A Study on the Survey of Levee Deformation around Sluices

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1. PREFACE

The floodplain (1,450 km^2) along the Ishikari River downstream is an area subject to ground subsidence consisting of at least 70% peaty soft ground. After development in the area over approximately 100 years, 1,300 km^2 of the area has been in use, its population has reached one million. In the floodplain, levees have been built over an extension of 950 km and sluices have been installed at 550 locations.

In response to the flood [1)] that hit the area occurred in 1981, 169 flood control measures were taken in an effort to prevent levee failures, among which 42 measures (25%) were taken at sluices. This indicates that sluices are the weak point of the continuous levee. These kinds of disasters result from loose soil or cavities developed in levees around sluices in association with ground subsidence. It is therefore necessary to develop a survey method to accurately understand the actual conditions of levee deformation. Technical standards [2), 3)] only show schematic drawings of levee deformation and the essential points of levee surveys.

Against this background, this paper proposes a survey method to accurately understand the actual conditions of levee deformation around sluices.

2. METHODS FOR INVESTIGATING DEFORMATION

In the latter half of the 1970s, disasters caused by water leakage from levees around sluices came to light; however, the actual conditions and risk of levee deformation was not fully understood and an in-depth survey was yet to be undertaken. To investigate levee deformation, levees were open-cut, which requires huge construction costs and a long construction period. In the wake of the 1981 flood [4)], an investigation method to clarify deformation accurately, at low cost and in a short period of time was designed.

Table 1 lists the investigation procedure and techniques. In field surveys, deformation is analyzed at each step and analytical accuracy is improved by using many techniques in the following steps. The survey area should be up to 30 m up and down streams in the transverse direction, and from the river bank to the channel on the land side in the vertical direction.

Table 2 shows survey sites and observation points. Deformation that accelerates river water seepage and inflow, and deformation hidden under vegetation or bank protections need to be found out and surveyed.

Table 1 Survey procedure and techniques

Survey items	Survey techniques
1. Sources	Topography, geology, design, construction records, existing data, etc.
2. Planning	Objectives, scope, schedule, procedure, applicable techniques, etc.
3. Field survey	Confirmation of the conditions of sluices, levees, surrounding environments and deformations, photos, etc.
4. Levee and structure surfaces	Observation, measurement, soil auger test, hammering test, sampling, photos, etc.
5. From levee surface down into soil layers	Sounding, boring, soil test, permeability test, photos, etc.
6. Levee excavation	Soil profile observation, measurement, soil auger test, sampling, photos, etc.
7. Observation/ experiment	Field observation, field experiment, model experiment, etc.

Table 2 Observation points

Survey targets	Observation points
Difference in the level of ground surface	Subsidence, uplift, difference in level, cracks, etc.
Surface soil properties	Water content, loosening, cracks, depression, cavities, permeability, etc.
Vegetation	Growth, species, hairy root conditions, etc.
Connection with structures	Differential settlement, bonding with soil layers, soil properties, water content, seepage water, opening, etc.
Concrete	Damage, subsidence, cracks, deterioration, leakage, etc.
Joints	Damage, opening, difference in level, deterioration, fracture, etc.
Wing walls, aprons	Damage, difference in level, opening, cut-off plates, cavities, scouring, etc.
Survey holes	Soil properties, cavities, pore interconnectivity, leakage, etc.
Channels, bank protections, etc.	Damage, difference in level, subsidence, scouring, cavities, etc.

Specific examples are provided using the photos below.

Photo 1 shows a case of levee surface deformation right above a box culvert. After removing grass, observation and measurement must be made to clarify the location of uneven surface, and deformation, loose soil and cracks at the ends of the uneven surface.

Photo 2 shows a deformation at the end of a parapet. After removing grass and debris, observation and measurement must be made to clarify the openings and loose soil around the structure, subsidence of and damage to the bank protection, cavities under the bank protection and other conditions.

Photo 3 shows a deformation under soil layers. Strings are tied in a grid pattern (1.0 m × 1.0 m) to identify the location of the deformation. Bonding between the box culvert and the soil layers, loose soil, cracks, cavities, spring water, water paths, soil properties and other conditions must be observed and necessary measurements must be taken.

