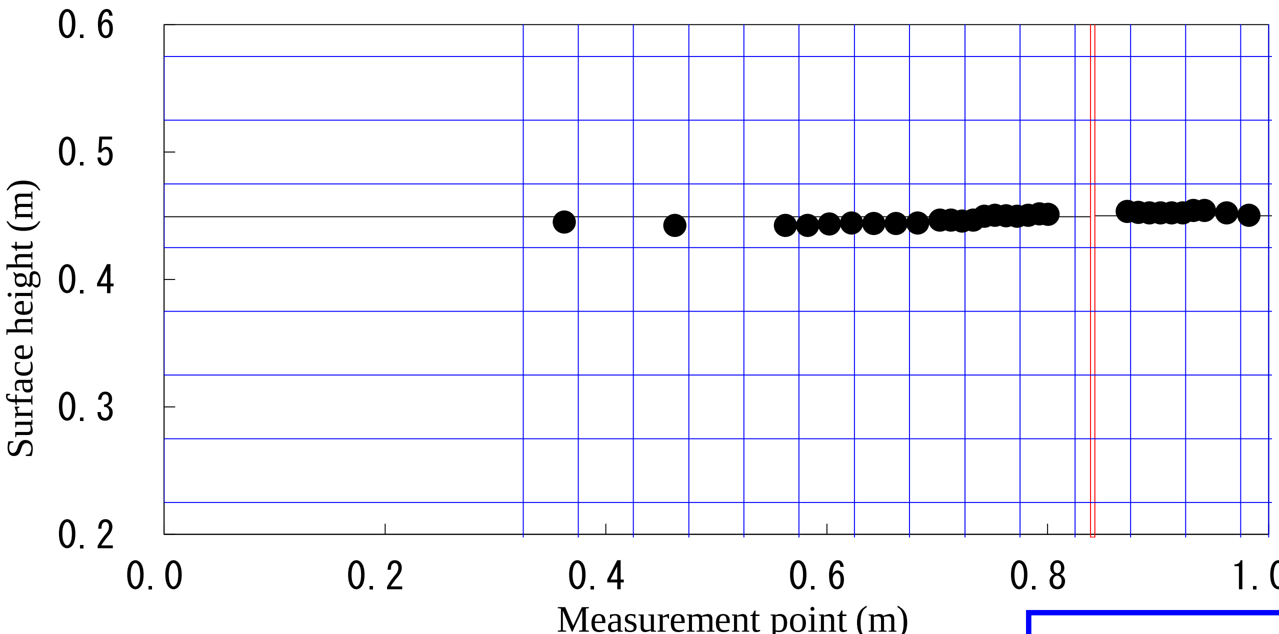


Downstream

H = 31.39 cm

Change in shapes of soil surface

Upstream

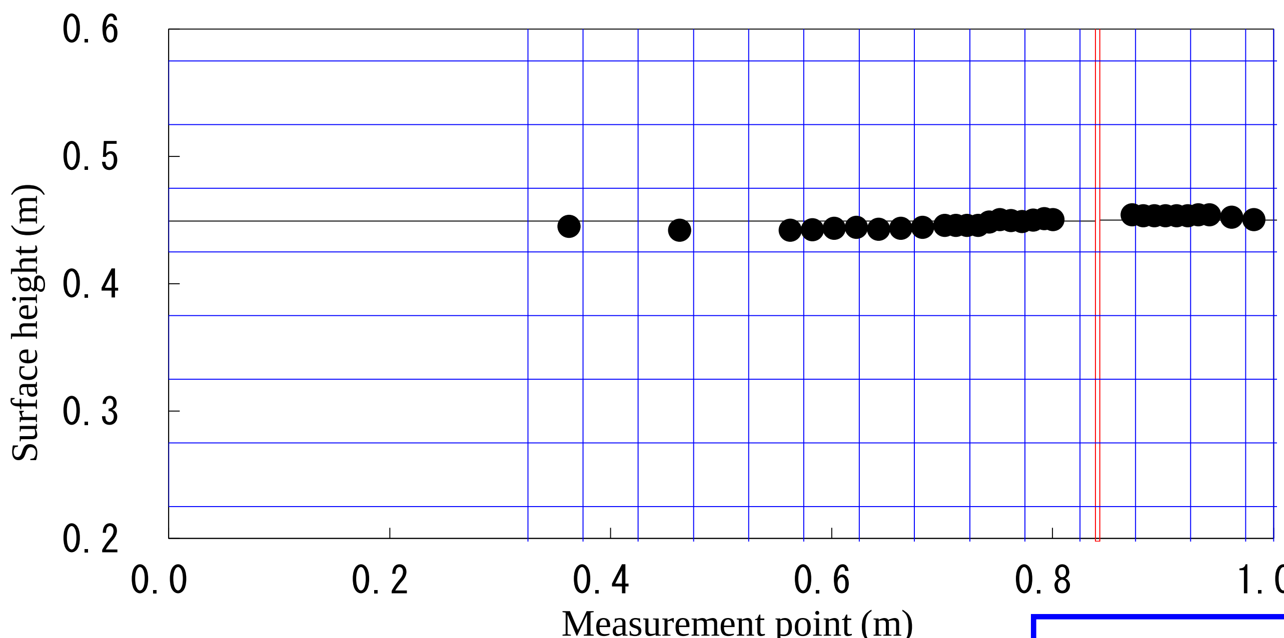


Downstream

H = 32.47 cm

Change in shapes of soil surface

Upstream



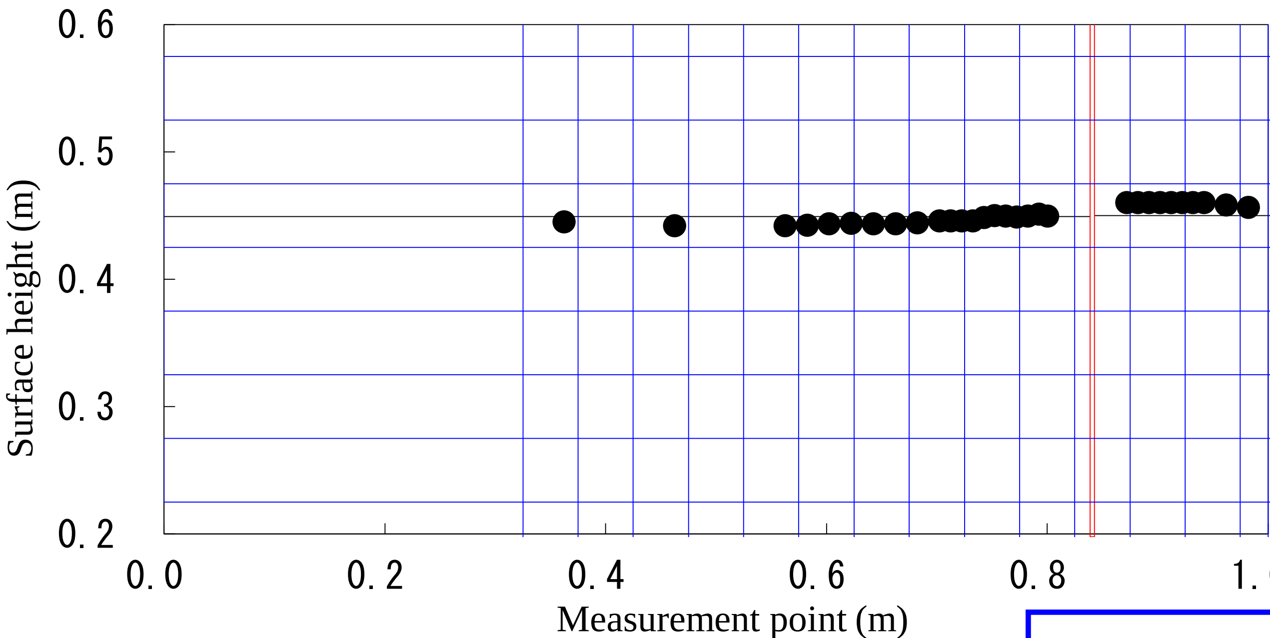
Downstream

H = 33.06 cm

Change in shapes of soil surface

(After deformation)

