The report of the panel to review the cause of Fujinuma-ike failure was published on January 25, 2012. JCOLD translated its summary version into English. According to the Japanese legislation of river law, the dam is defined as the water storage structure which is on a regulated river and having the height of 15 meters or greater. Fujinuma-ike was on a non-regulated river and is treated as an irrigation pond, although it is the dam by ICOLD definition.

February 6, 2012 (correction on February 28, 2012) *Tadahiko Sakamoto, Chairman, JCOLD*

Review of the Cause of Fujinuma-ike Failure

--Summary Report--

January 25, 2012

Panel to evaluate the seismic stability of dams and small ponds for agricultural purpose of Fukushima Prefecture

1. Introduction

Fujinuma-ike[1] (Location: Tamukaichi, Ebana, Sukagawa city) is an irrigation reservoir situated on the right branch of upper Sunoko River and it taps water from the main stream of Sunoko River by head race. There exists an auxiliary embankment dam on the right abutment saddle. The construction of Fujinuma dam, auxiliary dam and head race were started in April 1937, suspended during the World War Ⅱ and completed in October, 1949. Fujinuma Dam is an earthfill dam with the height of 18.5 meter and the crest length of 133.2 meter, while the auxiliary dam is of earth embankment type with the height of 10.5 meter and the crest length of 72.5 meter.

From 1977 to 1979, the spillway and surface protection work of Fujinuma Dam were repaired and from 1984 to 1992, counter measures against leakage by grouting as well as upgrading of intakes were conducted.

The agricultural water taken from Fujinuma dam irrigates the land of 837 ha and the dam is managed and operated by Ebanagawa Irrigation District.

Fujinuma Dam failed due to the 2011 Tohoku Earthquake (14: 46hrs. M=9.0) and large mount of released water reached the downstream community causing the loss of seven lives and one missing. And due to the earthquake, some 750 of other small embankment dams and irrigation ponds were damaged in the Fukushima Prefecture.

Therefore, the prefectural government set up "the panel to evaluate the seismic stability of dams and small ponds for agricultural purpose" consisting of experts with relevant knowledge and experience on August 4, 2011. The panel also reviewed the cause of the failure of Fujinuma Dam which incurred especially severe damage.

The first panel meeting was held on August 4 and 5, 2011 and up until January 25, 2012 on which day the fifth meeting was held, the panel had continuously made its efforts to investigate and find what had happened to the Fujinuma dam and the auxiliary dam, seismic stability before the earthquake and mechanism of the failure due to earthquake shaking.

This report describes findings of the panel on the cause of the failure.

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[1] "ike" means "pond" in Japanese.

2. Mapping the debris of Fujinuma main dam and auxiliary embankment after the quake

The mapping of debris of breached Fujinuma dam and damaged auxiliary dam confirmed the following findings.

(1) Most of upper part of embankment was washed away and most of middle and lower part of downstream embankment was also washed away.

(2) From the movement of the structural elements, firstly, masonry riprap of upper part of embankment fell to the reservoir and subsequently the surface protection work from the middle to the right abutment moved substantially to the reservoir (Figure 1).

(3) It was confirmed that slides occurred in the direction both of the reservoir and downstream judging from the distribution of main scarps, sliding surfaces and moved layers in Fujinuma Dam (Figure 2).

(4) In the auxiliary dam, the main slide with the width of 55 meter, length of 25 meter and depth of more than 3 meter occurred and the secondary slide happened at its front (Figure 3).