Photo 4 shows a deformation below the bottom slab of a box culvert. Soil is dug up to approximately 0.5 m below the bottom slab to observe soil separation, loose soil, cracks, cavities, spring water, water paths and other disturbed soil conditions and to take necessary measurements.

The clarification of the detailed conditions of a deformation using the techniques described above enables the identification of the configuration of the deformation and the appropriate evaluation of the risk associated with the deformation.

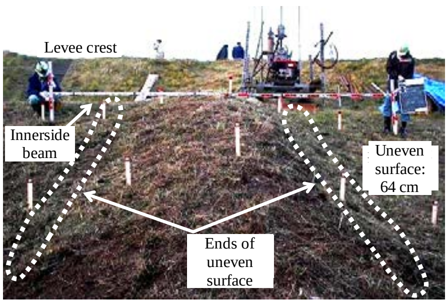


Photo 1 Measurement of uneven surface of a levee

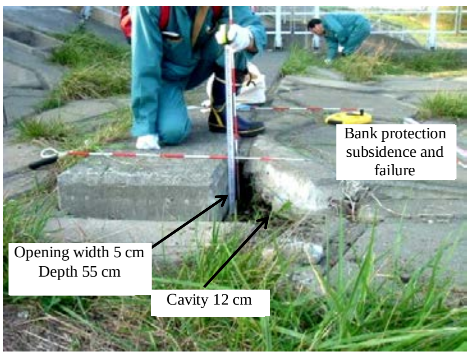


Photo 2 Measurement of parapet end

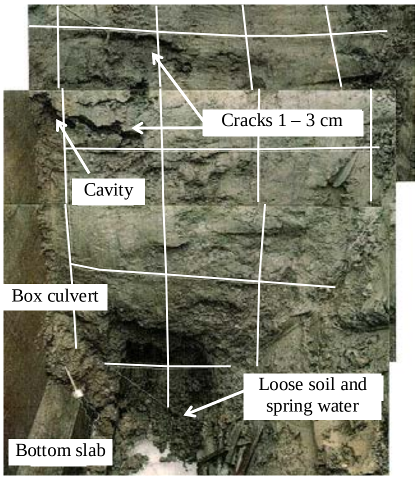


Photo 3 Measurement in soil layers

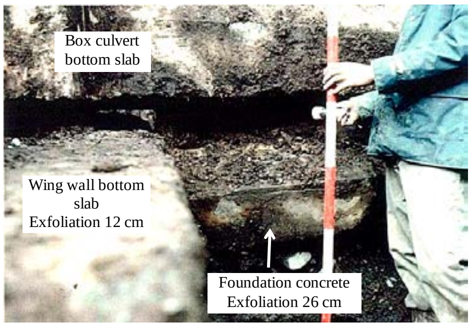


Photo 4 Measurement of box culvert bottom slab

To investigate a deformation around a box culvert, the location of the box culvert must be accurately projected on the levee surface and three survey points should be set at 0.3 m, 0.5 m and 1.0 m away from the box culvert in consideration of the area where minor deformations are developed.

Figure 1 shows a *qc* value distribution map obtained through a 2-t Dutch double-tube cone penetration test, in which the proposed survey techniques were used, overlapped with a soil layer observation map obtained through an open-cut survey.

The areas enclosed with the dotted lines in the figure indicate spots where cavities were observed, and the areas enclosed with the dashed lines in the figure indicate estimated areas of loose soil, the areas enclosed with the bold dotted lines indicate areas where $qc \leqq 0.5M/m^2$, and the circles indicate cone self-settlement points.

In terms of *qc* value, cone self-settlement points, which were considered to have cavities, and an area where *qc* was $0.1M/m^2$ or less were observed at measurement points CL-1 and CL-2 above the box culvert and at CL-3, CL-4 and CL-5 lateral to the bottom slab..

Areas where *qc* was measured to be $0.5M/m^2$ or less, which were considered to have loose soil, were CL-1 through CL-5 lateral to the box culvert and the bottom slab at upper and lower levels.

