A Case Study of Ground Cave-in due to Large Scale Subsurface Erosion in Old Land Fill

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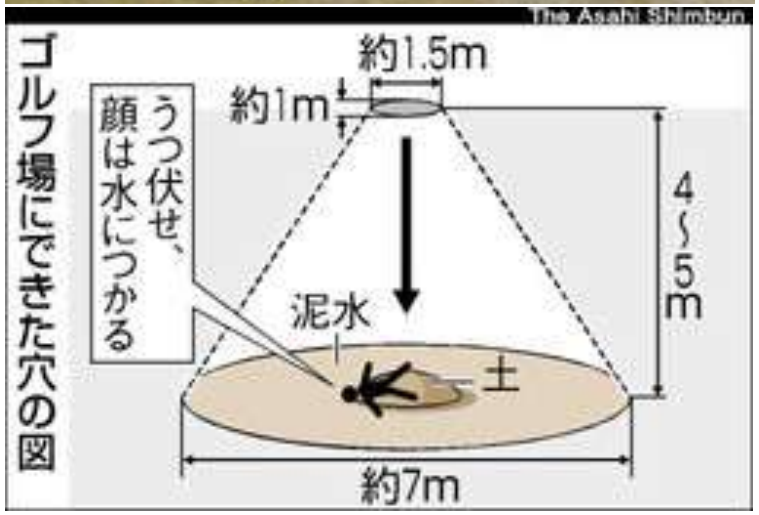
Accident of ground Collapse

A sudden collapse of the ground
in the fairway of a golf course in Hokkaido
on April 2, 2009
A woman fell and found dead.

Although the golf course was daily checked by maintenance staff, they could not get any sign of the hidden hole even in the morning of the accident. The ground collapse seemed to have happened all of sudden, as the victim's son who walked just a couple of meters behind her saw her suddenly disappearing into the ground.



（Hokkaido shinbun web **04/03 12:58**、Asahi web）

Inside the hole (2 days after the collapse)

The hole was 5m deep and 7m wide at the bottom.

Topography and ground condition

Originally built more than 15 years ago in hilly land, by filling a valley with local soil.

Mud rock covered with silty volcanic ash.
The land fill of 10 to 15 meters thick.

Gentle slope in the 8th fairway
There used to be a stream along the east-west direction at the location of the collapse.

Several artificial ponds around the fairway for water hazards

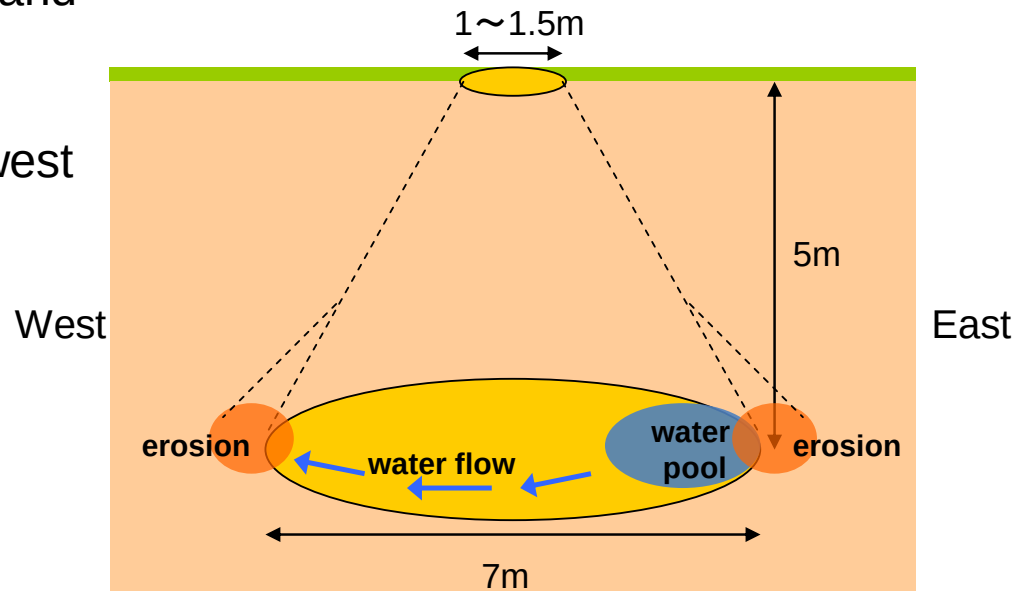
When the accident occurred, the ground water level was considered to be higher than usual, as it was the snow thawing season.