Upstream

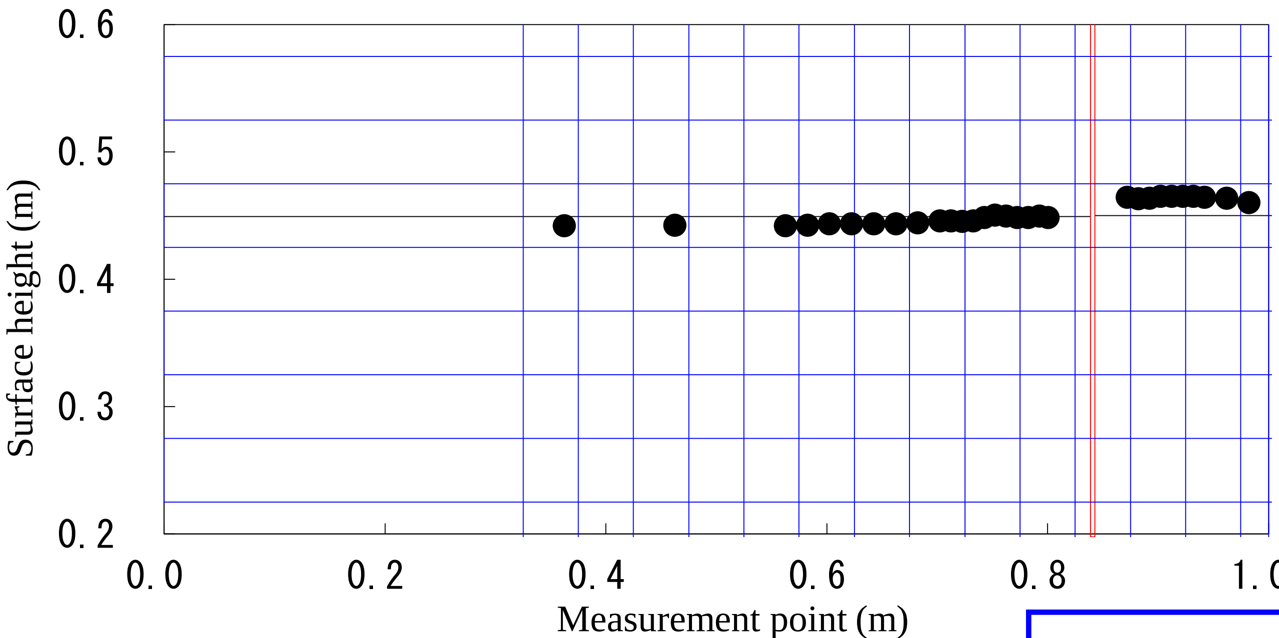


Downstream

H = 33.67 cm

Change in shapes of soil surface

Upstream

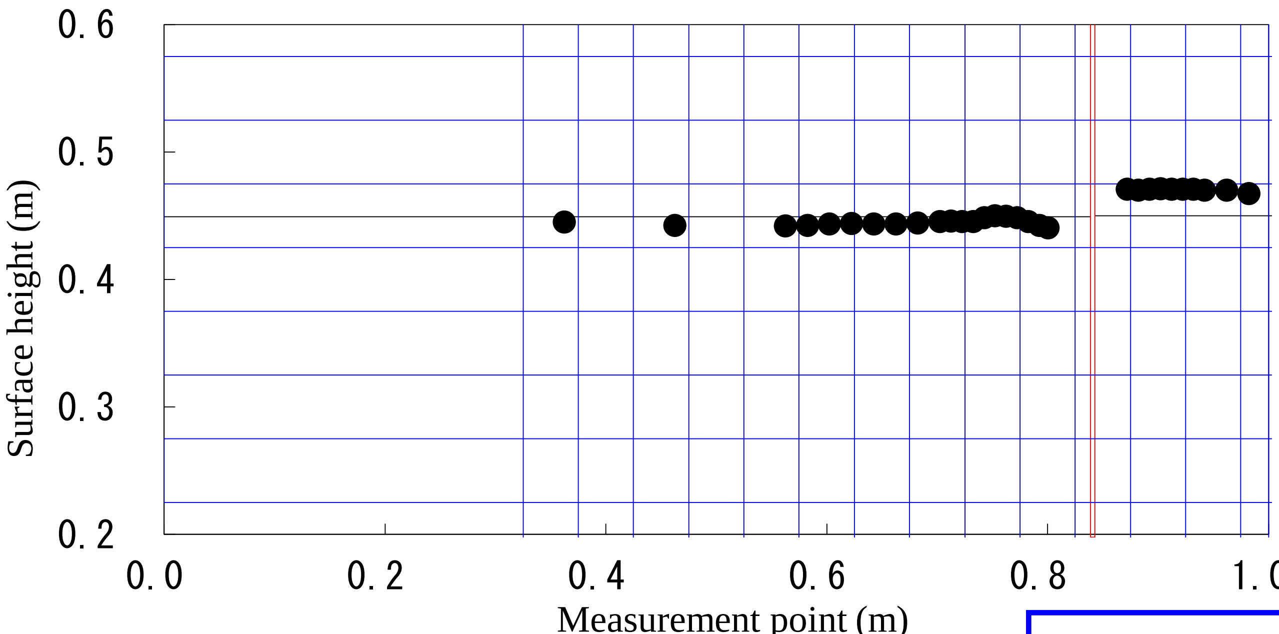


Downstream

H = 34.28 cm

Change in shapes of soil surface

Upstream

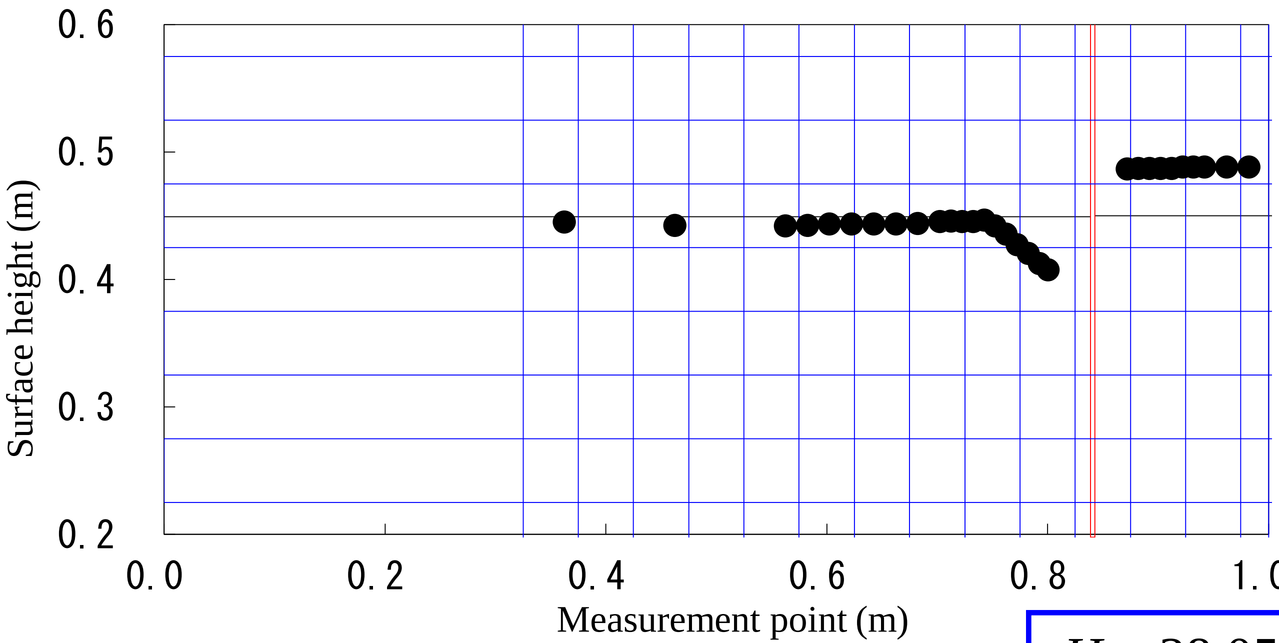


Downstream

H = 35.50 cm

Change in shapes of soil surface

Upstream

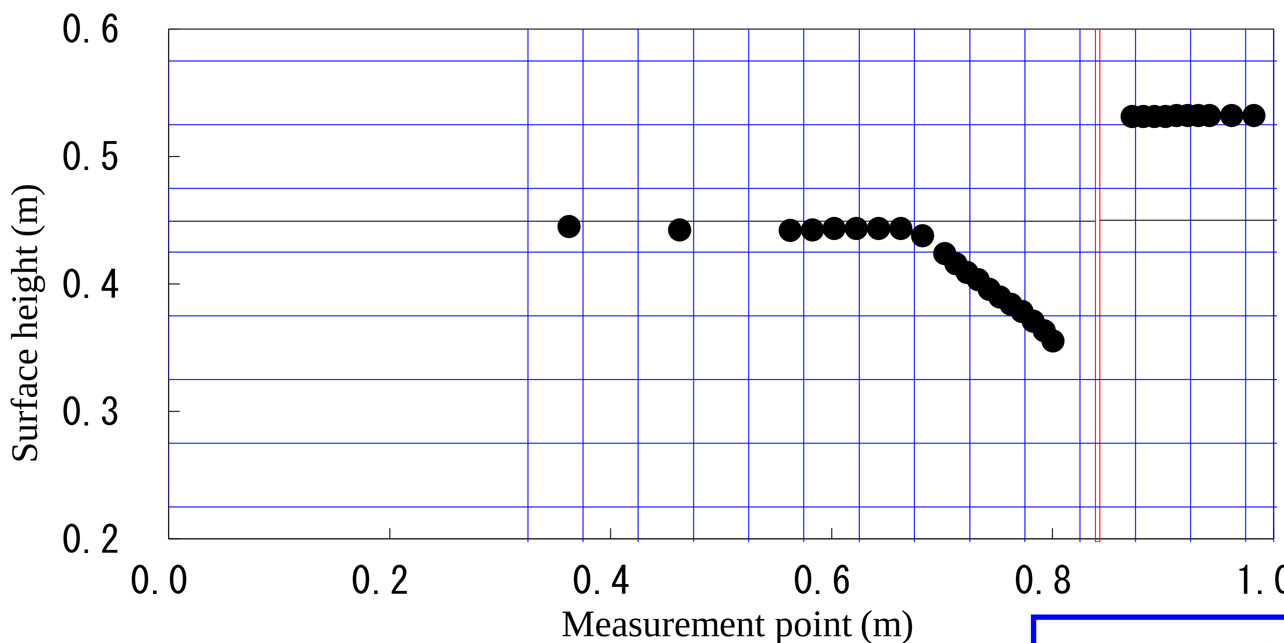


Downstream

H = 38.05 cm

