SEDIMENT BYPASS TUNNEL of THE OLDEST MASONRY DAM in JAPAN
～Kobe Nunobiki Dam Bypass System and Dam Resiliency Upgrade～

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ABSTRACT

Kobe Water started its water service in 1900. The original water system was planned by Mr. W. K. Burton (1856-1899), a British water engineer; however, the actual design and construction works were done by Japanese civil engineers. Dr. Tojiro Sano designed Kobe Water's Nunobiki, Karasuhara and Sengari dams. Among these three dams Nunobiki is the oldest masonry dam in Japan. It was completed in 1900 and had been supplying the world-famous "Kobe Water," which was supplied to vessels stopping at Kobe Port and to be said to maintain its freshness even if crossing the Equator. Of course, it has been supplied to Kobe citizens without dam cleaning for more than a hundred years. The secret of "Kobe Water" comes from the unique "Clear Water Separation" system. This system is closely linked with the By-pass system. As a result, the Nunobiki dam could prolong its lifespan. The structure of this bypass was designed to mitigate reservoir sedimentation according to some knowledge from the book of Mr. W. K. Burton. The first sediment bypass system was installed in Karasuhara Reservoir, completed in 1905. The Nunobiki system is the second installation in 1908, based on the experience of heavy sedimentation of the Nunobiki dam and the success of Karasuhara Reservoir.

In 1995 Kobe City was attacked by the Hanshin-Awaji Great Earthquake. Nunobiki Dam was also damaged and increased leakage from the dam body due to the strong shake. After this disaster, the Dam Research Committee was set up and discussed resiliency upgrade. Following this discussion, it was performed Dam Grouting and Fillet construction as the resiliency upgrade. In this paper, the author will explore the history of the Nunobiki dam, its construction and materials, and will introduce the sediment bypass system and seismic upgrade. After upgrading, Kobe's Nunobiki Dam was designated "Important Cultural Property" in 2006.

Keywords: water supply, masonry dam, bypass tunnel, seismic retrofit

1. INTRODUCTION

Fig. 1 Construction of Nunobiki Dam (1899)

Kobe – a beautiful port city – located on the slope of south side of the Rokko Mountains, its downtown area is a narrow stretch between mountain and sea. The Kobe Port opened to the world in 1868, and the year 2017 is the cerebration of the 150th anniversary. From around 1900, Nunobiki water has been supplied to the visiting ships as well as Kobe Citizens. It was very famous for its water quality, which has no deterioration even if it crosses over the Equator. Nunobiki Dam was constructed in 1900. It was the first masonry dam in Japan. Kobe's Karasuhara Dam is also the old dam constructed in 1905. Nunobiki Reservoir has been suffered heavy sedimentation from the beginning. Three small upstream dams were buried in a short time. When Karasuhara Reservoir was designed as the second dam in Kobe, the bypass channel and intake filter were taken into account instead of sediment control dams and sedimentation basin. After that, the same concept was adapted to Nunobiki Reservoir, and a bypass tunnel and an intake filter were installed in 1908, which can release flood water downstream of the main dam and then mitigate sedimentation inside the reservoir. A long time has passed. In 1995 a severe earthquake hit upon the Kobe City area, and water system was devastatingly damaged. It was Hanshin-Awaji Great Earthquake. These two dams could survive this disaster, but increased leakage slightly because it was drought this year, and water level was low. After this event, the Dam Research Committee suggested that it is effective to attach a concrete filet to the dam body itself. Construction works had been done during 2001 through 2005. At the same time, 200,000m^3 of sediment was removed.

