A Case Study on Seepage Failure of Bottom Soil within a Double-Sheet-Pile-Wall-Type Ditch

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A double-sheet-pile-wall-type ditch (or prefabricated ditch)

Boiling occurred in the bottom soil during puddling → Ditch border collapsed

Analyses of FEM seepage flow and stability against seepage failure using Pfc

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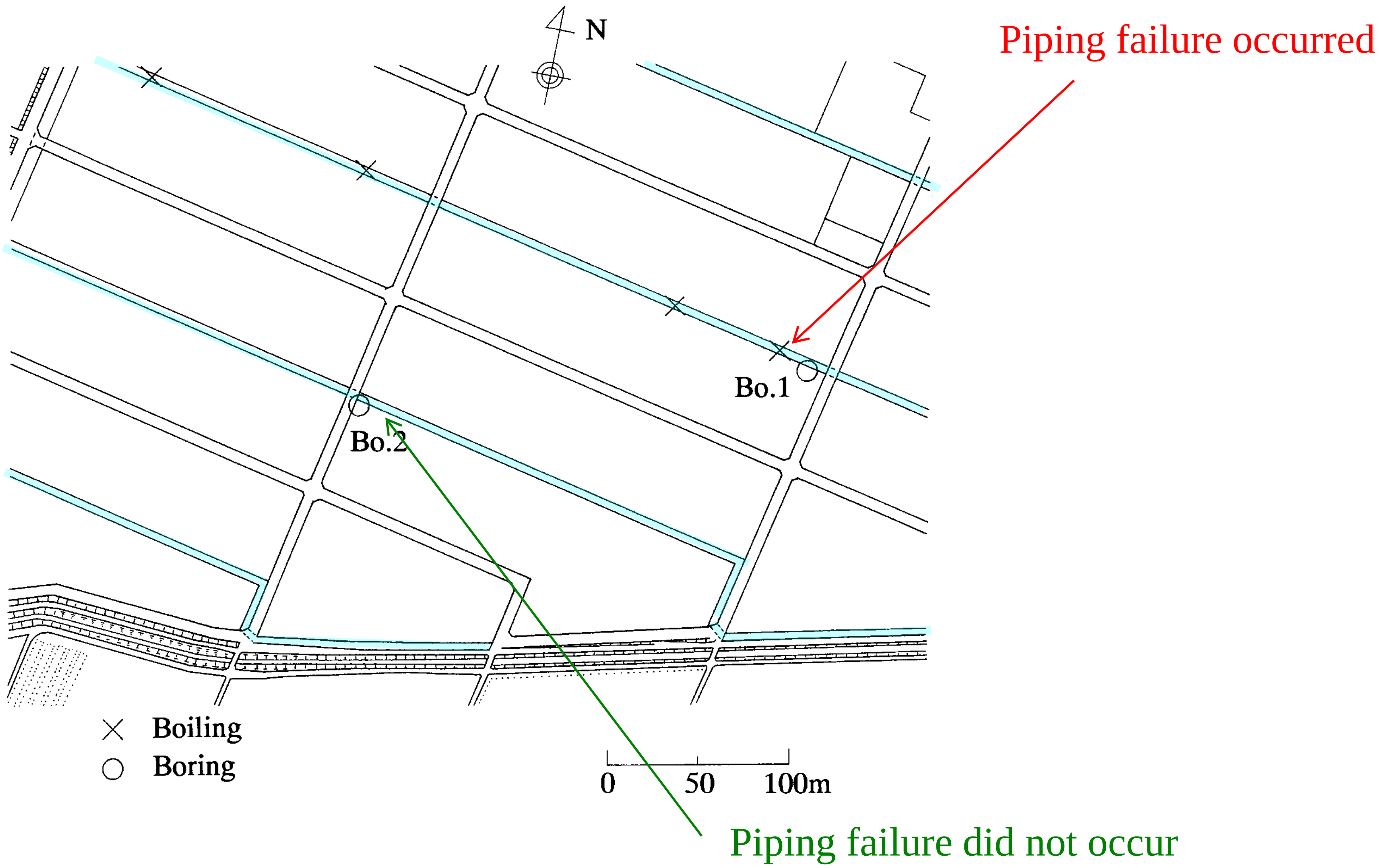
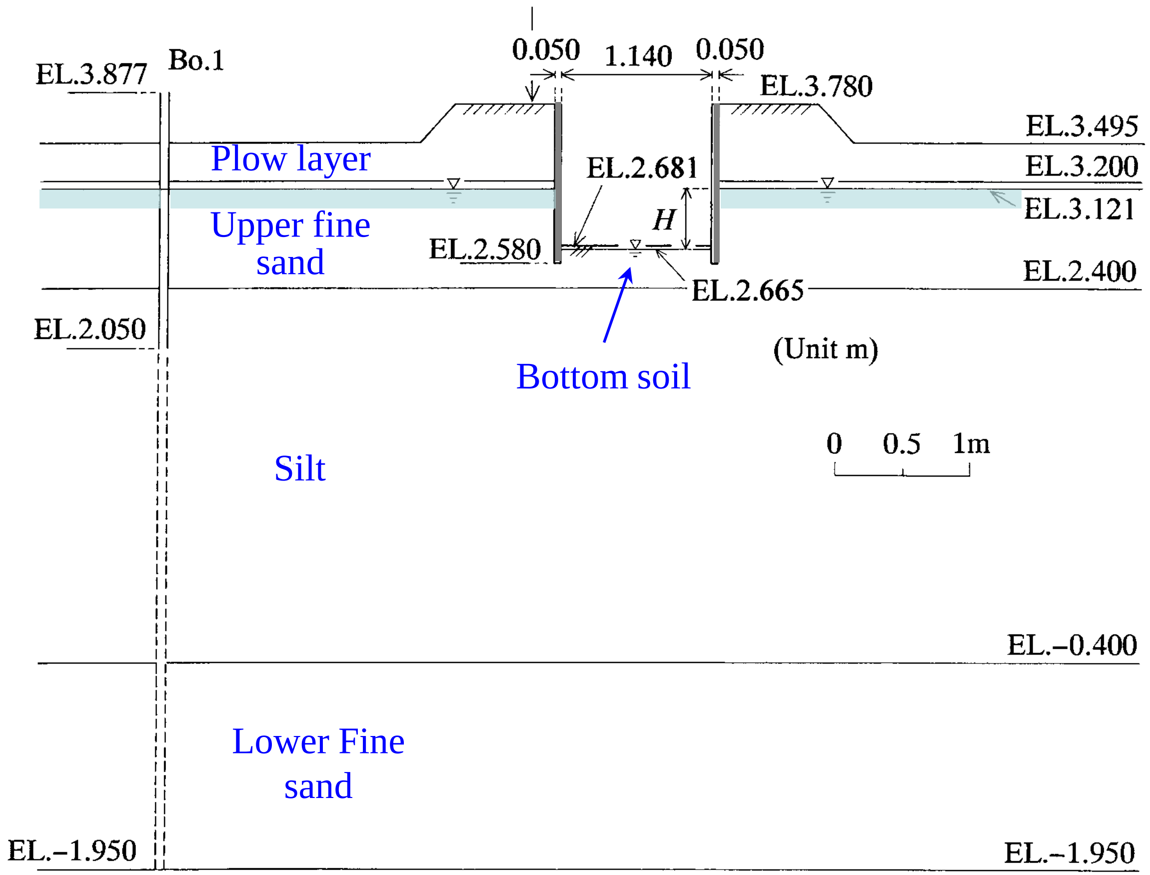
Discussion on causes of the failure, effects of 2DC flow, effects of backfills, and countermeasures against seepage failure