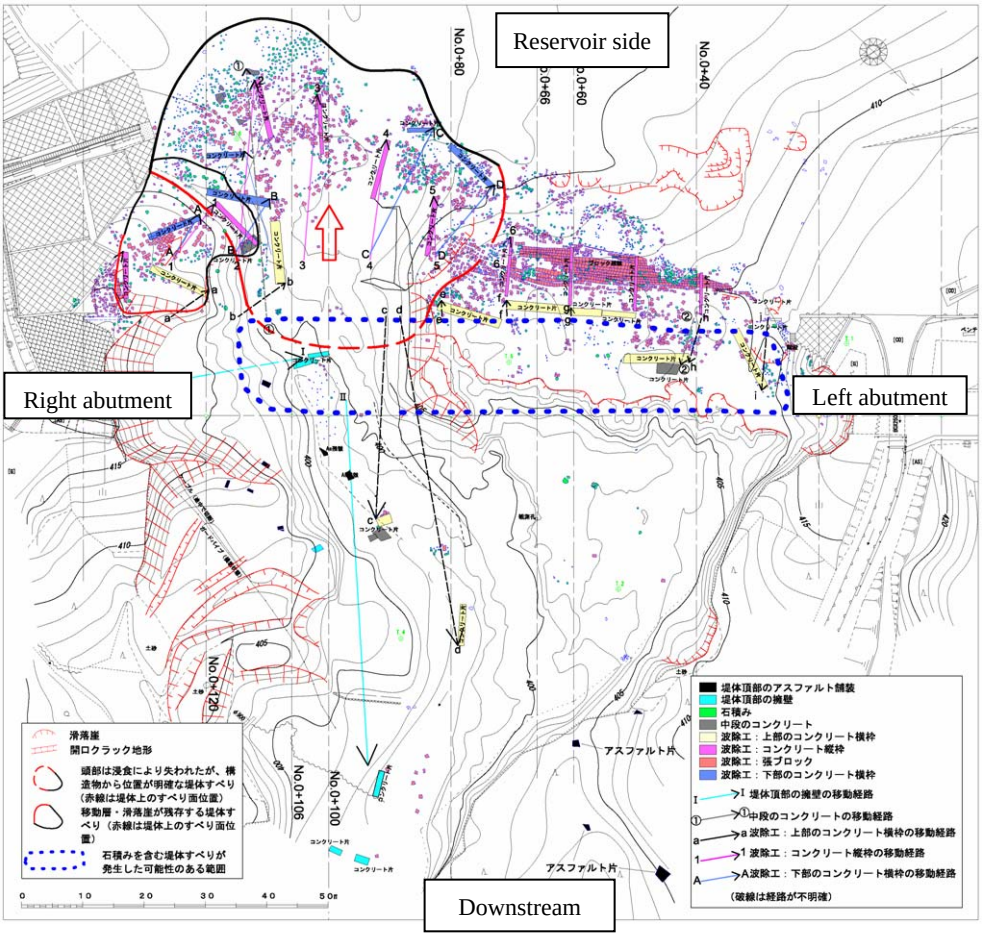

Figure 1. Mapping of structural elements after failure

Notes: The dot colored blue is the parapet wall. The dot colored green is masonry riprap. The small square colored purple is the surface protection work. The rectangular colored yellow is concrete beam on the upper upstream slope. Most structural elements moved to upstream.