These measurement results agreed with the areas of cavities and loose soil estimated based on soil observation.

Accordingly, it was proposed that qc $\leqq 0.5 \mathrm{M/m^2}$ should be the criterion for determining loose soil and qc$\leqq 0.1 \mathrm{M/m^2}$ for determining cavities.

This survey method is introduced in technical reports [5), 6)] and is presently used widely in many rivers.

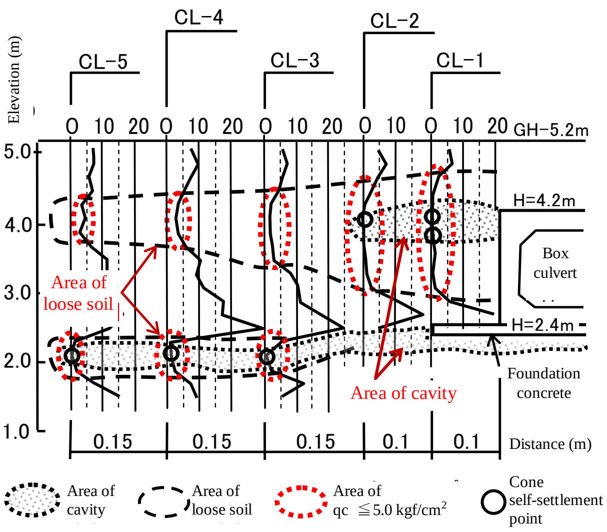


Fig. 1 Soil profile observation and different forms of levee deformation detected based on qc measurement

3. ACTUAL CONDITIONS OF LEVEE DEFORMATION

Field surveys were conducted using the method discussed in the previous section. The results are shown below:

Photo 5 shows a case of uneven surface with a difference in level of 50 cm on a slope right above a box culvert as a result of differential settlement. A crack accompanied with differences in level and openings was developed at the upper part covered with lawn, the bank protection at the bottom was significantly deformed, the ground around the pier was settled, and cavities were formed underneath the bank protection.

Photo 6 shows a deformed soft soil layer 21 m in thickness around a box culvert. There were a difference in level of 60 cm, cracks, and loose soil along the soil layer boundaries indicated by the broken line and the dotted line. A continuous cavity was developed under the bottom slab.

These two cases represent a deformation type that is highly likely to increase permeability through levee surfaces and around sluices.

Photo 7 shows a slope landslide 50 m in width across a sluice, which was judged to be caused by leakage through the sluice since there was peat soil below the box culvert and no overflow was seen.

Photo 8 shows a case of piping caused by cavities developed under a sluice in a soft layer 20 m in thickness and part of the levee was washed away.

In Photo 9, a 180-m section of a levee was washed away by the overflow (5 – 10 cm) that occurred while a flood control measure against leakage through the sluice was in progress, resulting in an inundation area of 350 ha.

These three cases indicate that cavities and other forms of levee deformation associated with differential settlement are generally seen in peaty soft ground and are likely to directly lead to levee failures in cases of flooding.

Accordingly, the cases shown above suggest that deformation develops sequentially and demonstrate the effectiveness of the method in accurately understanding levee deformation.