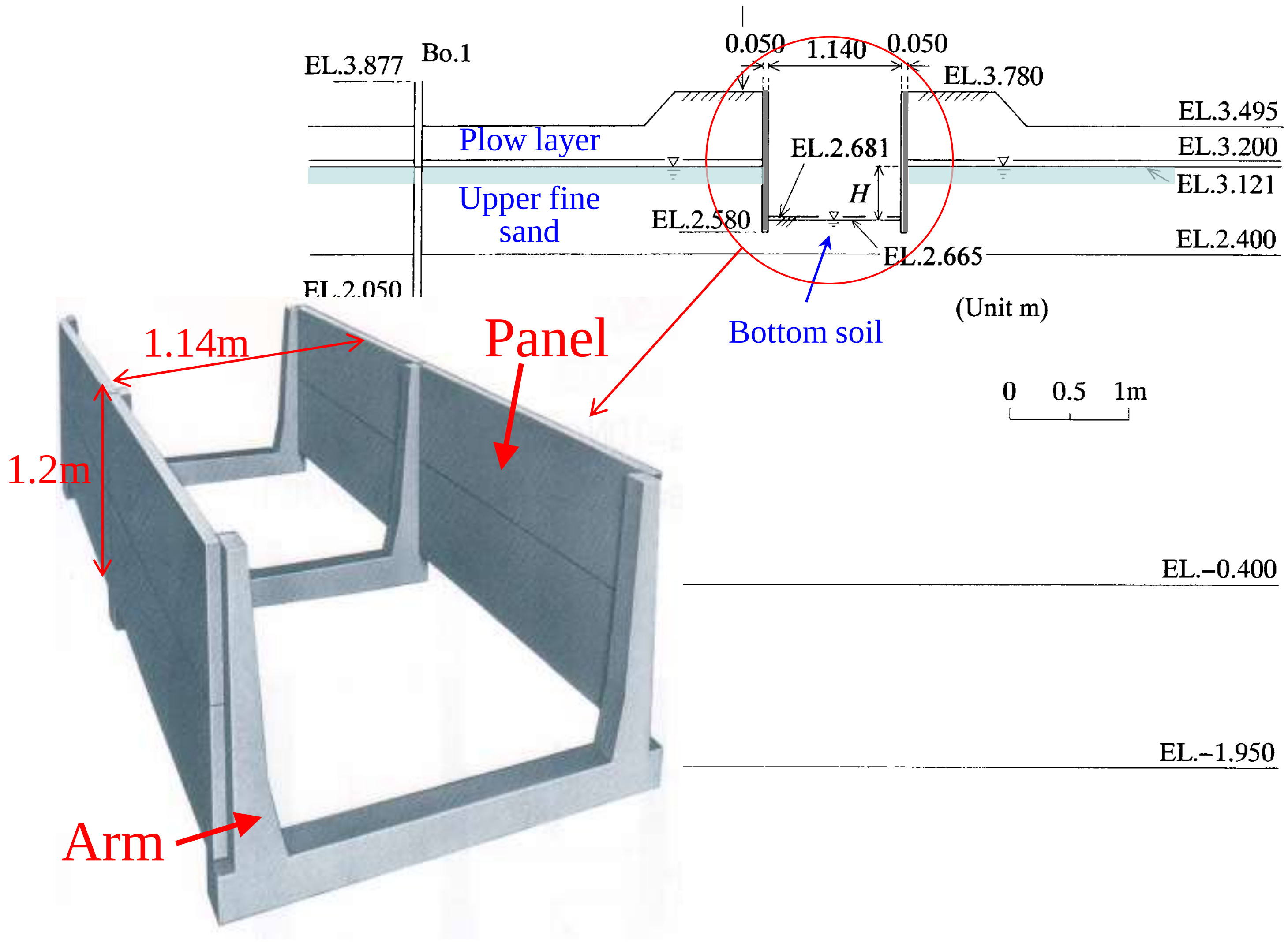
Plane of the site



Cross sectional view of the ditch near Bo.1

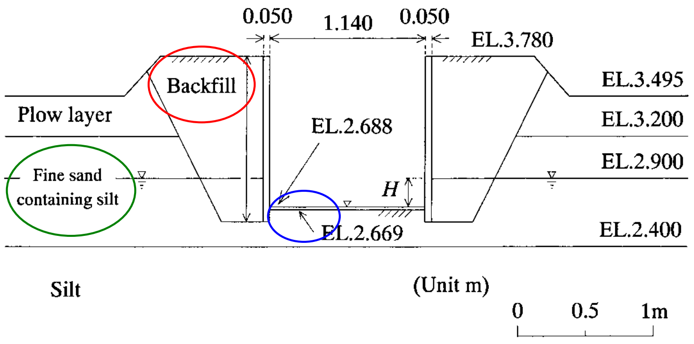


Cross sectional view of the ditch near Bo.1



Physical properties of soils

	Plow layer	EL.3.20～2.40	EL.2.40～-0.40	EL.-0.40～-1.95	Backfills	Boiled-out sand
(Boring log)	—	(Fine sand with silt)	(Silt)	(Fine sand with silt)	—	—
G_s	2.641	2.657	2.656	2.658	2.655	2.651
U_c	29.196	15.271	14.377	13.963	13.973	2.544
D_{50} (mm)	0.0424	0.172	0.00770	0.0598	0.175	0.227
e_{max}	—	1.290	—	1.585	1.242	1.231
e_{min}	—	0.521	—	0.701	0.616	0.670
w_L	25.215	—	41.209	—	—	—
w_P	22.140	—	29.032	—	—	—
k_{15} (cm/s)	2.712×10^{-5}	1.310×10^{-3}	7.659×10^{-6}	1.466×10^{-4}	2.265×10^{-3}	4.054×10^{-3}
Classification	Silt	Silty sand	Silt	Silt	Silty sand	Poorly graded sand