2. HISTORY OF RESERVOIR CONSTRUCTION IN KOBE

The first modern water system in Japan is Yokohama City in 1887. And Kobe Water is the 7th water system in 1900. The basic planning and design work for Kobe Water was done by W. K. Burton, a British water engineer hired by the Japanese Government. He assisted the construction of water and wastewater system in Japan in the latter part of the 19C. He wrote a textbook of the water supply system, which is "The Water Supply of Towns and the Construction of Waterworks." In this book, he mentioned "Works at the Head of the Reservoir," which contains "Bypass Channel, "and another arrangement. Actual construction works were performed by only Japanese engineers. Mr. Burton planned that the original water resource was some earth-embankment. But it was thought that the quantity of secured water would be too little. Extension or improvement work of Nunobiki Water Resource was required, new designing was done by Mr. Tojiro Sano under the leadership of Mr. Chosaku Yoshimura, skilled water engineer and the late president of JSCE (Japan Society of Civil Engineers). Mr. Sano decided that the original earth-embankment dams had turned to the concrete gravity dam. Works started in 1897 and completed in July 1900 through the test impounding. Just after the completion, a considerable leakage was detected, three sediment control dams were buried by a large amount of sand and stone from the Rokko Mountains. Mr. Sano thought that it was necessary to find solutions before starting construction in Karasuhara. He decided to go to India to see some examples of high gravity dams.

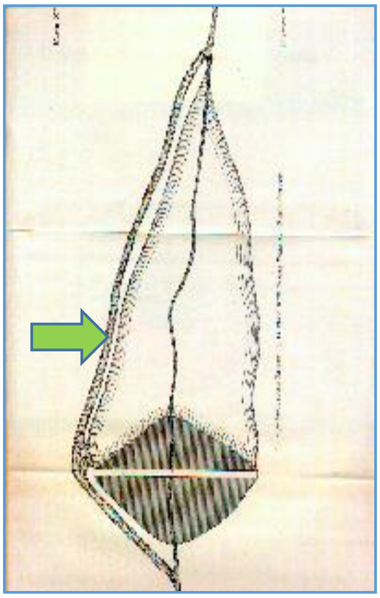

Fig. 2 Bypass channel on the W. K. Burton's textbook

The second gravity dam, Karasuhara, was completed in 1905 designed based on these experiences and the results from reconnaissance of Indian dams. Primary material was changed from concrete to mortar, and it was added the construction of sediment bypass channel, which would divide stream at the head of the reservoir and paralleled to the reservoir. The end of this channel is an artificial waterfall downstream of the main dam.

In both Nunobiki and Karasuhara reservoirs, there used to be a sedimentation pond at first, but if floodwater flowed in, some problems would arise, the one is the dirty water clarification required for a long time, and the other is the decrease of secured water capacity in reservoir. So in the Karasuhara reservoir, the planning of the sedimentation pond was abandoned and decided to construct sediment bypass channel, which was completed in March 1905. Completion Ceremony for all facilities was done in October 1905.

After that, in Nunobiki, the same bypass system was adopted, and construction started in Feb. 1906 and completed in March 1908. Due to this system, the sediment into the reservoir was significantly decreased. Behind this construction, there was a study tour to India and the book, "The Water Supply of Towns and the Construction of Waterworks," written by W. K. Burton. Mr. Sano knew this book and thought to be contributed to this book because this is a kind of textbook taught at Tokyo Imperial University.

The silting of suspended matters is inevitable in the reservoir. In this book "Works at the Head of the Reservoir," the countermeasures are described. The first one is "the Bypass". (Fig. 2) These are the reasons behind Mr. Sano decided to construct this system.

In the Nunobiki Reservoir, it was damaged by some floods, especially 1939 and 1968 floods are very famous. There is no report on how much volume of soils was removed after these events. From 2001 upgrading of earthquake-resistant factor started, and a concrete fillet was attached to the dam body. At the same time, the 200,000 m^3 of soil was removed from the reservoir by using a newly constructed road tunnel at the backside of the reservoir.

