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# Challenge for Reinforcement of Earthquake Resistance at Earth-fill Dam with Urbanization to Vicinity of Reservoir

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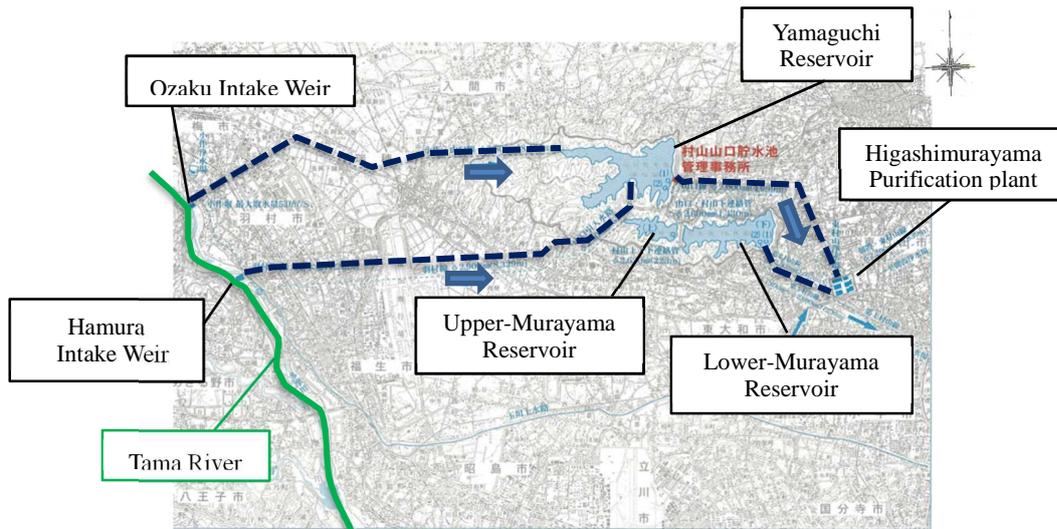
**Abstract:** With 13 million residents and 15 million, the Japanese capital of Tokyo is the core of Japan and functions as an international urban center. In the midst of imminent concerns regarding a potential earthquake in the Tokyo metropolitan area, we are pursuing a variety of countermeasures to protect Tokyo's urban functionality from large earthquakes. The Tokyo Metropolitan Bureau of Waterworks is engaged in efforts to improve the earthquake-resistance of facilities so that we can continue providing a stable supply of drinking water even during earthquakes, including improving the earthquake resistance of earth-fill dam reservoirs dedicated to water supply, which is rare in Japan. We report on three dam reinforcement initiatives begun after the January 1995 Great Hanshin Earthquake.

**Keywords:** earth-fill dam; earthquake resistant; reservoir for tap water

## 1. Introduction (Background)

The Tokyo Metropolitan Bureau of Waterworks is engaged in earthquake resistance initiatives at various facilities in order to maintain water supply to the greatest extent possible in the event of a large earthquake or similar disaster. Although rare for a water utility, we own three reservoirs dedicated to water supply. These reservoirs are essential facilities that have an effective water storage capacity sufficient to cover one week of water usage by Tokyo citizen, and we are also working to improve these facilities' earthquake resistance. The earthquake-resistance reinforcement project for the earth-fill dam was Japan's first when the project started in 1997, and creative innovations were required for reinforcement methods due to the advancement of urbanization to the vicinity of the dam body and the convenience of vehicle traffic over the top of the bank. (Fig. 1.)