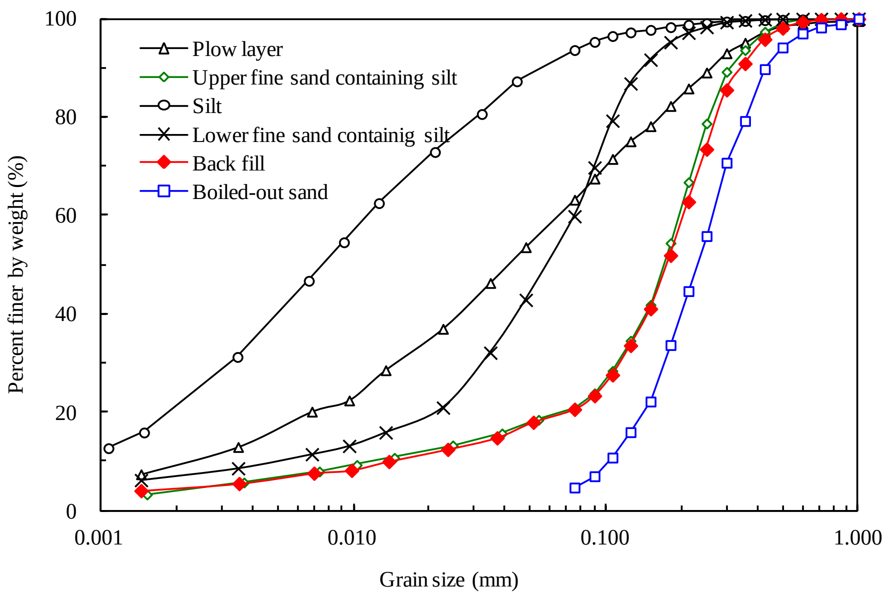


Grain size distributions of soils

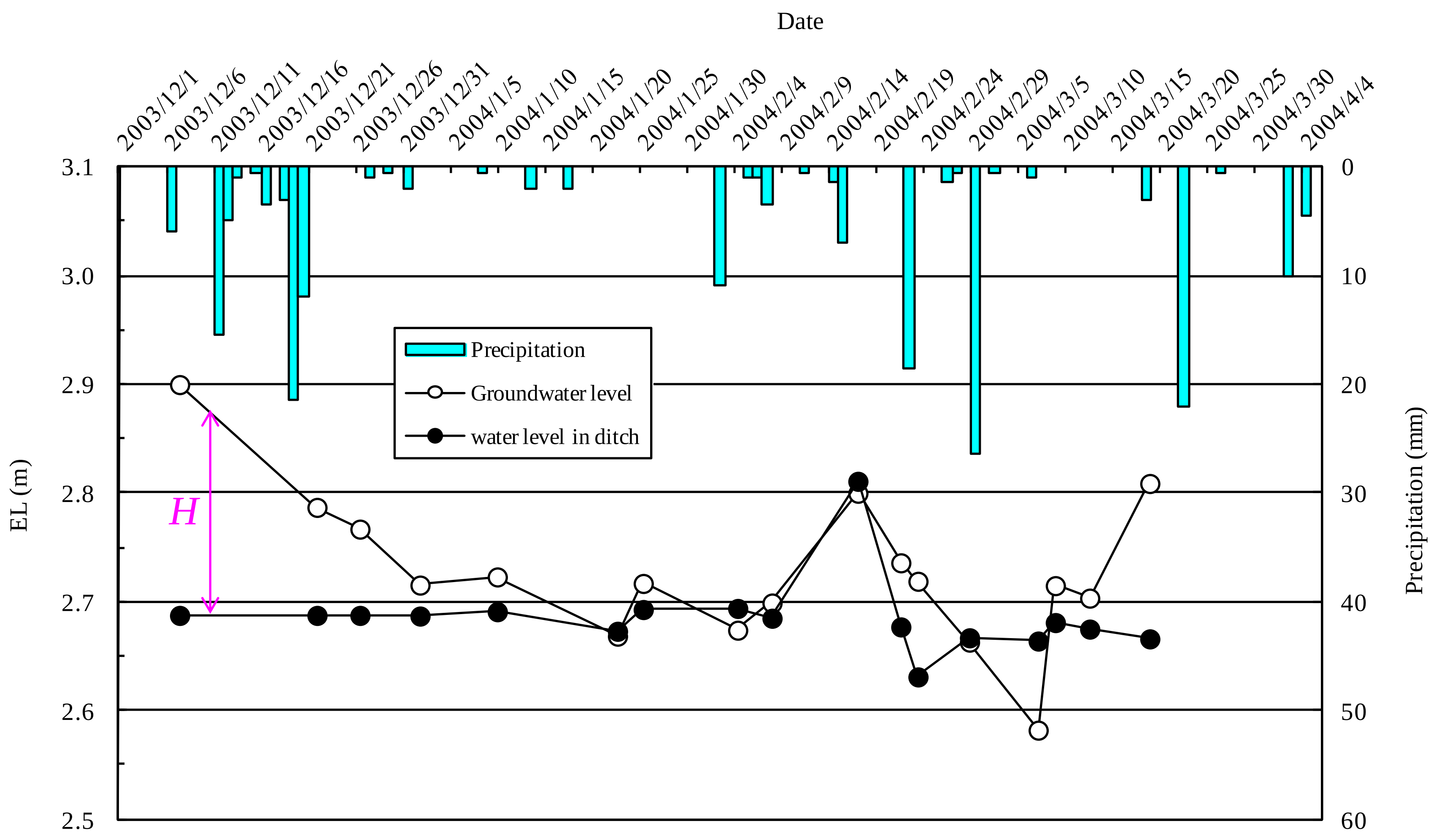
The backfill and boiled-out sand are the same soil as the upper fine sand containing silt.

The backfill is very soft, and is also more permeable than neighboring soils.

$$k_{BF} = 2.265\times10^{-3}\ \text{cm/s} > 1.310\times10^{-3}\ \text{cm/s} = k_{UFS}$$



Groundwater levels and water levels in the ditch (continuous observation)