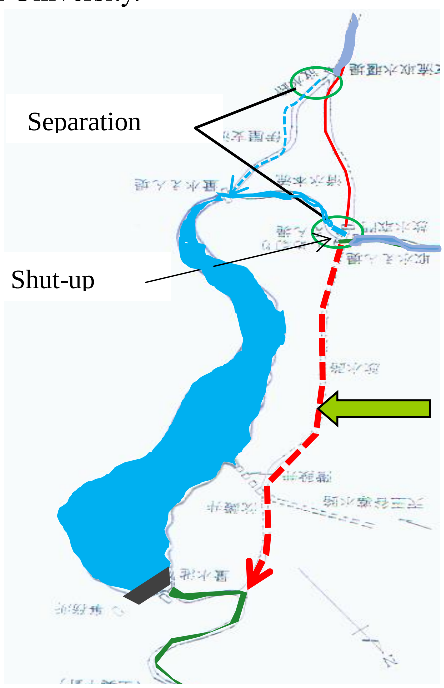

Fig. 3 Karasuhara Reservoir Bypass Channel

3. KARASUHARA SEDIMENT BYPASS CHANNEL

3.1 Overview

In Nunobiki Valley, there were three small sediment control dams upstream of the reservoir. These dams immediately filled up by the sediment from the mountain. And the reservoir kept dirty during 7 to 10 days after rainfall; otherwise, the stream already regains its clearness in a few days. So the dirty water should be conducted to the downstream the dam directly. When Karasuhara reservoir was designed, the sediment bypass channel was added to the original layout. It is said that these ideas come from the results of India Survey Tour, but it is not clear where the actual example existed.

3.2 Bypass Structure

In the head of the reservoir flow, the diversion facility was installed, and the channel runs parallel to the reservoir. In this route, four tunnels are constructed, and other parts are open channels. The clear water separation facility consists of a small dam and stone chambers. The gradient is 1 to 75. The reservoir located where the two flows meet, but the water quality of Iyagatani River was not good, so the flow diverted to the channel and not used for drinking water. In Karasuhara, this system consists of three tunnels, -132.72m, 139.39m and 78.78m, and open channel, 333.09m. And it also contains Separation dam, Shut-up dam and Intake filter.

Fig. 4 Karasuhara Bypass Channel – Channel (a), Tunnel (b) and Filter to Separation dam (c)

3.3 Clear Water Separation

Separation dam located at Karasuhara River and dams up water and made it easy to flow into the stone chamber through a perforated pipe under the filtering layer made of stones and soils. The separation dam takes water through the sand layer beside the dam. Separated water flows into the well within the limit flow rate, and then flow into the reservoir. In case of flood, excess water is diverted to the Bypass route. As a result, reservoir stores only separated clear water, which contains less sediment than usual water. The structure of the filter system is a set of sand layers, which is remaining on the old drawing of "Suido-shi-fuzu." The figure shows the filter and well of the intake facility. Water quality flowing into the reservoir is kept in good condition.

Fig. 5 Karasuhara Scheme - Separation dam (a, b) and meeting place (c) of two rivers.

4. NUNOBIKI SEDIMENT BYPASS TUNNEL

4.1 Overview

Based on the experience of heavy sedimentation in Nunobiki Dam, Karasuhara Dam was equipped with Sediment Bypass from the beginning. After completion of Karasuhara Sediment Bypass, it had begun an additional construction of Nunobiki Dam Sediment Bypass.

At first, Nunobiki Reservoir had some small sediment control dams upstream of the reservoir. But these dams were soon filled with sand due to the erosion of Rokko Granite Rocks. Dr. Sano felt some fear of being buried in the dam with sediment in a few years. This was also the theme when he went to India to investigate possible solutions from the other dams. In the Nunobiki dam, this system was put on the original reservoir in 1908. The construction was based on the Karasuhara reservoir. Clear Water Separation and Sediment Bypass are in one-set. In upstream works, a small Separation Dam was constructed. It has a sand filtration system besides the dam. Clearwater through the filtration is only collected in the clearwater tunnel, and then into the reservoir. Reservoir Water is very clean and keeps its quality.