Change in shapes of soil surface

Upstream

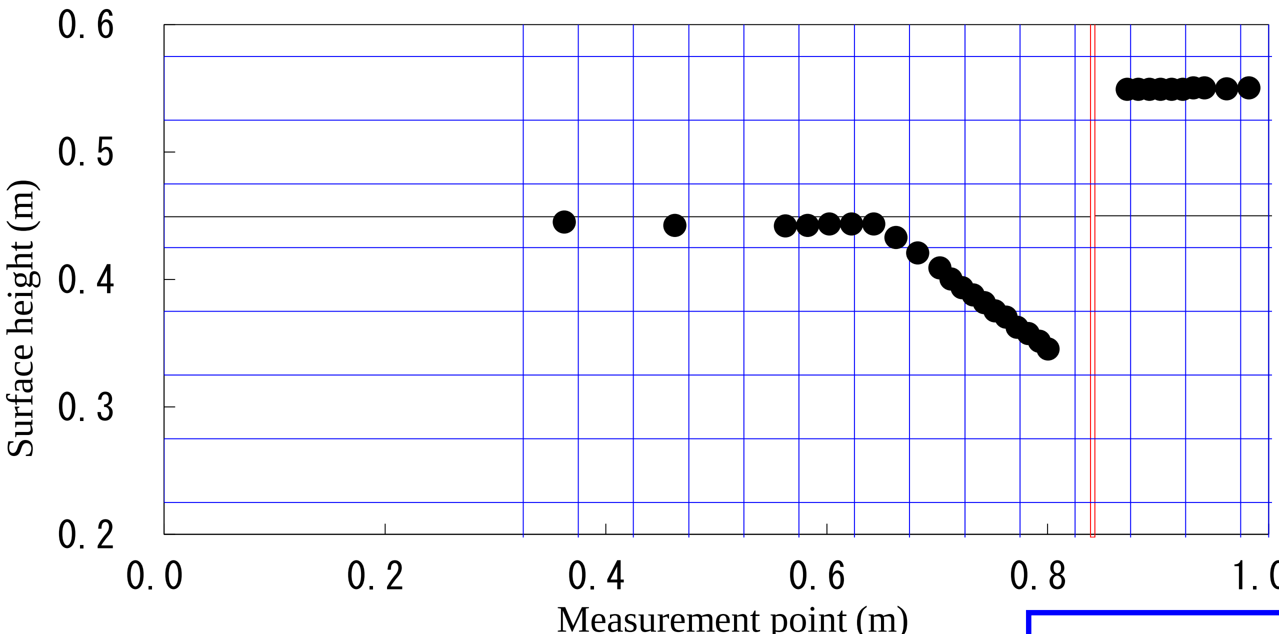


Downstream

H = 43.30 cm

Change in shapes of soil surface

Upstream

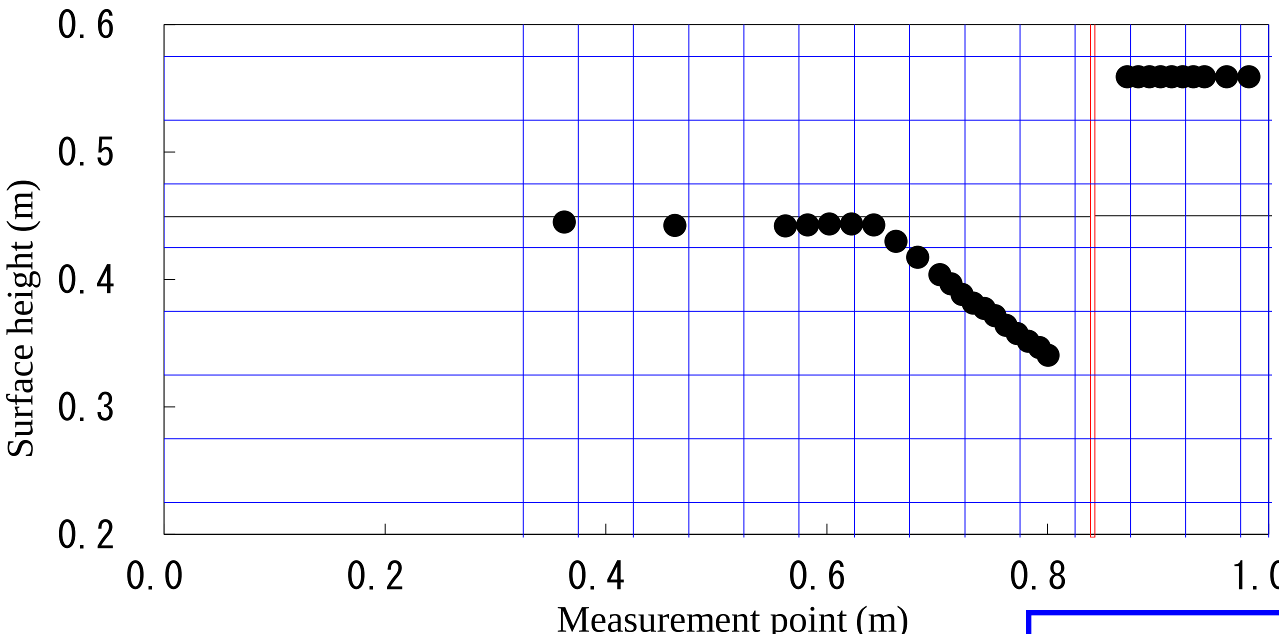


Downstream

H = 45.12 cm

Change in shapes of soil surface

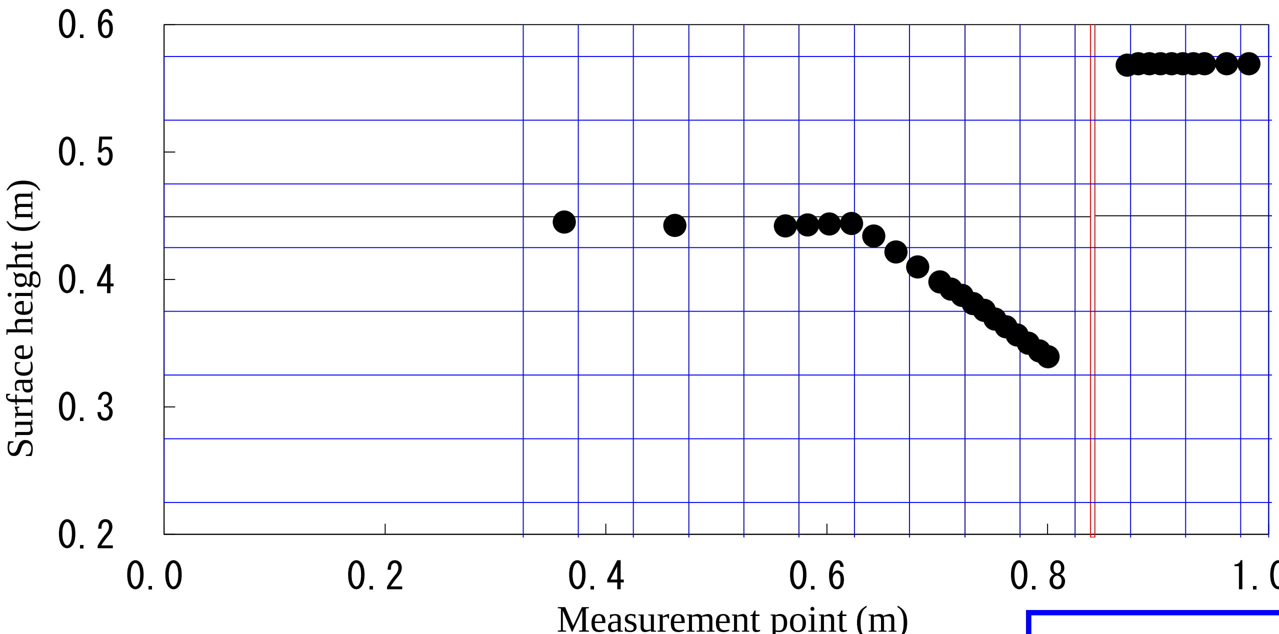
Upstream **Downstream**



H = 46.02 cm

Change in shapes of soil surface

Upstream

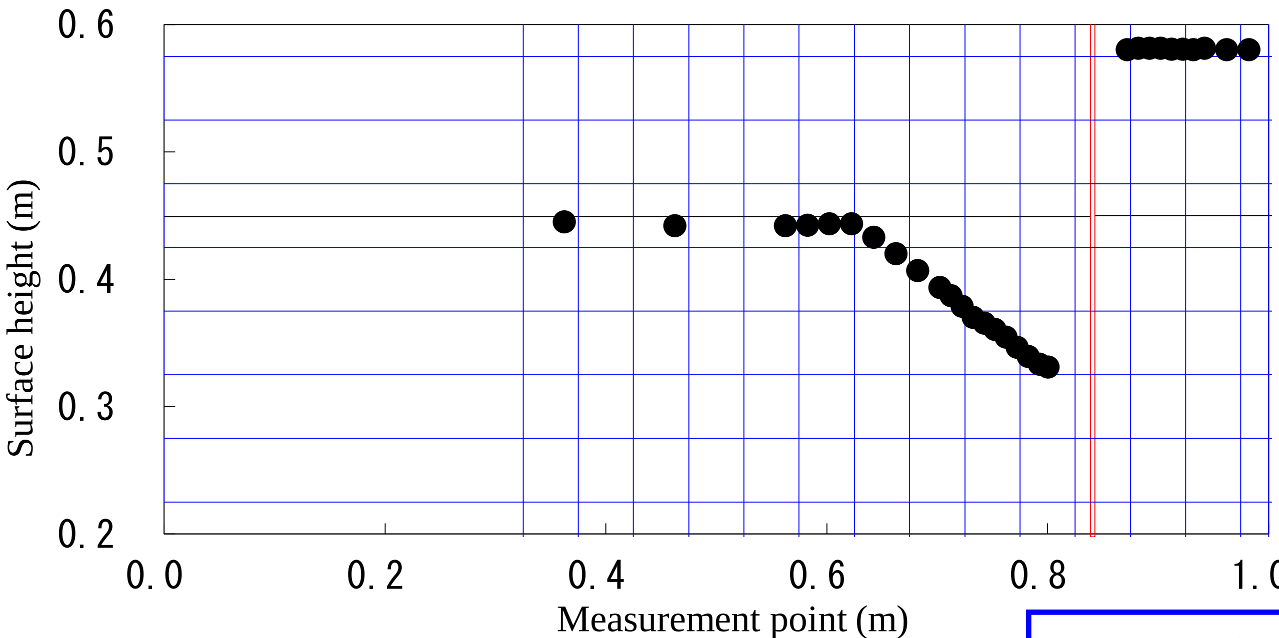