Surface boiling was observed

H = 0.317m on 2004/11/20,
H = 0.373m on 2005/11/12,
H = 0.273m on 2006/04/23.

(2003/08/24)

H = 0.600m was recorded on 2004/05/16 after heavy rain, and *H* = 0.456m on 2004/05/22 during puddling. Two days after the latter,

Ditch border collapsed

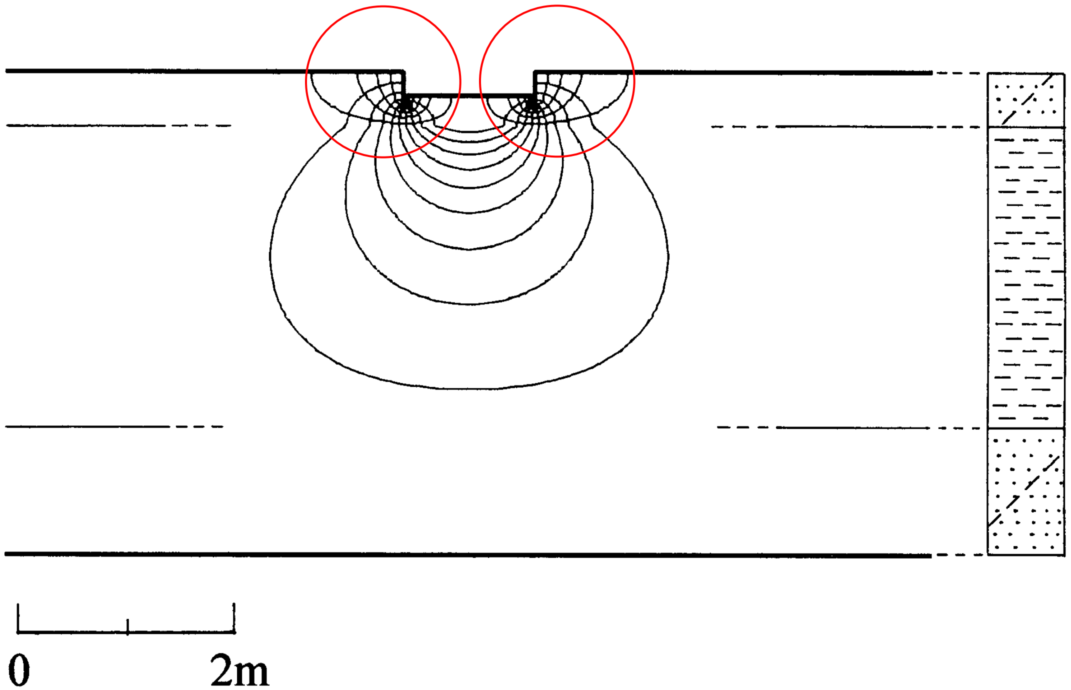
On 2004/05/24, the ditch border again collapsed about 10m from the observation point Bo.1.