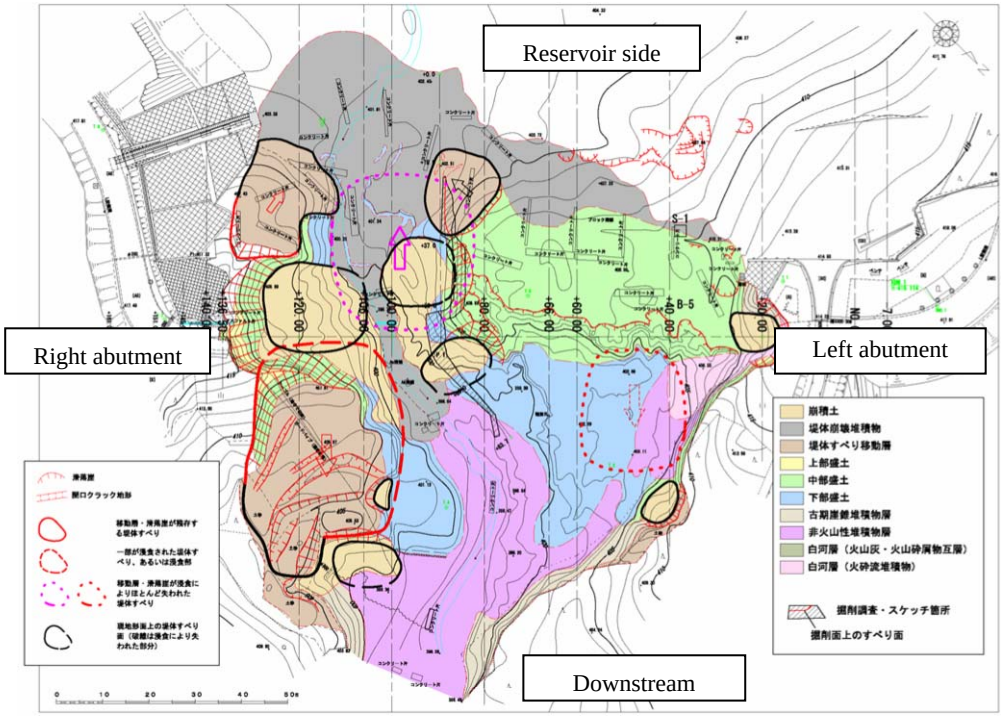

Figure 2. Possible slides estimated from geologic and topographic mapping

Notes: Encircled lines indicate the slide block.

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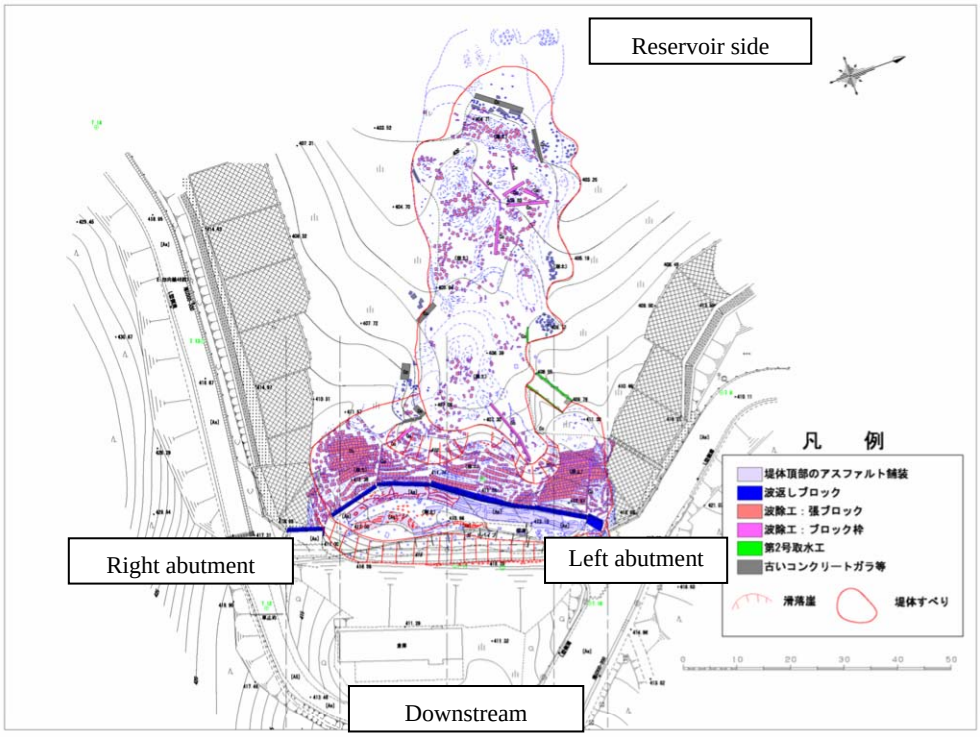

Figure 3. Damage of structure and slides of auxiliary dam

Notes: The area colored blue is concrete parapet wall. The small square colored purple is concrete block for surface protection work

3. Investigations, evaluation and review of the stability

The following investigations, evaluation and review of the stability were performed to identify the cause of the failure.