Downstream

H = 46.74 cm

Change in shapes of soil surface

Upstream

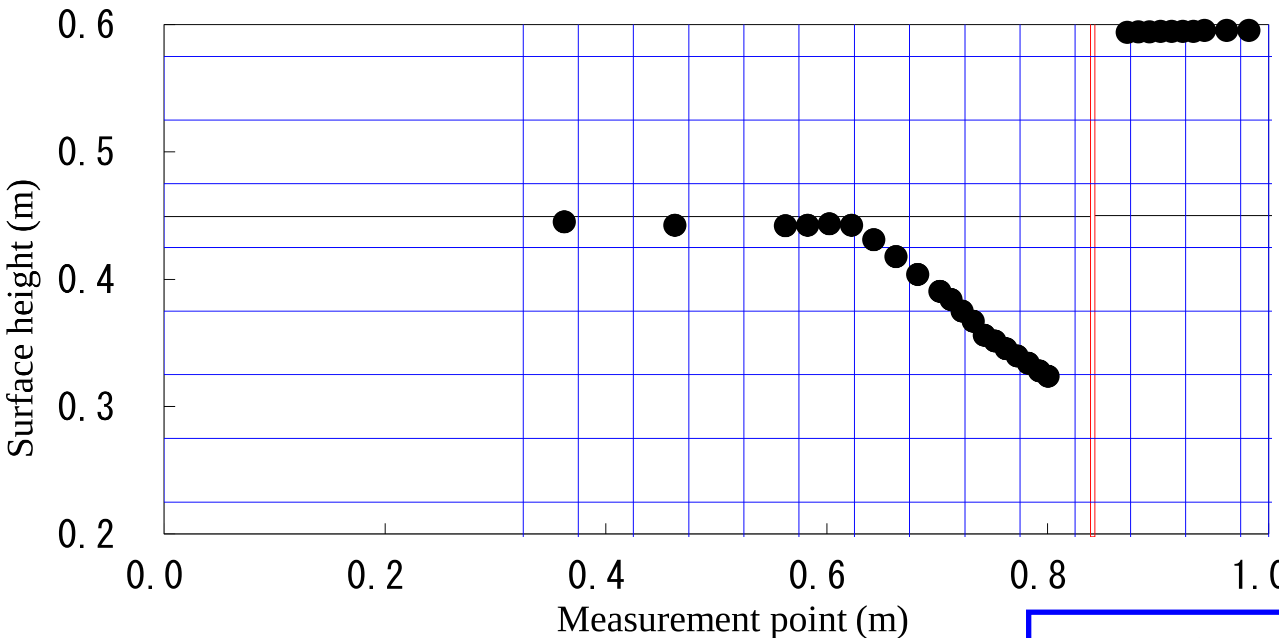


Downstream

H = 47.83 cm

Change in shapes of soil surface

Upstream



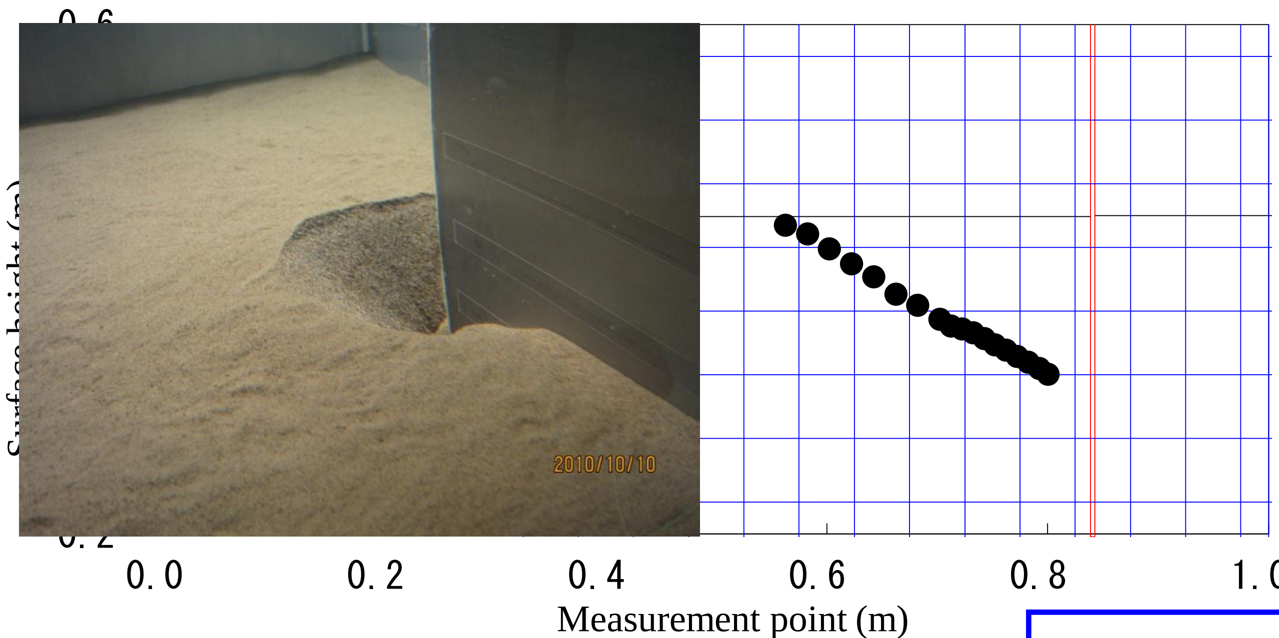
Downstream

H = 48.73 cm

Change in shapes of soil surface

(After failure)

Upstream

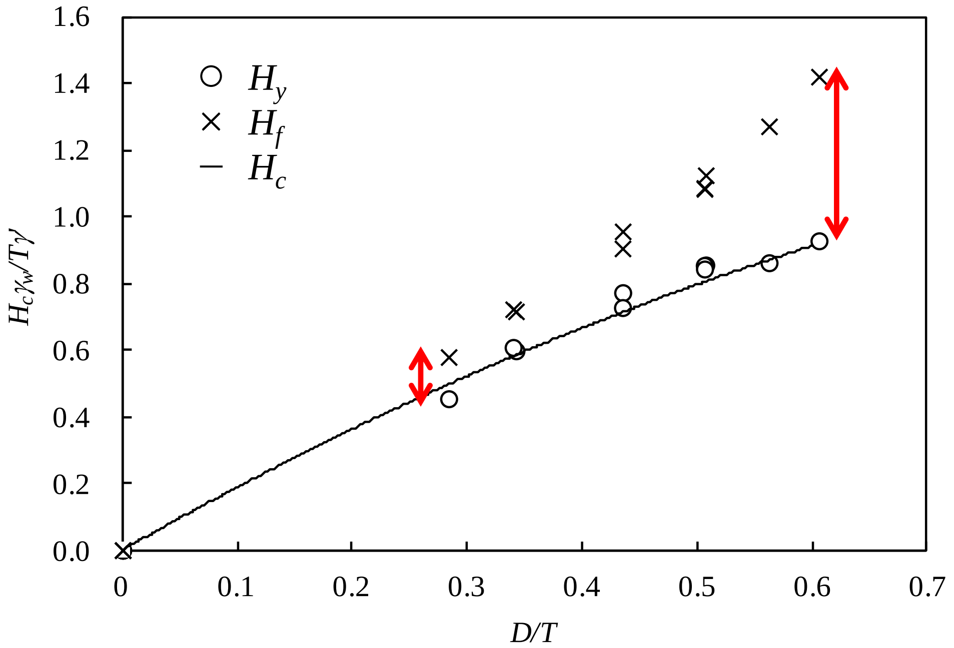


Downstream

H = 49.17 cm

- The upstream soil surface is an inverse conical shape.