The head difference at failure H_f was estimated to be 0.878m.

Here, we consider the two conditions: H equals to (1) 0.212m and (2) 0.456m, and the three cases: not considering backfill, considering backfill and considering a less permeable backfill.

SEEPAGE FLOW ANALYSES

H = 0.212m on 2003/12/12



Flow net when not considering backfills

Seepage flows are only limited to either side of the ditch and interactions with the other side's flow are small in this case.

Stability against seepage failure of the bottom soil within the ditch

Condition Date (H)	(a) No backfill		(b) Considering backfill (in fact)		(c) Less permeable backfill (on an assumed condition)	
	H_{PF} (m)	F_s	H_{PF} (m)	F_s	H_{PF} (m)	F_s
2003/12/12 (0.212 m)	0.416	1.961	0.362	1.706	0.682	3.216
2004/05/22 (0.456 m)	0.460	1.008	0.394	0.864	0.749	1.641

In the case of H = 0.212m (2003/12/12),

F_s = 1.961 when not considering backfill,

F_s = 1.706 when considering backfill, and

F_s = 3.216 when considering less-permeable backfill.

The ditch bottom is stable for seepage failure.

In the case of H = 0.456m (2004/05/22),

F_s = 1.008 when not considering backfill,

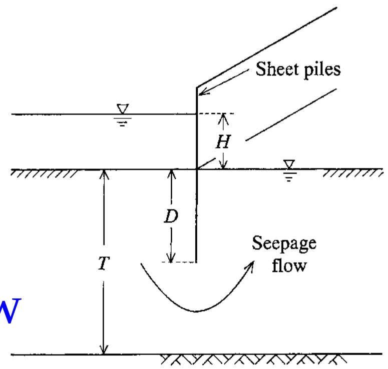
F_s = 0.864 when considering backfill, and

F_s = 1.641 when considering less permeable backfill.

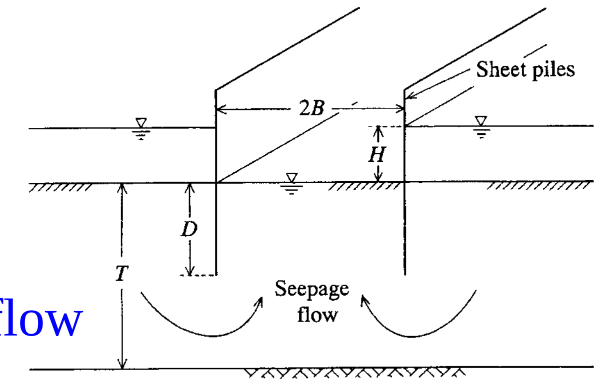
The ditch bottom was near critical or was subject to boiling for the first two cases.

The ditch bottom would be stable against boiling if the back fill was one order less permeable, as an assumed condition. Thus it is proved that a less-permeable backfill has a distinctive effect of increasing the stability.

Effect of 2DC flow condition in stability against seepage failure of soil



2D flow



2DC flow

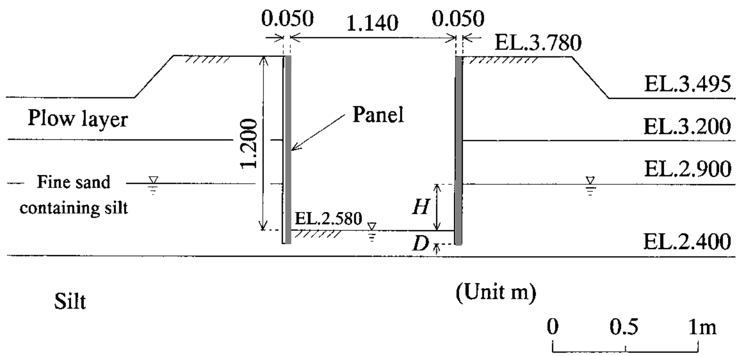
In the excavation of soil between double sheet pile walls, as shown in the right figure, seepage water concentrates into the soil two-dimensionally from the outside, which is called two-dimensional concentrated flow (2DC flow). The 2DC flow of water lowers the safety factor regarding the seepage failure than 2D flow.

From the analyses, the effects of 2DC flow are not the case for this problem.