**Fig. 1:** General plan for the Yamaguchi Reservoir, Upper-Murayama Reservoir, and Lower-Murayama Reservoir

<sup>1)</sup> Reservoir specification table

Name	Reservoir surface area (km <sup>2</sup> )	Water depth (m)		Reservoir volume ( m <sup>3</sup> )		Full circumference (km)
		Total depth	Effective depth	Full volume	Effective volume	
Yamaguchi Reservoir	1.893	26.152	20.00	20,648,850	19,528,000	22.65
Lower-Murayama Reservoir	1.108	20.909	18.00	12,148,307	11,843,000	9.6
Upper-Murayama Reservoir	0.406	16.067	11.40	3,320,616	2,983,000	7.1
				36,117,773	34,354,000	

Following the Great Hanshin Earthquake in January 1995, we conducted the latest analysis on the dam bodies of these reservoirs, incorporating elements of M7-class strong local earthquakes in the analysis. In studying reinforcement construction methods, we established technical review panels of external experts to conduct discussions on methods that would achieve target earthquake resistance levels, and then decided on a reinforcement policy. We proceeded to work on a detailed design, aiming to achieve the level of earthquake resistance required for the dam bodies. We began the reinforcement project in 1997 and have been reinforcing the dam bodies of the Yamaguchi Reservoir and the Lower-Murayama Reservoir, which have urban areas located downstream of the dam body.

## 2. Study of Reinforcement Construction Methods (Methodology)

### 2.1 Target Earthquake Resistance Performance

Target earthquake-resistance performance for dam bodies was determined to be “to not lose sound functionality against level-one earthquake ground motion (safety factor of at least 1.2 by seismic coefficient method)”; “to maintain water-storage functionality against level-two earthquake ground motion”; and “to suffer only damage within a repairable range (1.0 m or less settlement of the crown of the dam body via dynamic analysis).”

## 2.2 Seismic input motion

In their studies on the Yamaguchi and Lower-Murayama reservoirs, earthquake ground motion was created using past earthquake statistical analyses and fault parameters, with “level one” and “level two” earthquake ground motion set as per the waterworks guidelines such that “level one” is probable to occur once or twice during the service period of the facilities and “level two” is large in magnitude but unlikely to occur.

- Level 1 - Edo Earthquake (1855), M6.9,  
probability of reoccurrence once in 30 years, direct type
- Level 2 - Minami Kanto Earthquake, M 7.9,  
probability of reoccurrence once in 300 years, marine type  
Tachikawa fault earthquake, M 7.1, probability of reoccurrence  
once in 5000 years, near-direct type

In their study of the Upper-Murayama Reservoir, earthquakes were selected based on what was hypothesized to have a large impact on the Upper-Murayama Reservoir as shown in the table below, based on the “Guidelines for Seismic Performance Evaluation of Dams against Large-scale Earthquakes (draft) and Relevant Explanation (March 2005), River Department of the Ministry of Land, Infrastructure and Transport”.

**Table 1: Target Level-two Earthquakes**

Earthquake type	Hypothesized earthquake	Magnitude (M <sub>w</sub> )	Maximum acceleration (gal)
Active fault	Tachikawa fault	7.1	609
Subduction zone (inter-plate)	Directly beneath Tama	7.3	645
Subduction zone (intra-plate)	Directly beneath the city of Tachikawa	7.3	820

## 3. Overview of Dam Body Reinforcement Construction Methods (Results)

### • Yamaguchi Reservoir

Due to the absence of problems with the water-sealing and hydraulic stability of the current dam body and foundation, we compared reinforcement construction

methods that would ensure mechanical stability. Construction methods ensuring mechanical stability include two methods, the seepage surface lowering method and the counterweight fill method, or a proposed combination of these. The instability in the current dam body is caused by factors including insufficient cross-section width, the high infiltration surface, and the somewhat loose compaction of the downstream counterweight fill relative to the reinforcing soil and the core wall. Based on these factors, we selected as our reinforcement construction method a simple counterweight fill combined with a downstream inclined drain (planar) construction. (Fig. 5)

For the material used to build the reinforcing embankments, the Imokubo gravel layer found in the reservoir was selected based on its density, shear strength, and abundance.