- The rise in the downstream soil surface occurs uniformly.

Relationship between H_c and H_y



D/T : Penetration ratio of sheet piles

$H_c\gamma_w/T\gamma'$: Non-dimensional value of H_c

H_c : Critical hydraulic head difference (by theory)

H_y : Hydraulic head difference at the onset of soil deformation

H_f : Hydraulic head difference at failure

- $H_c \approx H_y$
- $H_f = (1.19\sim1.53)\ H_y$

⇨ The self-stabilizing effects are from 19% to 53%.

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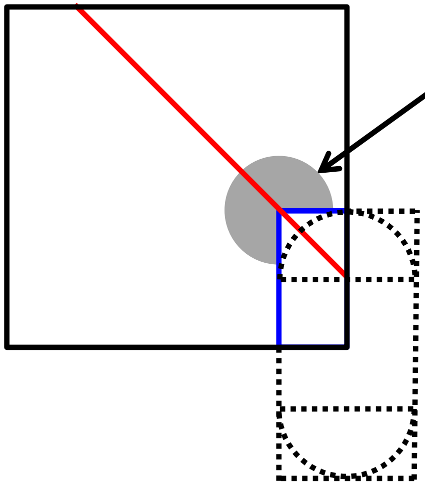
Axisymmetric modeling of three-dimensional seepage flow

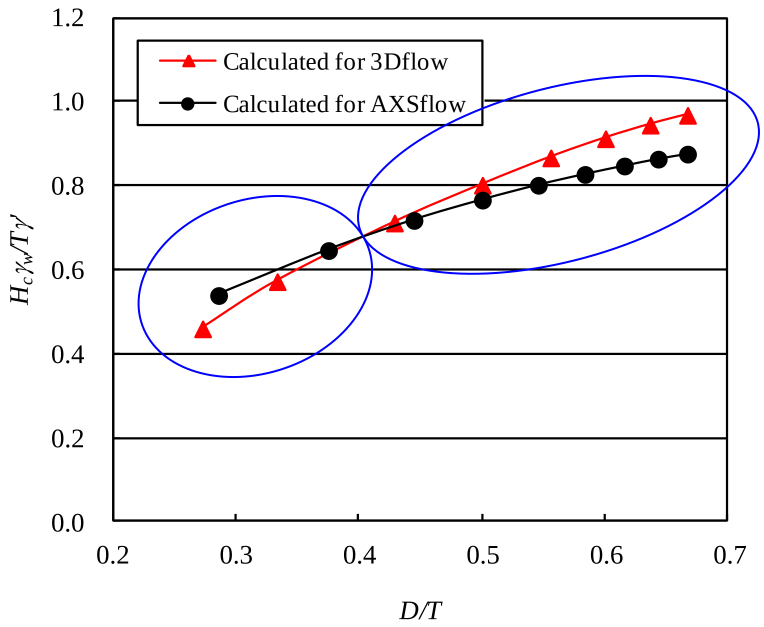


One quarter of
three dimensional region

- Soil surface is an inverse conical shape centered at the outer corner of the rectangular diaphragm.
- Critical for seepage failure on diagonal.