Underground cavity

A flask shape with a 1 m wide opening at the ground surface and was 5m deep and 7m wide at the bottom.

There was an about 0.6m deep shallow water pool in the east side of the hole, and the water flew to the west direction.

Noticeable erosion was found in both west and east sides.

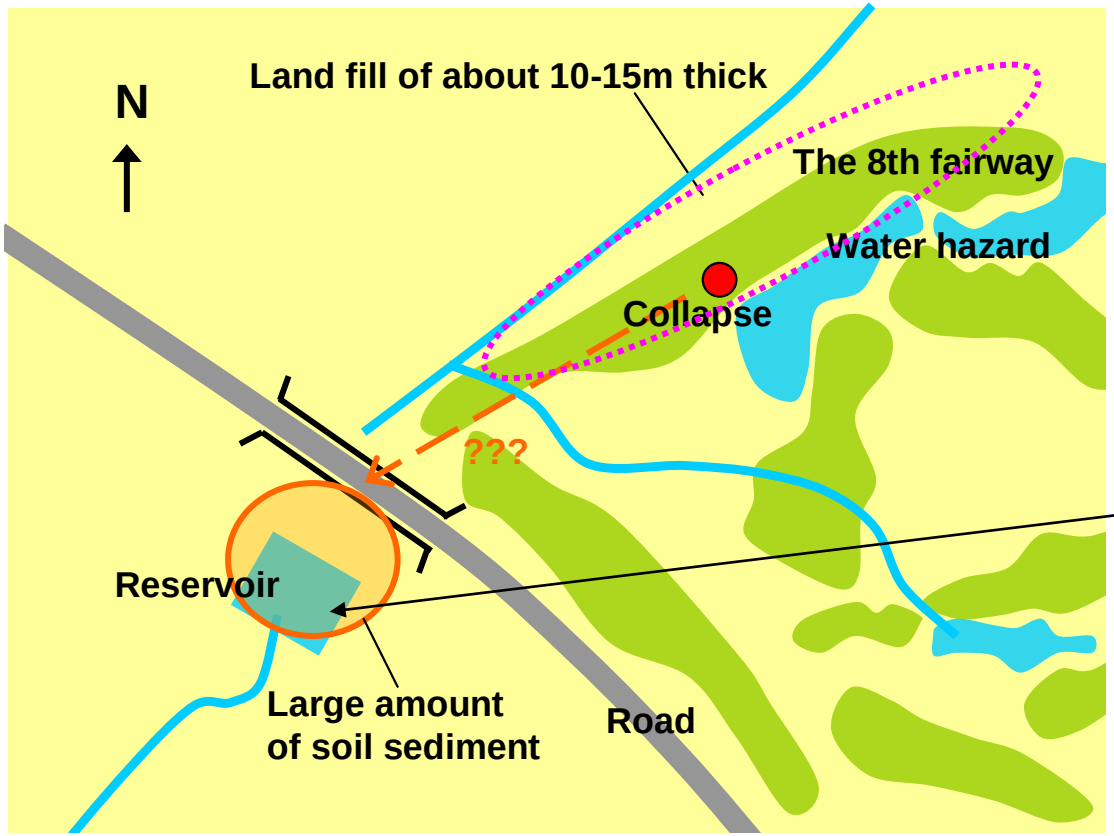


（erosion in the west side, April 3, 2009）

Possible destination of missing soil

The volume of the soil for the cavity is about 75m^3.

There is a water reservoir in the down stream of the 8th fairway, where large amount of soil sediment was found. It may be the possible destination of the soil flown from the cavity.



Investigation by excavation

AM, May 21, 2009

Asahi shinbun web 090516

East

West

Excavation

East

West

Investigation by excavation

PM, May 21, 2009

Excavated soil was mixture of volcanic clay, silt, sand, and relatively small gravel

Roots of plants were also included, which indicates the excavated strata was filled soil.