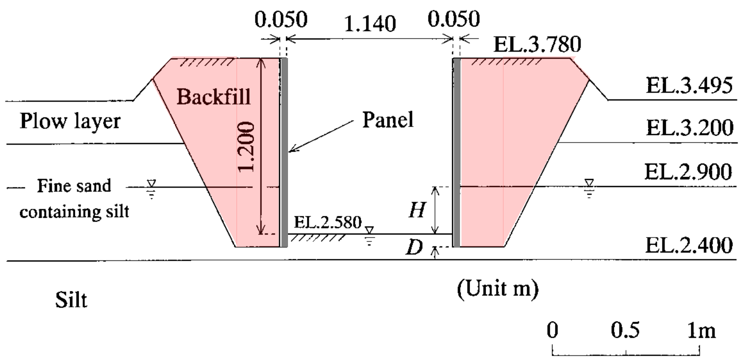
Countermeasures against seepage failure

Three methods:

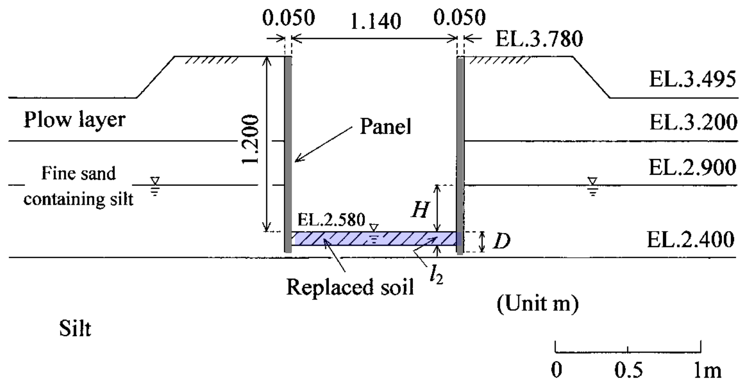
(1) increase in the penetration depth of the panel,



(2) decrease in the coefficient of permeability of backfills, and



(3) replacing the upper part of the bottom ditch soil with an inverted filter.



Countermeasures against seepage failure

(1) increase in the penetration depth of the panel,
(2) decrease in the coefficient of permeability of backfills, and
(3) replacing the upper part of the bottom ditch soil with an inverted filter.

↓ concluded

The first method is the most effective. For the penetration depth of the panel D = 0.18 m, the ditch bottom is stable against seepage failure even for the estimated maximum hydraulic head difference.

And establishing less permeable backfills and replacing the upper part of the bottom ditch soil with an inverted filter would also be effective in increasing stability against boiling of the bottom soil.

CONCLUSIONS

(1) The largest hydraulic head difference, *H*, was 0.212m, during continuous observation period for about four months. On intermittent observation for the following two years, the *H* values ranged from 0.600m after heavy rain to 0.456m during puddling. The greatest *H* value at the time of transplanting was estimated to be 0.878m, when boiling failure occurred.

(2) The bottom soil within the ditch was stable at $H = 0.212$m, but was near or beyond the critical condition for seepage failure at $H = 0.456$m.

(3) A less-permeable backfill has a distinctive effect of increasing the stability.

(4) The seepage flows are only limited to either side of the ditch, so the effects of 2DC flow are not the case for this problem.

(5) Three countermeasures against boiling were considered:

1) increase in the penetration depth of the panel,

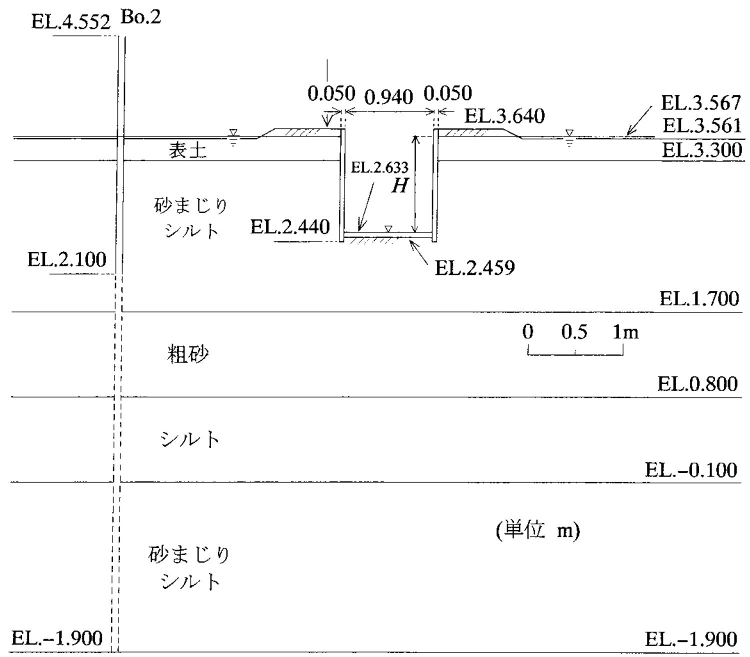
2) decrease in the coefficient of permeability of backfills, and

3) replacing the upper part of the bottom ditch soil with an inverted filter.

The first method was the most effective. The combination of the other two methods would also be effective in increasing stability against boiling of the bottom soil.

Thank you very much for your kind attention.

Stability against Heaving of Bottom Clay Soil in the Ditch where Boiling has not occurred



At a site 240m from Bo.1, boiling did not occur even under a similar sheet-pile-wall condition. We concluded the reason why the bottom soil of the ditch consisted of clay of low plasticity (CL).