**Fig. 2:** Levelling

Prior to beginning embankment reinforcement filling, the existing dam body was modified by removing the bomb-protection layer on top and removing the concrete blocks on the upstream side of the dam. These removed materials were crushed and particle size adjusted for effective reuse as a drain material on the downstream side of the dam. Due to environmental concerns, the base materials used for the embankment fill were all taken from

within the reservoirs, without any new harvesting of lumber. These base materials were mixed with purchased crushed stone at a ratio of 8:2, and this mixture was left to sit for three months, after which filling work was begun with intermittent adjustments made to particle size and water content. The method of compaction used, in order to achieve the prescribed compaction density via on-site compaction testing, was to level each layer at a depth of 23 cm using a 21-ton bulldozer, and then compact that layer six times using a 10-ton vibrating roller for a depth of 20 cm per layer (Fig. 2, 3). Concrete blocks were applied to the upstream side of the dam body to prevent corrosion by reservoir water (Fig. 4). The volume of the reinforcing embankments across both the upstream and downstream sides totaled approximately one million cubic meters.

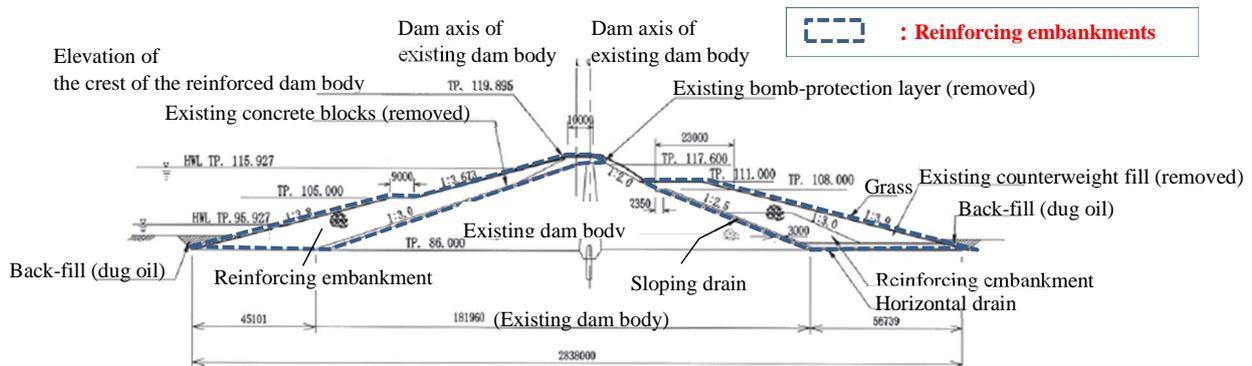


**Fig. 3:** Compaction



**Fig. 4:** Concrete blocks  
(Upstream side)

Dam body reinforcement construction:  
 Begun April 1999  
 Completed November 2002



**Fig. 5:** Cross-sectional diagram of the Yamaguchi Reservoir dam body reinforcements

• Lower-Murayama Reservoir

There are many historical ruins located in the Lower-Murayama Reservoir, and therefore it is necessary to consider the impact of dam body reinforcement work on these buried cultural properties. Also located downstream of the reservoir dam body is Sayama Park, a place where local residents go to relax, and there is a need to minimize the impact of construction on this site. For these reasons, our first requirement in selecting a dam body reinforcement method was to use a construction method “that is capable of reinforcing the dam body within the bounds of the existing dam body,” such that there will be no impact on the total area of the park or the buried cultural properties at the bottom of the lake. After extensive study of reinforcement construction methods, we selected a cross-section consisting of “a reinforcing embankment of geotextiles placed on the downstream side of the dam body, and cement-stabilized soil placed on the top of the dam body” (Fig. 12) due to its affordability and reliability of construction and structure.