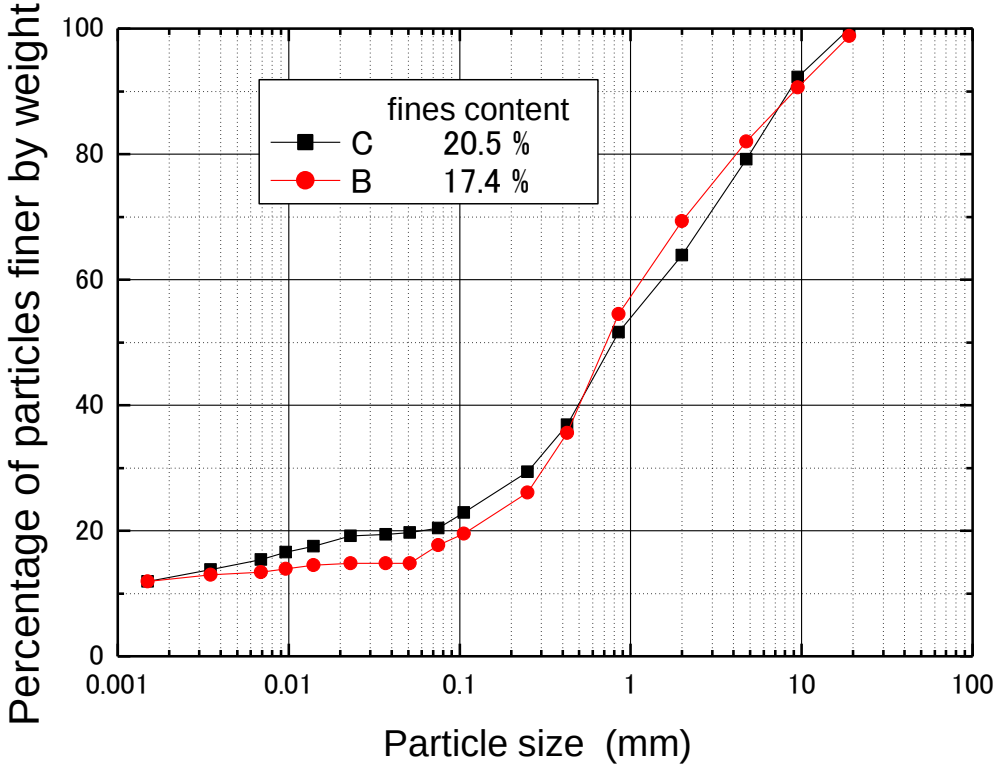
Plant root

Sand with high water content

Soil in the excavated wall (GL-approx.6m)

