

# On The Inspection of River Levee Safety in Japan by MLIT

Yusuke HONJO <sup>a</sup>, Hirotohi MORI <sup>b</sup>, Masanori ISHIHARA <sup>c</sup> and Yu OTAKE <sup>d</sup>

<sup>a</sup> Gifu University, Gifu Japan

<sup>b</sup> National Institute for Land and Infrastructure Management, MLIT, Tsukuba, Japan

<sup>c</sup> Public Works Research Institute, Tsukuba, Japan

<sup>d</sup> Niigata University, Niigata, Japan

**Abstract.** The ministry of land, infrastructures, transportation and tourism (MLIT) of the Japanese government maintains governmental managed river levee for the safety against flood whose total length is more than 10,000 km. The design standard of river levee had been traditionally done based on so called *shape based specification*, where levee is judged to be safe as long as a section satisfies the specified dimensions. In 2002, this policy had been changed and a new inspection guideline which is based on the modern soil mechanics principles had been introduced. The method mainly consists of the non-stationary seepage analysis followed by the circular slip line stability analysis. The exit gradient and uplift pressure are also checked based on specified safety factors. The way of the safety assessment is that, first a river is divided into so called *a continuous strip* (CS) which is judged to have similar configurations, geotechnical and hydraulic conditions. The typical length of a CS is half to several km long. Then a *representative cross section* (RCS) that is considered to represent all the CS section is selected. At RCS, detailed soil investigations are carried out, and the inspection is done to assess the safety of the section for stability and piping. A CS is judged to be safe if all the verification items satisfy the specified safety factor, but judged to be NG (no good) if any of the items could not fulfill the threshold value. The first round assessment at year 2011 indicated, only 60% of the all levee is judged to be safe for all verification items. 25% of the levee could not satisfy the stability requirement, 30% piping requirement, and 14% the both requirements. In the paper, the details of the verification methods are described. Furthermore, some recent flood events are introduced. Finally, further challenges for the second screening of the safety of levee are discussed.

**Keywords.** Levee safety inspection, seepage stability, piping, MLIT, levee safety, design.

## 1. Introduction

In Japan, 51% of the whole population, 71% of the whole properties are concentrated in flood plain areas that is only 10% of the whole land space. This is because the Japanese islands are very mountainous where only 30% is non-mountainous area.

Japanese islands are located in the monsoon climate area where average annual precipitation is 1700mm. The rainfalls are concentrated in the rainy season in June and July, and the typhoon season around September. Because the Japanese islands are relatively small, the length of the rivers is relatively short, and runoff time of the floods is also short. Also the duration of the flood is not very long.

It is said that Johannis de Rijke (1842-1913), a Dutch river engineer who came and stayed in Japan from 1873 to 1903, who had much

contributed to the development of Japanese river engineering, had said “it is not a river, but a water fall” when he made investigation in one of the rivers running into Japan sea through a mountainous area. This words symbolically highlighting the characteristics of the rivers in Japan.

This paper tries to describe the inspection procedures that are carried out by the Japanese government in recent years. The procedure naturally reflects the characteristics of the rivers in Japan. In next section, the brief flood control history of Japan is described. In chapter 3, the inspection procedures as well as results are presented. Finally, future challenges concerning river levee safety assessment are discussed.

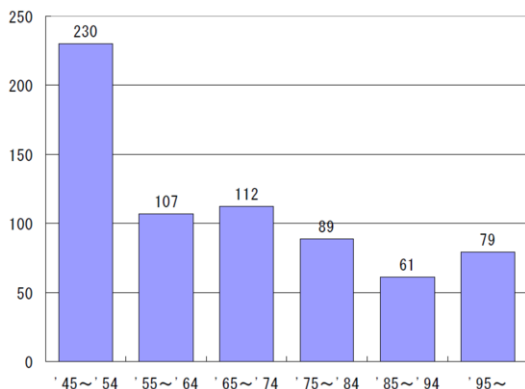
## 2. History of River Flood Control in Japan

### 2.1. River Levee Design before 1990th

Japan has its own long history for flood control. However, modern flood control techniques are introduced from Meiji years (1866-1912), which was mainly transferred through Dutch river engineers hired by the Japanese government. The river act was established in 1896, which is the starting point of modern river administration. The main purpose of the act at that time was flood control the main policy for designing river levee was so called *shape based specification* at that time. It is recorded in one of the reports written by C. J. van Doorn (1837-1906), a Dutch river engineer hired by the Japanese government, as follows:

*The width of crown be 4.8-6.1m, the gradient of front slope be 2.5 to 1, that of back slope be 2 to 1, and the height of the levee be more than 0.6-0.9m higher than the past maximum flood level.*

After the Second World War, between 1945 and 1960, many flood occurred due to the poor river levee conditions and other flood controlling facilities. Many efforts have been put to develop river levee during and after this period. Figure 1 presents the number of river levee failures after 1945. There were many failures before 1955, but the number has been reducing. About half of the failures are by overtopping of the flood.



**Figure 1** Number of river levee failure between 1945 and 2002.

The river act had revised in 1964, and water resource utilization view point had been added on top of the flood control. In order to support this revised act, “the structural orders for the river management facilities” was established in 1976 which gave the bases for river levee administration today.

The river act has been revised again to add the river environmental development in 1997 and maintenance view points in 2013. This is the river act we are having today.

### 2.2. From Quantity Development to Quality Development

It is recognized today that the river levee administration in Japan is changing from *quantity development to quality development*. In this context, the former implies the shape based specification of river levee. In this scheme, an embankment that is not satisfying the specified dimensions is judged to be incomplete levee, and expansion of the section is required to fulfill the specification.

On the other hand, the quality development implies levee need to be checked by the modern soil mechanics based method and enforcement measures to be taken if it is judged unsafe.

This concept was gradually developed in 1990<sup>th</sup>. The idea was to move from the shape based specification to the direct verification of performances and functions that are required for river levee by the mechanical design calculations.

As a result, “a river levee design guideline” was published by MLIT (the ministry of land, infrastructures, transportation and tourism) in 2002. The guideline describes the external force evaluation methods, verification procedures and safety criteria for seepage instability, erosion and earthquake. As far as the seepage instability is concerned, the guideline specifies procedure for setting rainfall and flood wave, a method for unsteady saturated-unsaturated seepage analysis, and circular slip method to check the stability of front and back slopes of levee based on the results of the seepage analysis. The details of the inspection procedure for seepage instability are presented in the next section.

### 3. Procedure of Inspection Against Seepage

#### 3.1. "Continuous Strip (CS)" and "Representative Cross Section (RCS)"

The first step of inspection is to divide continuous river levee into *continuous strips (CS)*. The *continuous strip* is set to make the inspection more efficiently. It is a stretch of river levee whose typical length is from several hundred meters to a few km, and usually separated by branching and channeling points of a river, or for different flood plains. The conditions such as characteristics of the river, geological and topological conditions, land usage of the hinter land, and characteristic of flood are also considered in determining a CS.

A *representative cross section (RCS)* is selected for each continuous strip. It is for this RCS the inspection calculation is made. It is important to know that once the RCS is judged to be necessary for reinforcement (NG: no good), all the stretch of the CS is judged to be NG.

#### 3.2. Method of Inspection

Major damages to river levees by seepage are:

- (1) Slip failure caused by rises in phreatic surface within the embankment by rain or penetration of river water, and
- (2) Piping failure caused by rise of pore water pressure within the foundation ground or the embankment, which causes high exit gradient or uplift of low-permeable soil layer.

In safety verification, levees should be checked on whether they satisfy the required safety levels or not by setting external forces and using methods appropriate for each item to be checked.

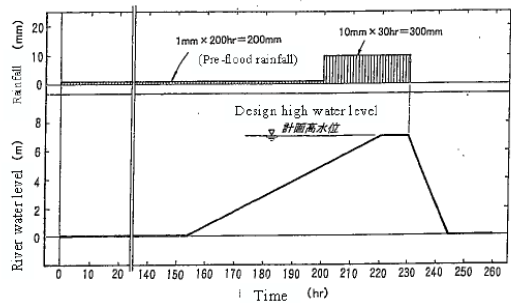
Design external forces against seepage are "flood states that reach the design high water level" and "rainfall during flood of the design scale". External forces should be set so as to satisfy these values. Safety is also verified against rainfall or flood waves during the largest flood in the past (which showed the highest water level peak or the longest flood duration). The concept of setting the basic conditions for rainfall and flood wave is summarized in Table 1. Furthermore, a typical example combination of

rainfall and river water level waveform is presented in Figure.2.