Fig. 6 Nunobiki Reservoir Bypass Tunnel

4.2 Bypass Tunnel

The system of Bypass Structure consists of a shut-up dam, a separation dam and a bypass tunnel, as shown in fig. 6, 7, 8, 9 & 10. Shut-up dam stopped original stream. Water is taken from the Separation dam and Intake facility. The detail of Intake facility is described below. With the filtration system and a shut-up gate, water quality into the reservoir is kept clean.

Fig. 7 Nunobiki Sediment Bypass Tunnel – Inlet (a), Inside (b) and Outlet (c)

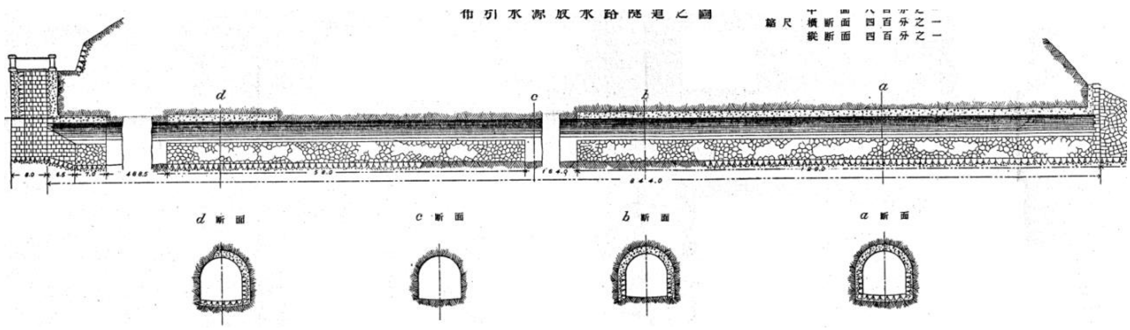

Fig. 8 Cross Section of Nunobiki Sediment Bypass Tunnel

4.3 Clear Water Separation

The system of clear water separation is formed by a conduit leading to the Intake facility. The conduit is filled with large, small stones and sand. Water dammed up by the separation dam flows into the conduit, then the Intake facility. Due to this system, the turbidity of filtered water is always lower a little bit than the original stream water. When it is raining, the gate will be closed, then all the water goes into the Bypass Tunnel and can be led to the downstream of the main dam. As a result reservoir water is protected from pollution with turbidity.

Fig. 9 Nunobiki Separation dam (a), Intake (b) and Shut-up dam(c)