Soil Properties

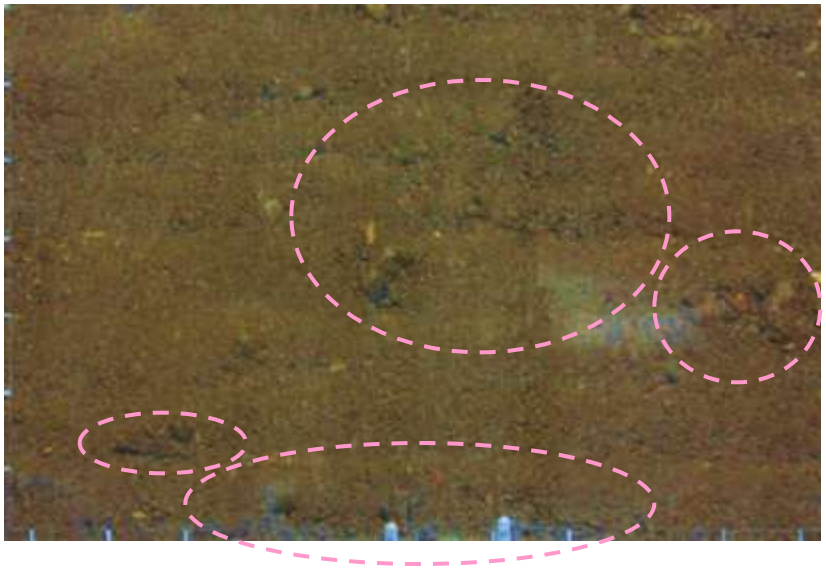
Particle size distribution



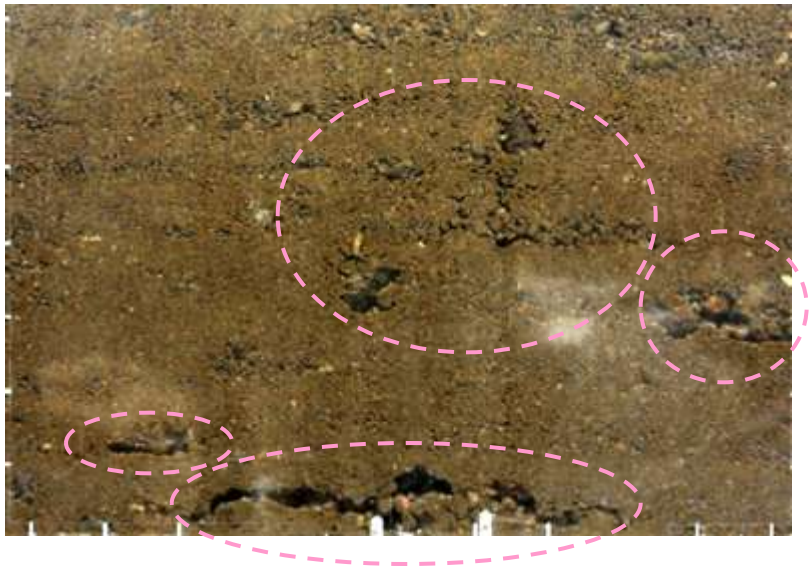
Atterberg limit

	B	C
Liquid Limit	24.40	23.20
Plastic Limit	18.36	15.27
Plasticity Index	6.04	7.93

Loss of fines due to water infiltration



Initial state



After the repeated water infiltration of 24 times

The soil seemed to be highly permeable. When the repeated water infiltration was applied to the compacted soil sample, fine particles around gravels tended to easily move and flown out with water, resulting in the formation of scattered voids in the sample

Discovery of soil pipe

AM, May 22, 2009

a lateral ground cavity: soil pipe

GL-8m , at the boundary between original stiff ground and filled soil
about 20m west from the center of the hole.

the clear sound of water flow
at least 6m in length, 2m in width

A path through which soil with water was transported out of the hole.

Search for the destination of the water flow in the soil pipe

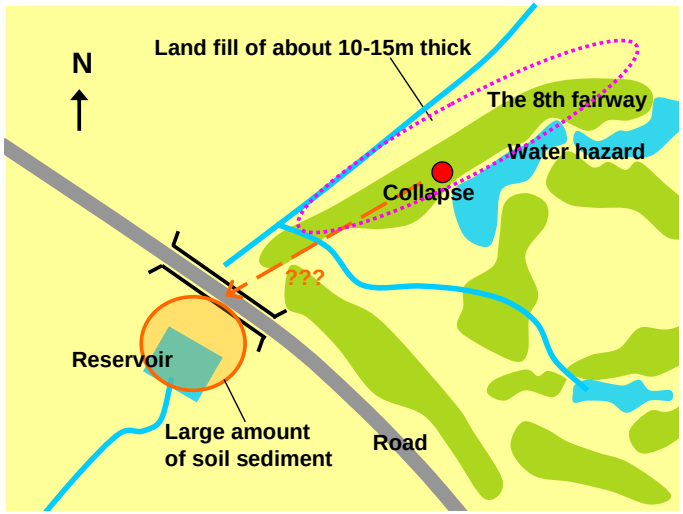
PM, May 22, 2009

Water colored by fluorescent paint was poured into the cavity

20 minutes later

the colored water started flowing out at the reservoir, 700m down from the cavity.