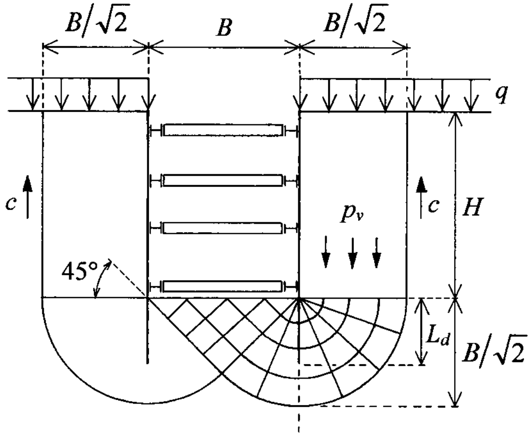
We examined the stability against heaving for the ditch bottom soil under the following two cases:

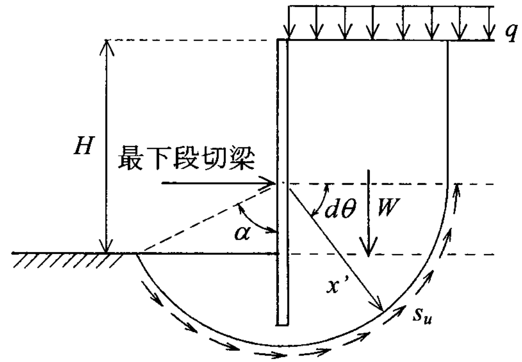
2005/05/07

Two cases:

(1) *H* = 0.370m (2004/02/29), the maximum hydraulic head difference during the continuous observation period,

(2) *H* = 0.934m (2005/05/07), the maximum hydraulic head difference after heavy rain.



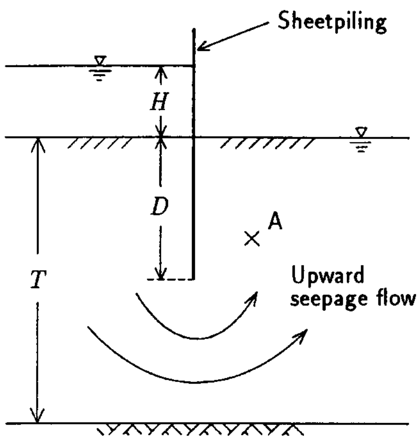


Even under the most severe condition on 2005/05/07 (H=0.934m after heavy rain),
(1) Stability number N_b against heaving of the bottom soil of the ditch were equal to 1.804 (<4.0).

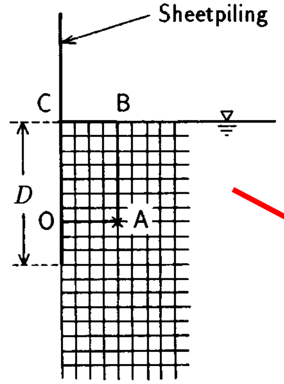
(2) Safety factor F_s against heaving of the bottom soil of the ditch were
F_s=3.160 > 1.5 based on the method proposed by Terzaghi & Peck,
F_s =3.483 > 1.2 based on the method of the Architectural Institute of Japan.

The bottom soil of the ditch consisted of clay of low plasticity (CL), so boiling did not occur even with a high ground water level. And the bottom soil of the ditch was also very stable against heaving.

Prismatic failure Concept considering Friction (PFC)



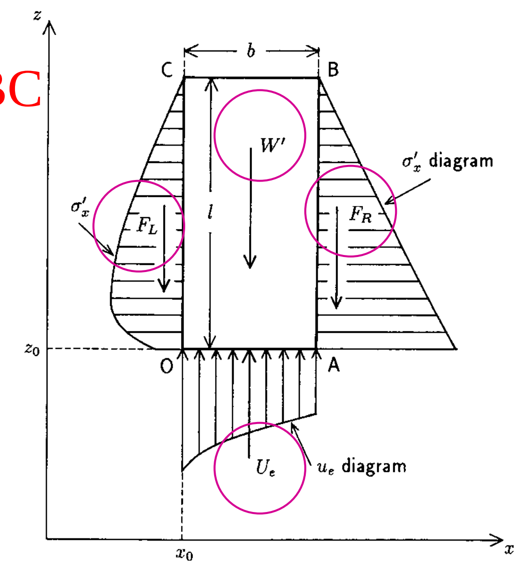
(a) Cofferdam



(b) Prism

Forces exerted on a prism

Prism OABC



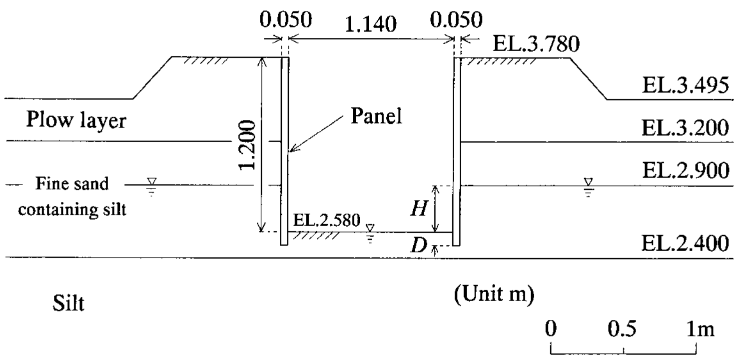
$$F_s = \frac{W' + F_L + F_R}{U_e} \qquad (3)$$

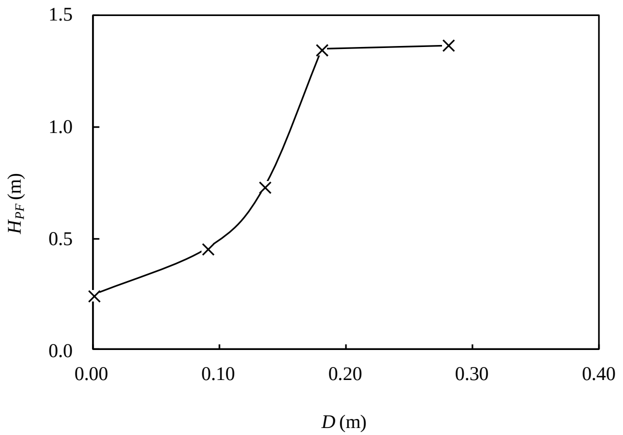
The critical prism is determined by the condition that the minimum safety factor $F_{s\,\min}$ becomes just equal to 1.0 among all of the prisms.