a. Field investigations and laboratory tests to recognize the zoning and properties of embankment materials

b. Investigations and evaluation of construction

c. Evaluation of the repair work

d. Evaluation of the safety of the dam by inspection before the earthquake

f. The stability evaluation based on the current design criteria

The results of investigations, evaluation and review follow;

[Field investigations and laboratory tests to recognize the zoning and properties of embankment materials]

The results of field investigations including core boring revealed that Fujinuma dam consisted of three different zones and in the middle and lower zones, construction on a layer-by-layer basis with the thickness of 20 to 30 cm was conducted. The upper zone consisted of sand rich materials as a whole and lacks clear compaction layer of placement.

[Investigations and evaluation of construction]

Hearings and evaluation of field investigations suggested that the dam was built by the normal construction method and the state-of the-art at that time.

However, it is considered that the upper zone was constructed at the period of immediately after the war when the construction environment was poor.

[Evaluation of the repair work]

It is considered that the repair work employed at Fujinuma Dam was selected from the normal methods of construction and was effective to reduce the amount of leakage judging from the measurement of leakage and phreatic surface.

[Evaluation of the safety of the dam by inspection before the earthquake]

Unusual behavior was not found by the ordinary and regular inspection of the owner of Fujinuma Dam. Therefore, within the scope of ordinary and regular inspection, it is considered that the dam was stable.

[The stability evaluation based on the current design criteria]

According to the criteria based method of stability analysis, the factor of safety is 1.15 which is less than the required value of 1.2 of the criteria when the seismic force is applied to the upstream direction. The panel regards that the dam was not in such condition as required any special measures.

4. Mechanism of failure of the dam

Summing up the investigation results, slides are broadly classified to seven stages (Figure 4). Among these slides, the upstream slide No.1 and No. 2 triggered the subsequent overflow and erosion and resulted in a failure of the dam. The slide No.1 occurred in the upper embankment and it was recognized from the remnant of the structural elements in the reservoir and sliding surface was lost by wash-out. However, the earthquake deformation analysis (by modified Newmark procedure) considering the strength reduction due to cyclic loading indicated the existence of this slide.

There may be some possible processes of breach (initiation of overflow) such as the case of the slide No.1, No.2 combined with the secondary downstream slide and the case of the downstream slide caused by the reduction of water tightness in the upper embankment and others.

Considering the loss of upper embankment in the large areas in a short period, it was possible that these processes were combined resulting in a cause of overflow hence accelerated the velocity of erosion of the dam.