**Fig. 6:** Bomb-protection layer removal



**Fig. 7:** Production of the recycled aggregate made using removed bomb-protection layer materials

The bomb-protection layer on top of the dam body was removed, as with the Yamaguchi Reservoir, and the material was converted into aggregate. This aggregate was effectively recycled for use in the foundation of the temporary holding site where the embankment material was temporarily left to sit, and as roadbed material for roads at the construction site (Fig. 6, 7). Prior to beginning embanking reinforcement filling, the existing counterweight fill on the downstream side was removed, and a drain layer was created using purchased crushed stone (Fig. 8). Base materials used for the embankment fill consisted of removed counterweight-fill soil, park embankment soil, and some dam body reinforcing soil, as well as dug soil resulting from other construction. With reference to the particle-size distribution of embankment fill materials used at the Yamaguchi Reservoir reinforcement construction, materials were mixed at a 1 : 1.5 : 1.5 ratio of base materials : crushed stone : crushed sand, and this mixture was temporarily left to sit on the left-bank side of the reservoir. The method of compaction used, in order to achieve the prescribed compaction density via on-site compaction testing, was to level each layer at a depth of 23 cm using a 21-ton bulldozer, and then compact that layer eight times using a 10-ton vibrating roller for a depth of 20 cm per layer (Fig. 9). Due to the steepness of the embankment slope running from the park to an approximately 10-meter tall berm, mesh-like polyethylene geogrids were installed every 1.6 meters deep into the embankment (Fig. 10). After the entire face of the steep slope was reinforced with wire mesh for its preservation and for greenery planting, it was next sprayed with a coat of thickening material (consisting of a mixture of fine wood chips, manure, and seeds) (Fig. 11).



**Fig. 8:** Horizontal drain  
Levelling and compaction



**Fig. 9:** Reinforcing embankment materials  
Levelling and compaction



**Fig. 10:** Geotextiles  
Reinforced soil embankment fill

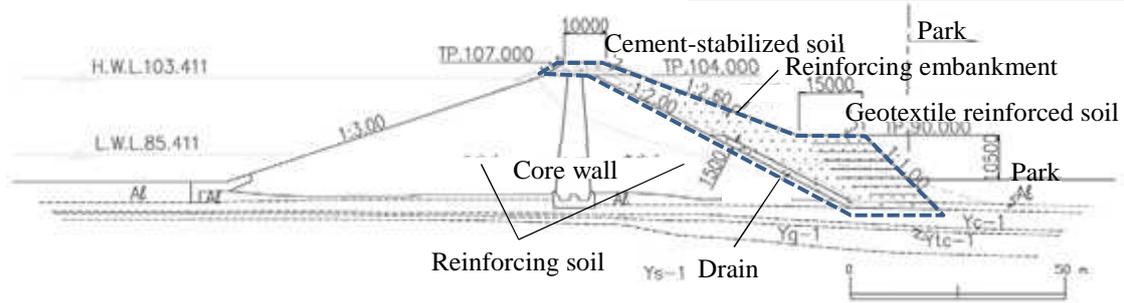


**Fig. 11:** Downstream slope preservation work  
(spraying thickening material)

Dam body reinforcement construction:

Begun May 2004

Completed November 2008



**Fig. 12:** Cross-sectional diagram of the Lower-Murayama Reservoir dam body reinforcements

• Upper-Murayama Reservoir

The Upper-Murayama Reservoir reinforcement project differs from the preceding two cases in that the top of the embankment serves as an important roadway connecting Tokyo and Saitama Prefecture (Fig. 13, 14).