The breakings of levee by seepage can be classified into the following two items:

**Table 1** The concepts of setting basic conditions

	Rainfall		Water level of river
	Total rainfall	Rainfall intensity	
Initial condition	About the mean monthly precipitation during the rainy season in an average year	About 1mm/hr.	About the normal water level
During flood	Designed rainfall	About 10mm/hr.	A trapezoidal waveforms with its peak at the design high water level.



**Figure 2.** A typical example combination of rainfall and river water level waveform.

- (1) Safety against slip failure during flood, and
- (2) Safety against piping failure of the foundation ground during flood.

The procedure for the safety verification for the seepage failure is illustrated in Figure.3, so as the control standards in Table 2.

In Table 2, "complicated embankment history" denotes unknown history or embankment that started in old times and has been repeated. "Landforms requiring attention" denote landforms that are prone to destabilizing levees, such as former river beds and crescentic levee lakes.

The safety of levee against seepage shall be verified by conducting unsteady saturated-unsaturated seepage analysis and stability calculation of the circular arc method. It is considered difficult to set soil parameter for the initial condition in unsaturated soil layer. Some

conservative default values are given in the design guide (JICE, 2012)

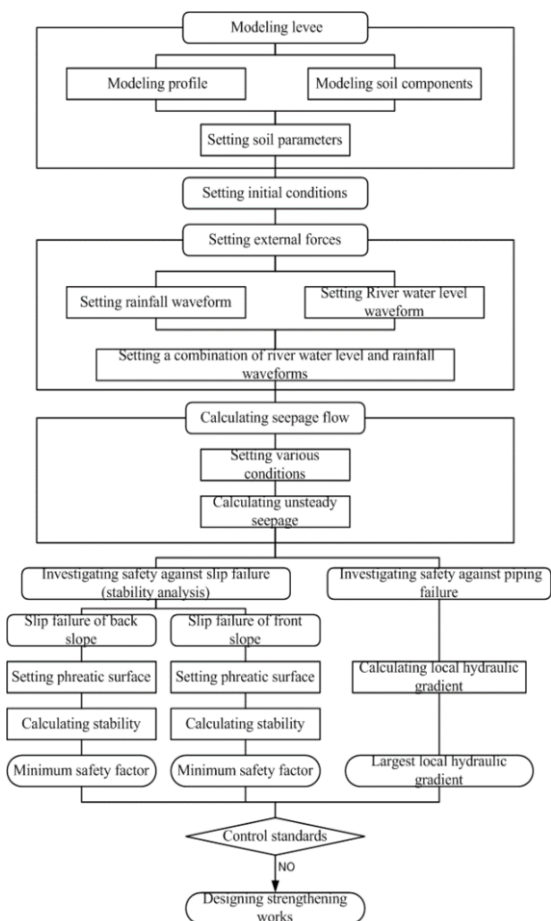


Figure 3 Procedure of safety verification against seepage

Unsteady seepage calculation involves tracing time historical changes in the position of phreatic surface and the head of water by giving unsteady external forces, determining the shape of the phreatic surface at the target time, and calculating local hydraulic gradients *etc.* from the distribution of the head. On the other hand, stability calculation of the circular arc method involves estimating phreatic surfaces that are most dangerous to the front and back slopes and determining safety factor against slip failure during flood.

The safety of the levee is verified by comparing the safety factors determined from local hydraulic gradients and stability calculation with the control standards shown in Table 2.