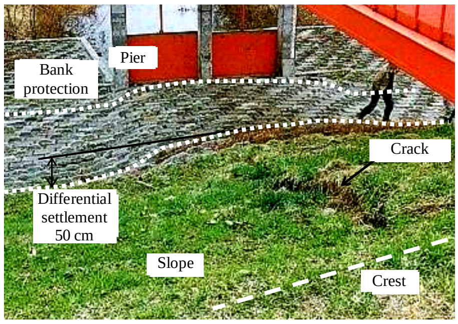


Photo 5 Differential settlement on slope

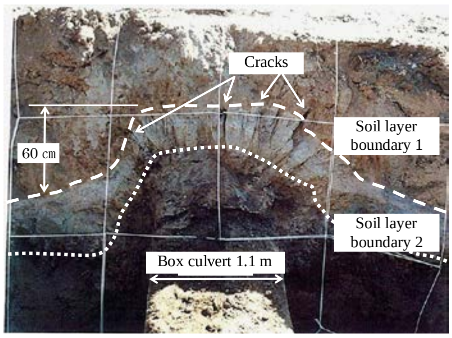


Photo 6 Soil layer deformation

Photo 7 Slope landslide on the land side

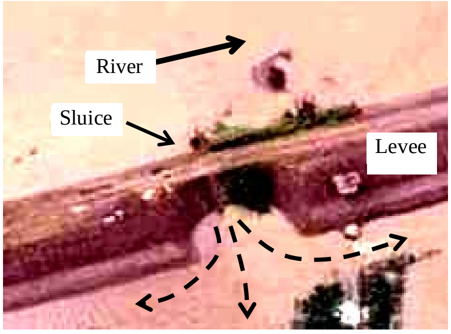


Photo 8 Leakage through under a bottom slab

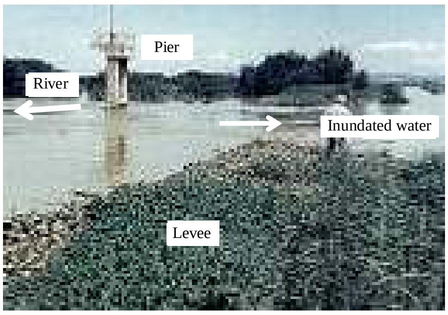
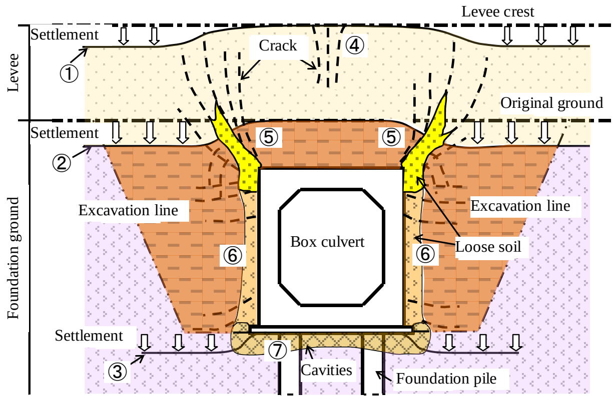


Photo 9 Levee failure at sluice

4. AREAS OF DEFORMATION DEVELOPMENT

Figure 2 shows the profile of a box culvert deformation model approximately 20 years after since its installment, which was revealed by an open-cut survey based on the results obtained in the preceding sections, It was found that differential settlement occurred between the levee and the box culvert, resulting in continuous differences in the level of the soil layers, loose soil, cracks and cavities developed in an area approximately 4.0 m to the right and left from the sluice and from the crest down to approximately 2.0 m below the bottom of box culvert.



① Levee crest ② Original ground ③ Differential settlement at the bottom
④ Cracks right above the box culvert ⑤ Area of loose soil above the box culvert
⑥ Area of loose soil at the lateral sides of the box culvert
⑦ Cavities at the bottom of the box culvert

Fig. 2 Box culvert cross-section deformation model

5. SUMMARY

This paper proposed a survey method regarding levee deformation around sluices and actually conducted a field survey using the method. The findings obtained from the study are summarized below:

(1) On peaty soft ground, deformation develops in levees around sluices as a result of differential settlement.

(2) A survey method for levee deformation related to sluices was devised and a field survey was conducted using the method to verify its effect. It was proposed that qc $\leqq 0.5\mathrm{M/m^2}$ should be the criterion for determining loose soil and qc$\leqq 0.1\mathrm{M/m^2}$ for determining cavities.

(3) It was suggested from the study that the area of deformation was approximately 4.0 m to the right and left from a sluice and from the crest down to approximately 2.0 m below the bottom of box culvert.

Accordingly, this paper proposed a method of surveying levees around sluices along the Ishikawa River downstream. The study results show the basics for safety measures necessary for all levees around sluices constructed on soft ground and contribute to the improvement of the safety of continuous levees in the future.

REFERENCES

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