→ Inscribed circle

Axisymmetric modeling of three-dimensional seepage flow



D/T : Penetration ratio of sheet piles

$H_c\gamma_w/T\gamma'$: Non-dimensional value of H_c

$H_{c\ \mathrm{AXS}}$: H_c in axisymmetric flow condition

$H_{c\ \mathrm{3D}}$: H_c in 3D flow condition

- $D/T \leq 0.40$

  $H_{c\ \mathrm{AXS}} > H_{c\ \mathrm{3D}}$, Approximate accuracy is about 10%.

  → **Dangerous and unreasonable**

- $D/T > 0.40$

  $H_{c\ \mathrm{AXS}} < H_{c\ \mathrm{3D}}$, Approximate accuracy is less than 10%.

  → **Appropriate but uneconomical**

Contents

Conclusions

1. As H increases beyond H_d, Q_{15} becomes larger with increasing H more steeply than before.
2. The upstream soil surface is an inverse conical shape centered at the outer corner of the rectangular diaphragm wall.
3. The ground is subjected to irreversible damage and cannot be restored when H increases beyond H_y.

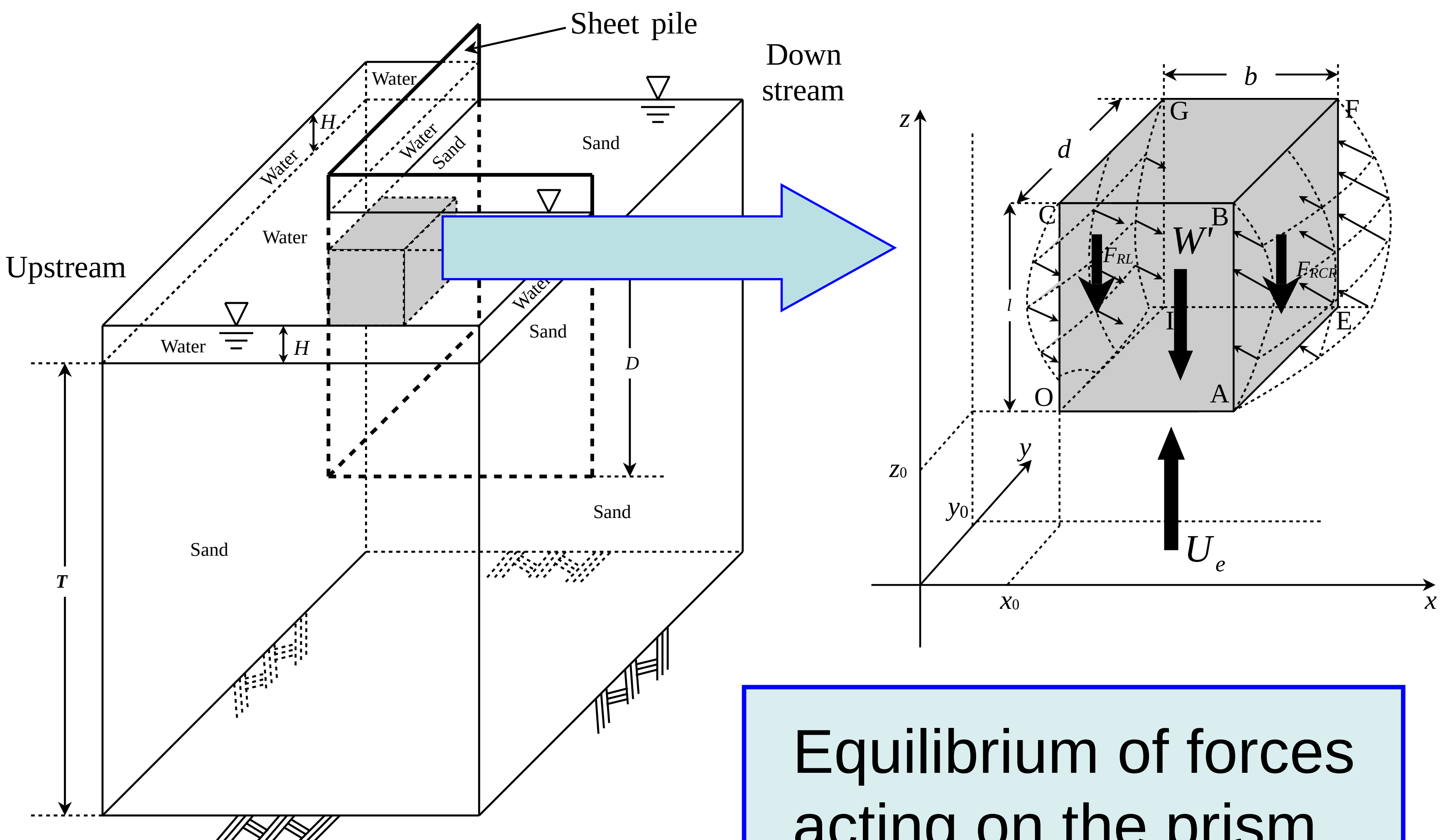
Conclusions

4. H_y are nearly equal to H_c for the same cases.

5. An axisymmetric seepage flow can be used to model such a three-dimensional flow.

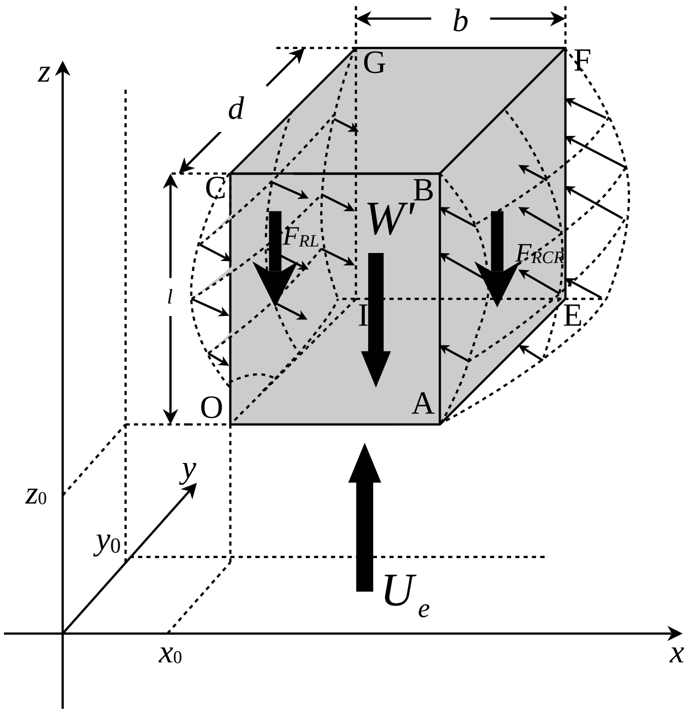
Thank you for your kind attention.