Table 2 Safety criteria against seepage

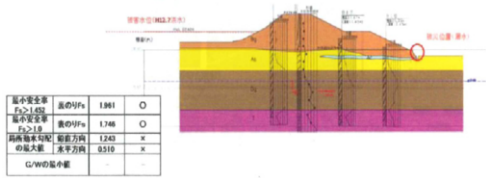
<p>■ <b>Safety against back slope slip failure:</b></p> <p><math>F_s \geq 1.2 \times \alpha_1 \times \alpha_2</math></p> <p><math>F_s</math>: Safety factor against slip failure</p> <p><math>\alpha_1</math>: Extra coefficient for the complicatedness of banking history</p> <p>For complicated banking history <math>\alpha_1 = 1.2</math></p> <p>For simple banking history <math>\alpha_1 = 1.1</math></p> <p>For newly constructed levee <math>\alpha_1 = 1.0</math></p> <p><math>\alpha_2</math>: Extra coefficient for the complicatedness of foundation ground</p> <p>For districts with damage history and/or landforms requiring attention <math>\alpha_2 = 1.1</math></p> <p>For districts without damage history or landforms requiring attention <math>\alpha_2 = 1.0</math></p>
<p>■ <b>Safety against front slope failure:</b></p> <p><math>F_s \geq 1.0</math></p> <p><math>F_s</math>: Safety factor against slip failure</p>
<p>■ <b>Safety against piping failure without molding</b></p> <p><math>i &lt; 0.5</math></p> <p><math>i</math>: Largest of local hydraulic gradients of the foundation ground near the toe of the back slope.</p>
<p>■ <b>Safety against piping failure with molding</b></p> <p><math>G/W &gt; 1.0</math></p> <p><math>G</math>: Weight of the molding</p> <p><math>W</math>: Lifting force acting on the bottom surface of the molding.</p>

### 3.3. Results of the inspection

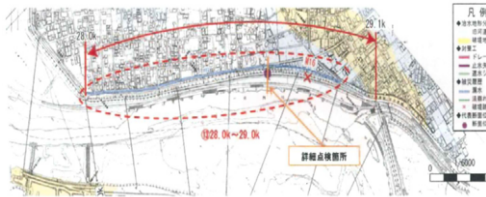
MLIT has completed the detailed inspection by the method presented above for the levee of the major rivers in Japan whose total length is about 10050 km by 2009.

An example of such inspection result is presented in Figure 4 (a) and (b). Figure 4(a) is the representative section taken from the continuous strip shown in Figure 4(b). The length of the strip in this case is 1 km from station 28.0 to 29.0 km. The station indicates the distance from the river mouth. The results of the inspection is summarized in the table in Figure 4(a), which presents the cross section is safe for both front and back slopes stability of the embankment, but is NG (no good) for local exit seepage gradient for both horizontal and vertical directions at the place indicated by a red circle in Figure 4(a).

Figure 5 illustrates the result of whole inspection for 10050 km length of the major rivers at January 2011. Only 59% of the levee is judged to be safe for both seepage failure and piping. 14% is NG by the both phenome, 11% is NG by seepage failure and 16% by piping.



(a) The representative section for the continuous strip and its inspection results.



(b) A continuous strip

Figure 4. An example of an inspection result.

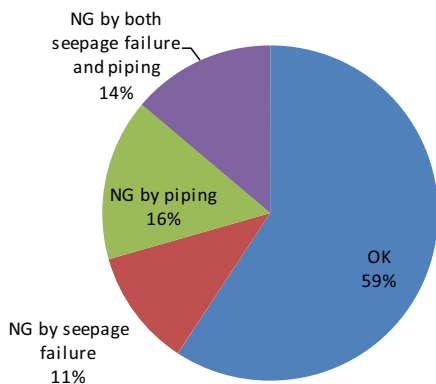


Figure 5 The result of the inspection (as of January 2011).

3.4. Discussions

The biggest issue of the result of the inspection is that the length of NG levee is too long, which makes it difficult to establish the reinforcement scheme for the levee. One of the reasons for this outcome is the way the NG judgement is made: If one item of the inspection of a RCS is NG, all stretch over the CS becomes NG.

In addition to the issue above, there was a piping failure of embankment in 2012 in the Yabe River, which struck many river engineers in our country, because the cause of the piping was overlooking of a thin sand layer that distributed locally under the embankment.

Yabe River is located in the northern part of Kyushu Island. In July 2012, due to the heavy rain, the water level reached 8.36m and kept the level for at least 5 hours at station 7.3km left bank. The design high water level is 7.23m at this station. The levee failed when the flood started to draw down from the peak.

According to the witnesses, the paddy filed behind the levee had been covered by water, and they found muddy water flushing out for 1m high from a 2m long crack on the embankment back slope running along the river flowing direction. They tried to stop the flushing water by covering it by soil, but while they were carrying the soil, the slope failed for about 1 m width, and quickly developed to the whole embankment section. The failure developed to the direction of the upstream, and 50 m of the levee eventually destroyed.