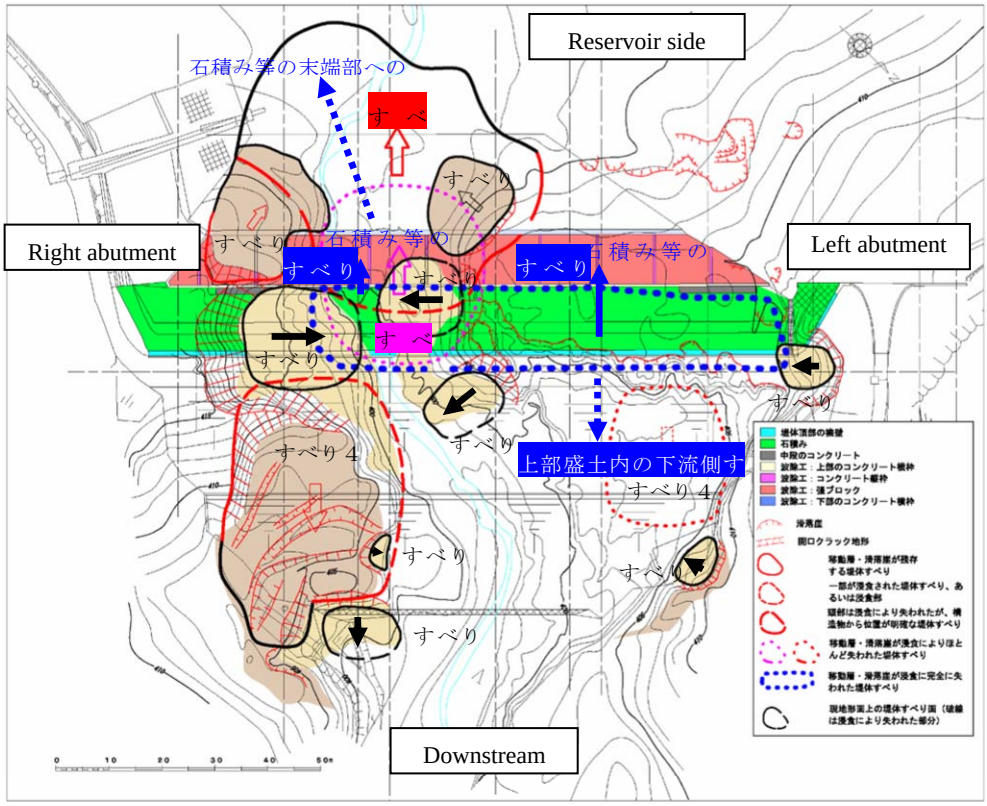

Figure 4. Integrated map of slides of Fujinuma main dam

Notes: The solid lines are existing slide bodies. The broken lines are estimated slide bodies which were lost by wash-out.

5. The cause of the failure of Fujinuma Dam

The panel considers that the primary cause of the failure of Fujinuma Dam is the nature of its upper embankment and middle embankment and the triggering cause is the strong earthquake motion and its long duration.

In addition, the panel obtained the following findings from integrating the results of field investigations, laboratory tests and analytical procedures.

(1) The earthquake response analysis suggests that the peak acceleration at the dam crest is 442 cm/s^2 and the duration of the motion over 50 cm/s^2 continued for 100 seconds which was an earthquake motion never had been experienced.

(2) The compaction of the embankment was low compared to the compaction of the modern construction method and the strength of the embankment is small in undrained condition during earthquakes. Especially in the upper embankment consisting of sand rich materials there was a saturated portion and it was proved the strength loss occurs when it is subjected to the earthquake motion such as that of Tohoku Earthquake.
(3) The slide occurred in the auxiliary embankment consisting of similar material to upper embankment of main dam and one of its failure causes is the nature of the soil of embankment, rich with sandy materials.
(4) In the slide occurred in the auxiliary dam, sliding surface was restricted to the embankment boundary of the different construction periods. In the main dam, the difference of the degree of compaction depending on the different construction periods is possibly attributable to the occurrence of the sliding.

6. Final remarks

In order to identify the cause of the failure of Fujinuma Dam the panel grasped the geotechnical properties of embankment by investigations of the remnant embankment and evaluated the construction and repair works and examined the stability of the embankment before the earthquake.

The panel inferred the failure process based on the damage and movement of the structure and locations of embankment slides from field investigations and estimated the cause of the failure by detailed analysis.

Through this verification, it has been proven that, among old earthfill dam and small irrigation ponds, even if the dam was constructed by the normal method and the-state-of-the-art in that period, and, further, any abnormality had not been detected by regular inspection, the possibility of incurring failure still exists if and when it is exposed to strong earthquake motion such as that of Tohoku Earthquake, depending upon its construction material and degree of compaction.

The panel hopes the findings obtained from reviewing the cause of the failure of Fujinuma Dam will contribute to upgrading the evaluation technology of seismic safety of dams and small irrigation ponds and is happy if they help to enhance the safe and secure society for the prefectural people.

List of members of the panel to evaluate the seismic stability of dams and small ponds for agricultural purpose

Position	Name	Organization
Chairman	Tadatsugu Tanaka	President, JARUS
Member	Fumio Tatsuoka	Professor, Tokyo University of Science
Member	Yoshiyuki Mohri	Director, National Agriculture and Food Research Organization

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Original report: http://wwwcms.pref.fukushima.jp/download/1/nosonkeikaku_kensyo_houkoku1.pdf

Translation by Japan Commission on Large Dams (N. Matsumoto)