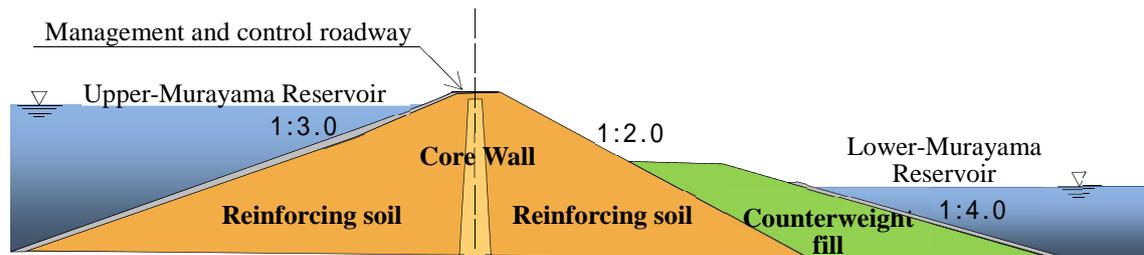
The basic approach to reinforcement construction consists of the following:

1. A “counterweight fill method” is to be used for reinforcement due to its high structural reliability and numerous cases of implementation in the past. Work is performed on the downstream side due to its inadequate (settlement) safety factor.
2. Due to the low shear strength of the existing counterweight fill and other factors, it is to be removed, improved, and recycled.
3. The embankment is to maintain its role as a bridge for vehicle traffic throughout construction (Fig. 15).

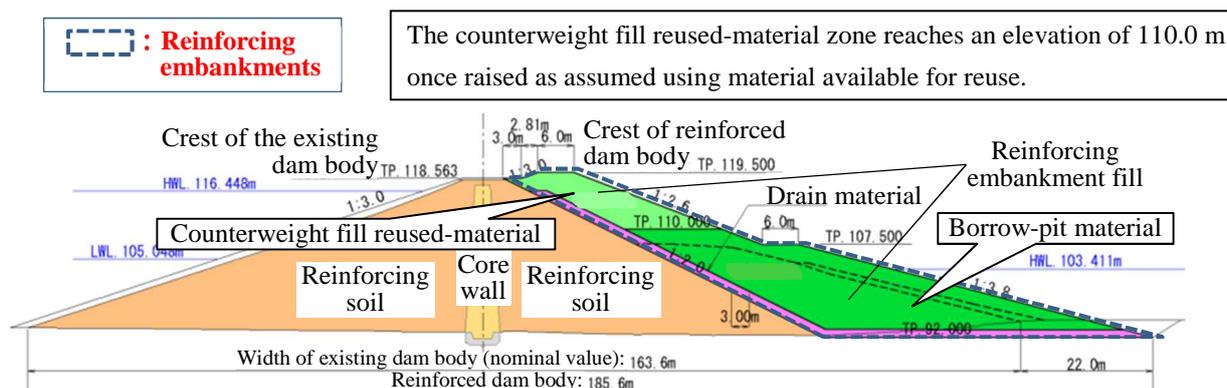


**Fig. 13:** Upper-Murayama Reservoir Dam Body after an earthquake directly beneath the city of Tachikawa, after which the top of the reinforced dam body would settle by 53 cm. This satisfies the target evaluation standard of settlement under 1.0 m.

In (settlement) safety analysis, the (settlement) safety factor was occasionally less than 1.0, but the maximum settlement deformation reached was 0.27 cm, satisfying the target evaluation standard of settlement under 1.0 m. Residual deformation analysis found that maximum settlement would be reached



**Fig. 14:** Upper-Murayama Reservoir, existing dam body – Standard cross-sectional diagram



**Fig. 15:** Reinforced dam body – Standard cross-sectional diagram

The Upper-Murayama Reservoir reinforcement construction project was begun in March 2017, and as of August 2018 work on the borrowing pit is diligently underway to produce the embankment fill material in advance of the main construction work, which is (scheduled) to begin in 2019. This project is scheduled to complete in FY 2023.

These are rare case studies of earthquake-resistance reinforcement work on earth-fill dams in which urbanization has advanced to the vicinity of the reservoirs themselves. However, if the dams remain sound even after a major earthquake, the supply of raw water can be reliably maintained, and the lives and property of nearby residents can be protected. It is hoped that these initiatives can serve as examples for reinforcement work on similar dams both in Japan and around the world.

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