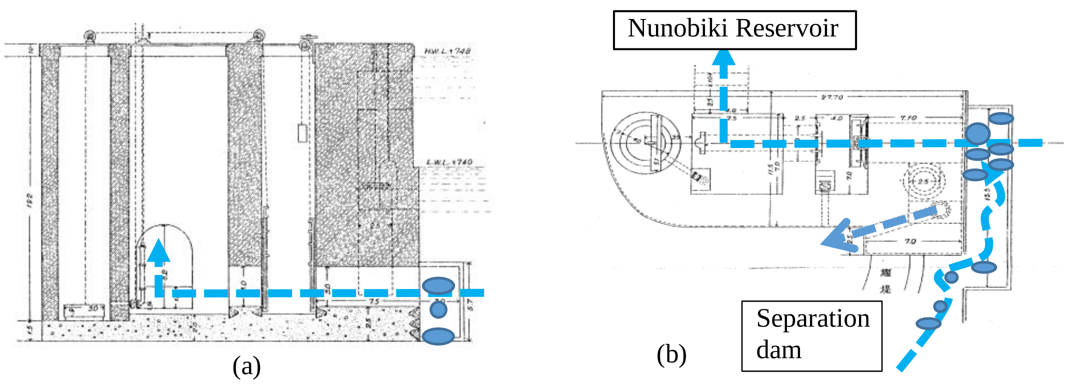

Fig. 10 Cross Section (a) and Plan View (b) of Nunobiki Intake Facility

5. DAM RESILIENCY UPGRADE AFTER THE 1995 KOBE EARTHQUAKE

Kobe City was attacked by a strong earthquake in 1995. Kobe's water system was devastatingly destroyed, and water supply was suspended for more than three months in the most damaged area. The Nunobiki dam itself was caused some concrete cracks on the dam body, and small leakage was seen on the surface of the dam. It was fortunate that the dam was not filled with water due to the drought. So the water level was rather low, and the strong impact was not added to the dam body. There was no consideration of Earthquake Resistance for the Nunobiki dam when it was constructed in 1900. There could be thought that the possibility of massive damage to the dam body against the next earthquake. After the 1995 Earthquake, the Dam Research Committee was held and discussed Dam stability. The best way to increase stability against an earthquake is to add the ***concrete filet*** to the upstream side of the existing dam. The size of the filet was determined by the stability analysis when the water level is full in an earthquake attacking, not so that excess tension may occur at the heal of dam sole. (Fig. 11, Fig. 12)
The cost of this construction work was 2.74 billion yen. The work started in Aug. 2001 and completed in March 2005. Through this work, the method of concrete settling, waterproof sealing, and composition of concrete mix was revealed. And 200,000 m^3 of sediment was removed while the dam was empty. And more, the observation deck was installed to observe wild animals.

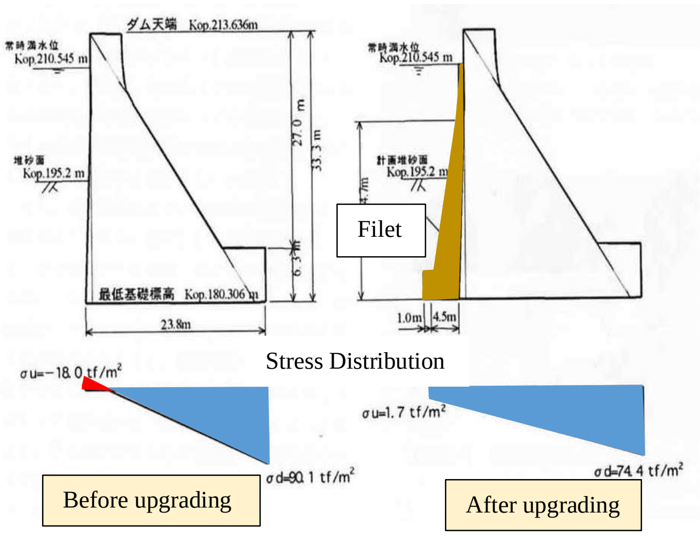

Fig. 11 Stress Distribution on the sole of dam body


Fig. 12 Concrete Filet of Nunobiki Dam from the upstream side

6. Method and Material of Nunobiki Dam

6.1 Designing of Mix Proportion of Concrete

Five kinds of Concrete mixes were used in this construction. (Table 1, Fig. 13) The amount of cement is different. The rich cement concrete was used where water-tightness is required. At that time, cement was rather expensive material. This method was contributed to reducing the total volume of cement in this construction.

6.2 Method for Concrete Settling

Nunobiki Dam construction was the first work in Japan. In various fields, the engineers faced completely new problems. Concrete settling was also the new work. They used masonry work first and then settled concrete by using masonry work as shuttering. This time a piece of concrete was removed out by chainsaw. (Fig. 14) This cross section is showing that one lift of settling was around 36 cm, and it was two-step settling. (18cm x 2) The solid line in the photo means settling the joint, and the dotted line means the boundary of two-step settling. The purpose of this method is to avoid empty spaces inside the concrete. However, this method led to the increase of water leakage from the dam body because the number of settling joint was increased.