The soil profile at the site drawn based on the investigation is illustrated in Figure 6(a). It was confirmed that a thin sand layer (As layer hereafter) with relatively high permeability distributed continuously under the clayey embankment. The thickness distribution of this sand layer is shown in Figure 6(b). As the layer is very thick at the place failure took place, and the layer extends to the downstream direction, but terminates in a short distance. It was also confirmed that As layer is outcropping in the river bed so that the water pressure induced by the flood might be propagated through this layer without much losing the pressure head.

Based on these findings, a presumed scenario for this failure event is as follows: First, induced by the rising of river water level, the pore water pressure in As layer rose which eventually broke through the top covering clay layer. The soil particles in As layer were washed out, and flushed out with the flushing water. As a result, cavities were developed in As layer under the embankment. As the cavities developed, soil in the embankment dropped into them, which resulted collapse and settlement of the embankment. Then, the collapsed part was overtopped by the river water, which eroded and expanded the failed portion of the levee.

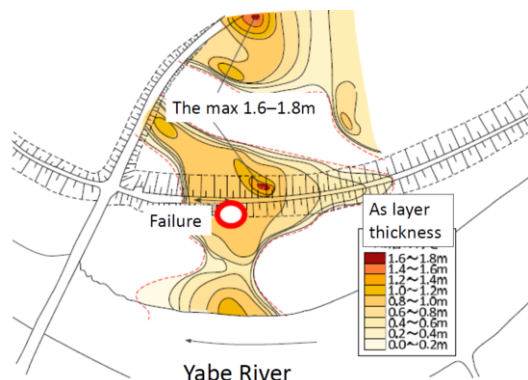
This thin sand layer, As layer, had been overlooked in the soil investigation before the event. Because the distribution of this sand layer is very local, it is considered difficult to find

such layer in all cases. This fact focused difficulty of protecting levee from piping failure.

Quite amount of research efforts are made to elucidate the mechanism of piping in Japan now.



(a) The estimated soil pedophile of Yabe River levee at station 7.4km



(b) Estimated As layer thickness at Yabe River station. 7.4km

Figure 6 Piping failure at Yabe River

One of the focuses of the investigation is try to find criteria for distinguishing the progressive vs. non-progressive piping event.

#### 4. Conclusion

The new inspection scheme for the river levee by MLIT started from 2002 is introduced in this paper. The major challenge of the new inspection scheme is the introduction of design

calculation method based on modern soil mechanics knowledge. The inspection checks for the seepage induced instability of levee as well as piping. Unsteady seepage analysis is employed combined with the circular slip stability analysis. Both rainfall and flood wave are taken into account in the inspection.

The first round of the inspection has been completed by 2011, and it was found only 60% of 10,000 km, long governmental managed river levee in Japan is judged to be safe. One of the remained challenges in this inspection procedure is the employment of the idea of the continuous strip (CS), where if the representative cross section (RCS) is NG, all the CS becomes NG. This makes it difficult to focus the levee where reinforcement is really required. Furthermore, it is recognized important to understand more details of the mechanism of piping, and method to detect problematic layers that only locally distribute.

#### References

- MLIT (2002, 2007). *A river levee design guideline*, [http://www.mlit.go.jp/river/shishin\\_guideline/bousai/gij\\_yutukaihatu/pdf/teibou\\_sekkei.pdf](http://www.mlit.go.jp/river/shishin_guideline/bousai/gij_yutukaihatu/pdf/teibou_sekkei.pdf)
- JICE (2012). *A guide for structural inspection of river levee (revised edition)*, [http://www.jice.or.jp/siryot1/pdf/teibou\\_kouzou02.pdf](http://www.jice.or.jp/siryot1/pdf/teibou_kouzou02.pdf)
- PWRI (2014). *Points of verification and design for seepage in river levee*. <http://www.pwri.go.jp/team/smd/pdf/syousasekkei%20point1306.pdf>
- Fukushima, M., Ishihara, M. (2013). River levee: a history of river levee development and failure morphology, J. of JGS 61-10, 46-53.
- Nagata, H., Nakayama, S (2013). Functions and structure of river levee, J. of JGS 61-11/12, 55-62.
- Sugii T., Sako, T. (2013). River levee: Assessment and measures for seepage failure, J. of JGS 62-11/12, 63-70.

(Note) all the references are in Japanese.