The hydraulic head difference at the condition $H=H_c$ is defined as the critical hydraulic head difference.

Countermeasures against seepage failure

(1) Increase in the penetration depth of the panel



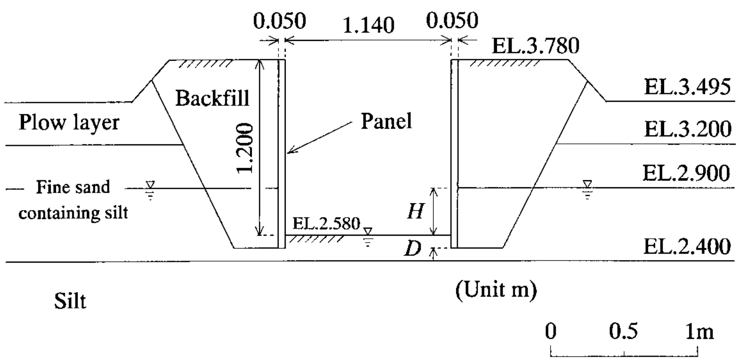


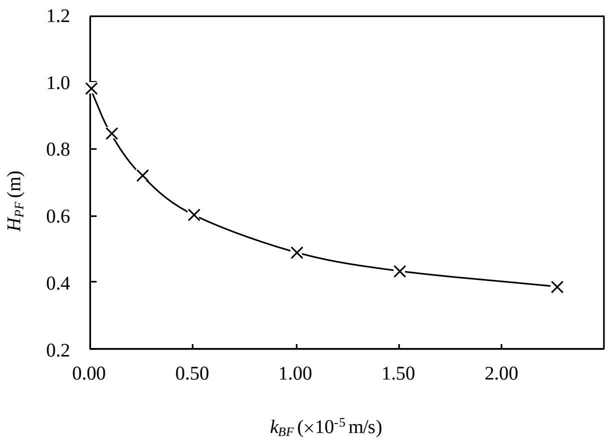
Right figure shows the relationship between the depth of the panel D and the theoretical critical hydraulic head difference H_{PF}.

It is observed from Figure 14 that H_{PF} efficiently increases with increase in D. H_{PF} however does not increase more with increase in D beyond 0.18 m, because the less permeable silt layer appears for the depth $D \geq 0.18$ m in this site.

Countermeasures against seepage failure

(2) Decrease in the coefficient of permeability of backfills

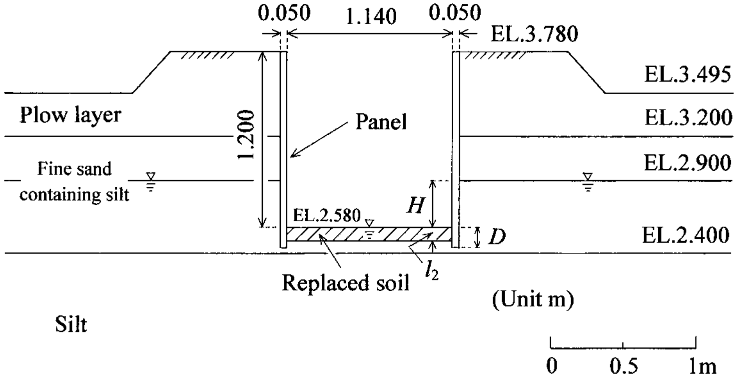


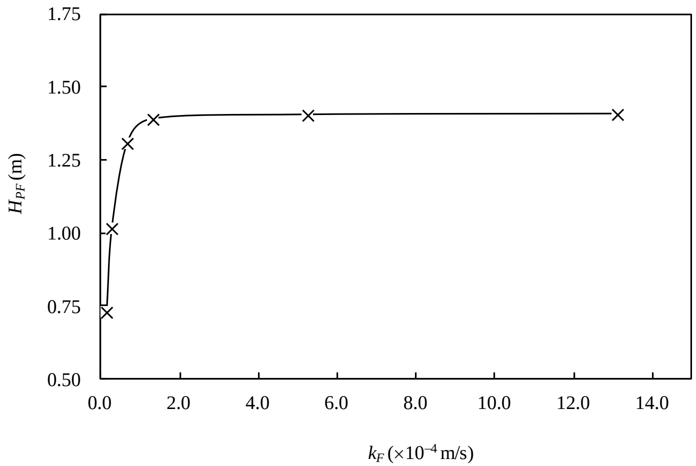


Right figure shows the relationship between k_{BF} and H_{PF}, it is found from the figure that the value of H_{PF} increases and converges in the vicinity of 1.0 m with decreasing k_{BF}. Less-permeable backfill is also effective in increasing stability against boiling of the bottom soil.

Countermeasures against seepage failure

(3) Replacing the upper part of the bottom ditch soil with an inverted filter





Right figure shows the relationship between k_F and H_{PF}. It is observed from the figure that H_{PF} effectively increases with increase in k_F. The H_{PF} value is given as 0.729 m for k_F = 1.31×10^{-5} m/s which corresponds to the case with no replacement, and is given as 1.390m for the coefficient (k_F = 1.31×10^{-4} m/s) ten times as large as the above one. Thus replacing the upper part of the bottom ditch soil with an inverted filter is also effective in increasing stability against boiling.