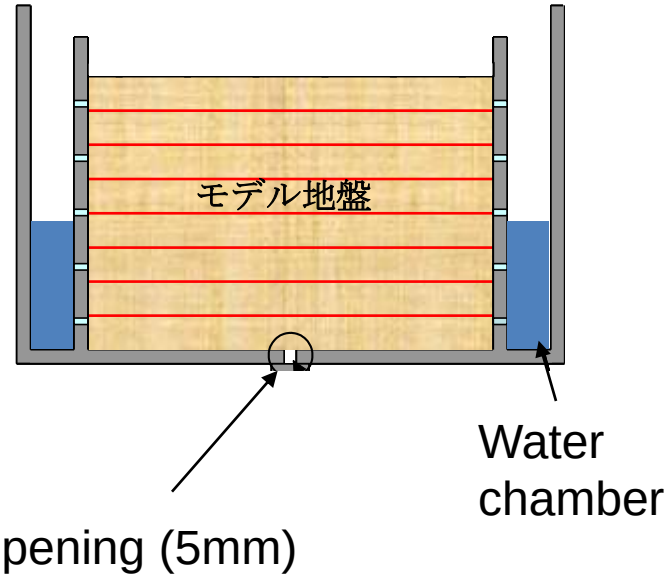
A soil pipe seemed to be formed in the ground between the collapsed location and the reservoir

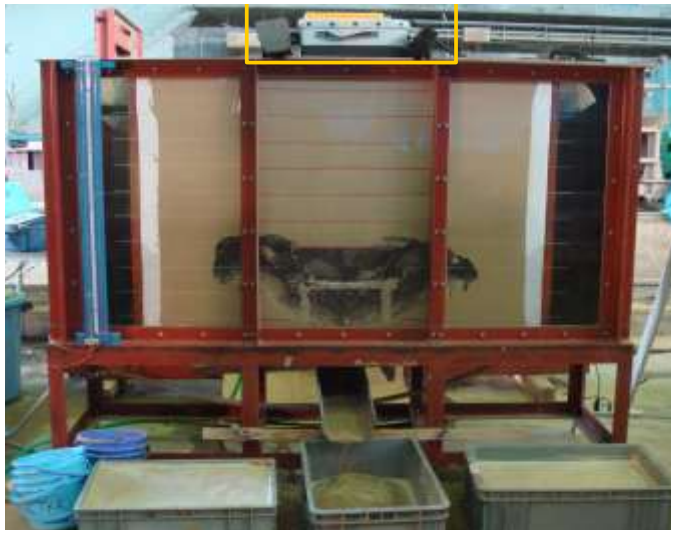


Model test of ground cavity

According to the previous investigation of the mechanism of ground cavity and surrounding loosening due to the failure of sewer pipes, the state of water infiltration and soil properties are the governing factors for the growth of the ground cavity and loosening, while the failure of pipe is a trigger of the phenomenon.