Prismatic failure concept 3D



Equilibrium of forces acting on the prism

Prismatic failure concept 3D



$$F_s = \frac{W' + F_{RL} + F_{RCR} + F_{RF} + F_{RCB}}{U_e}$$

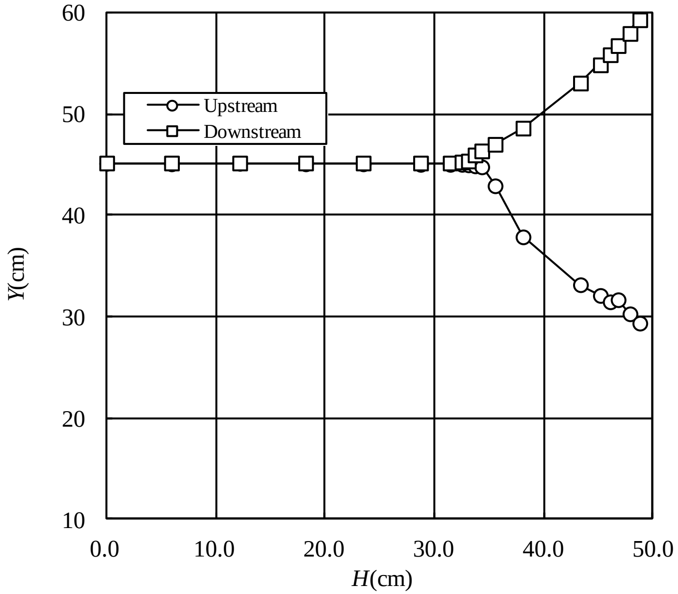
F_s : Safety factor W' : Submerged weight

F_{RL}, F_{RCR}, F_{RF}, F_{RCB} : Frictions

U_e : Excess pore water pressure

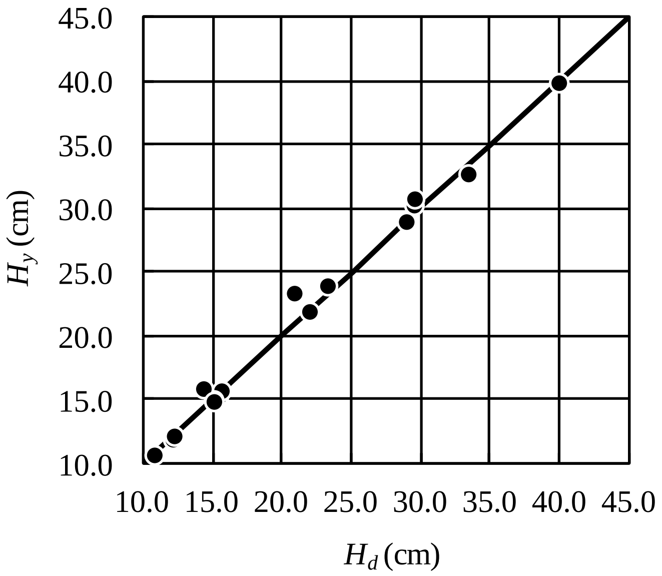
- F_s are calculated for all of the prisms, and F_s takes the minimum $F_{s\,\min}$ for a certain prism.
- H_c is the critical hydraulic head difference ($F_{s\,\min}$=1.0).

Change in shapes of soil surface



H : Hydraulic head difference

Y : Height of the soil



$$H_y = H_d$$

Change in shapes of soil surface

Hydraulic head differences
$H = H_f$

→ Fine grains of soil boil at the downstream side.

→ A bulk of soil moves slowly from up- to downstream.

→ Sand model collapses.

Subsidence on upstream side and rising on downstream

Three dimensional experiments

Exp.No. (Mnemonic name)		e	D_r (%)	γ' (gf/cm^3)	d (m)	T (m)	D (m)	D/T	Excavation
E0301	(30, 30)	0.945	48.1	0.858	0.000	0.299	0.102	0.342	No
E0302	(35, 35)	0.932	51.7	0.863	0.000	0.348	0.151	0.435	No
E0303	(35, 35)	0.941	49.1	0.859	0.000	0.350	0.152	0.435	No
E0304	(35, 30)	0.930	52.2	0.864	0.051	0.296	0.100	0.337	Yes
E0305	(30, 30)	0.943	48.7	0.859	0.000	0.298	0.101	0.340	No
E0306	(40, 40)	0.933	51.4	0.863	0.000	0.399	0.202	0.507	No
E0307	(40, 35)	0.939	49.7	0.860	0.050	0.349	0.152	0.436	Yes
E0308	(35, 27.5)	0.935	50.9	0.832	0.073	0.275	0.078	0.285	Yes
E0309	(27.5, 27.5)	0.942	48.7	0.859	0.000	0.274	0.078	0.284	No
E0310	(40, 30)	0.941	49.1	0.859	0.101	0.299	0.102	0.342	Yes
E0311	(45, 45)	0.936	50.6	0.862	0.000	0.449	0.252	0.562	No
E0312	(35, 27.5)	0.936	50.6	0.862	0.075	0.274	0.077	0.282	Yes
E0313	(35, 30)	0.943	48.6	0.859	0.053	0.297	0.100	0.338	Yes
E0314	(35, 30)	0.938	50.1	0.861	0.050	0.299	0.102	0.342	Yes
E0315	(40, 40)	0.932	51.6	0.863	0.000	0.399	0.202	0.507	No
E0316	(50, 50)	0.934	51.1	0.862	0.000	0.498	0.302	0.606	No
E0317	(40, 40)	0.938	49.9	0.861	0.000	0.398	0.201	0.506	No

- Critical hydraulic head differences are calculated using Prismatic failure concept 3D beforehand.