Soil chamber（2m×0.5m×h1.2m）

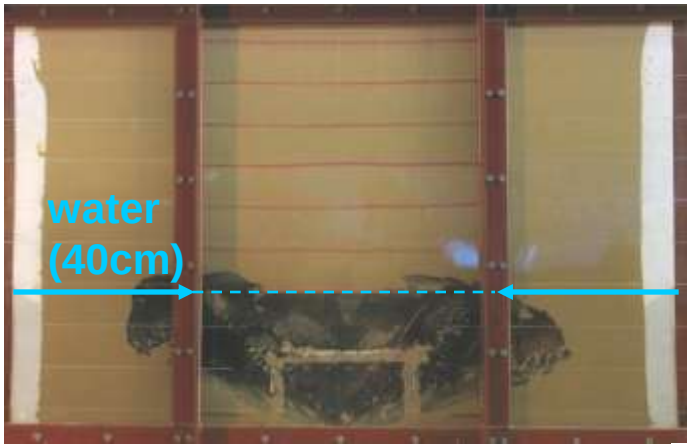




Cavity and loosening formed in the chamber

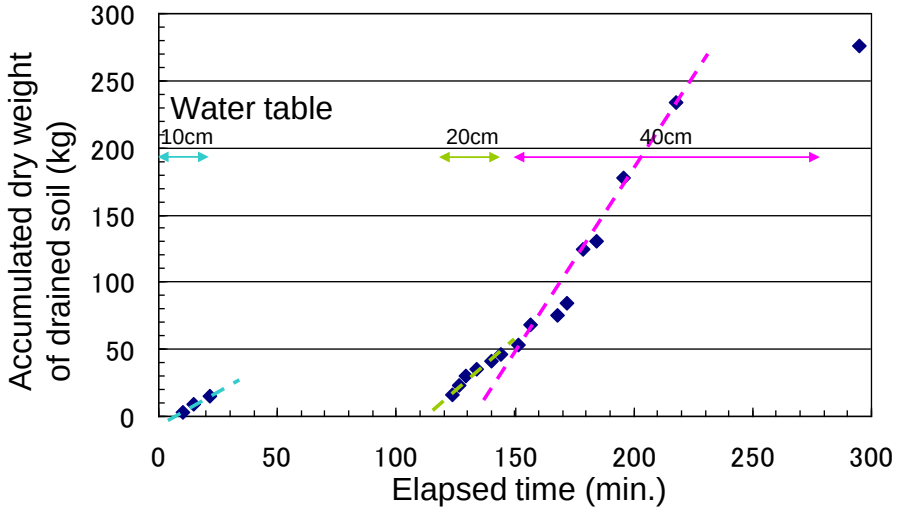
Model test of ground cavity

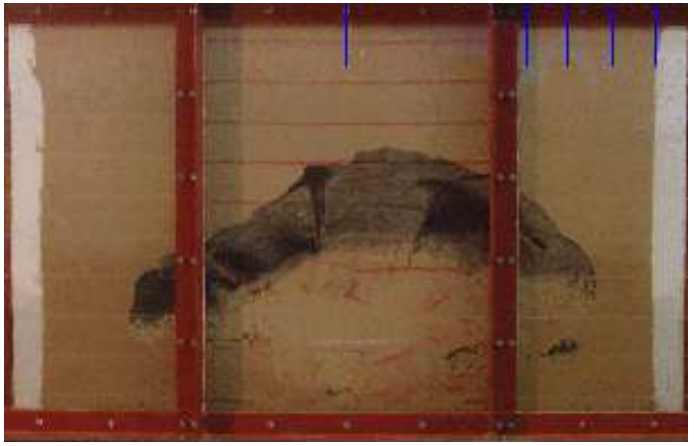
16 min.
after water table was raised to 40cm



84 min.
after water table was raised to 40cm

Soil above the cavity fell





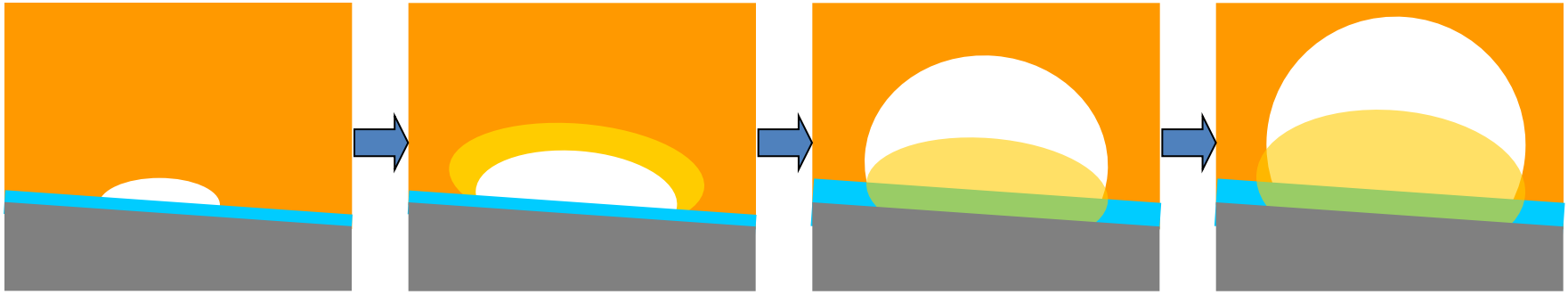
after the test

Mechanism of large hole formation

Original stream

Land fill constructed

Natural water path is formed
along the old stream



Formation of small cavity
due to erosion
at some point

Erosion progressed
Cavity and surrounding
loosening expand

Failure of cavity ceiling

By repetition of erosion
and failure of cavity ceiling,
a cavity moves upward

Possible factors for large cavity formation

Soil properties
The soil was permeable, subjected to the erosion relatively easily.
Fines can be first flown away with water, which created ground loosening around the cavity.

Ground water
There was a subsurface water path which can transport soil out of the hole with water. There is also seasonal change in ground water level, which may accelerate the cavity growth as the saturation of soil at the ceiling helps failure and expansion of the cavity.

Escape route of soil
Direct trigger of the formation of natural water path may be a defect of drainage pipe. But the state and the current condition of the pipes have not yet examined.