Table 1 Concrete Mixes of Nunobiki Dam

Mix	Composition C : S : G	Where to use
A	1 : 2 : 4	Upstream side facing water
B	1 : 3 : 5	Lower body of dam (Bottom～19 feet)
C	1 : 3 : 6	Upper body of dam (19～78 feet)
D	1 : 4 : 8	Crest of dam (78 feet ～Top)
E	1 : 2 : 3	Piping Penetration
※	C:cement S:sand G:gravel (in weight)	

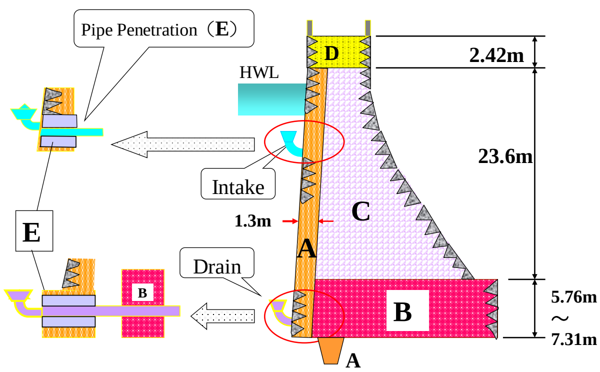

Fig. 13 Cross Section of Nunobiki Dam

6.3 Method for Waterproof of stone joint

The stone joint of the upstream side is carefully covered by sealing material. Namely, once removed the surface material and then set the sealing between the stones. (Fig. 15) Core sampling confirmed that the actual procedure was matched to the description in the construction report. The purpose of this work is to avoid penetration of water from the surface of the stonewall, even receiving the high pressure at the bottom of the dam. This aimed high quality waterproof between stones, and consequently stonewall surfaces in the upstream side.

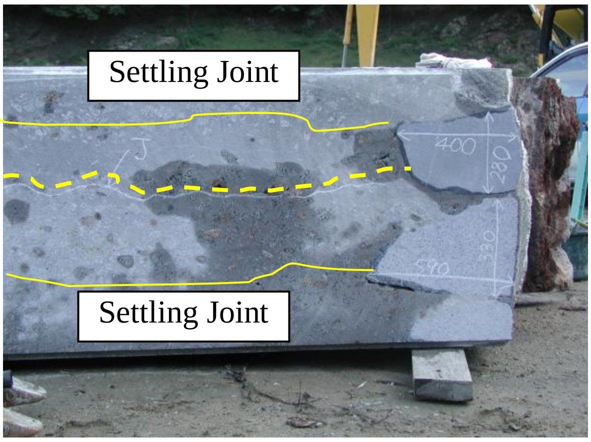

Fig. 14 Cross section of concrete piece

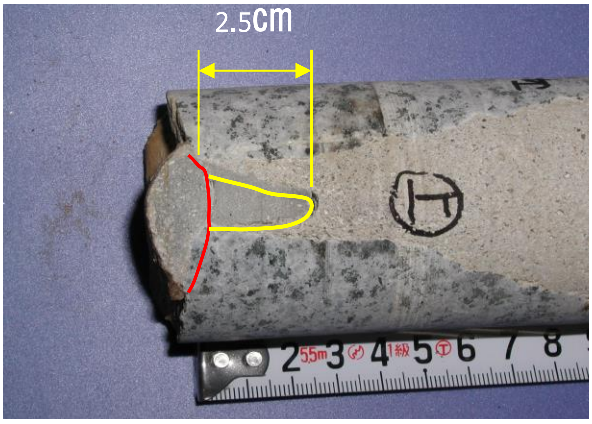

Fig. 15 Sealing of stone joint

7. SEDIMENT REMOVAL FROM THE NUNOBIKI DAM AFTER 100 YEARS

When the dam was emptied, it could be observed the soil quality and particle size on the concrete surface, and it was revealed the speed of sedimentation was significantly suppressed by using a bypass system.
The rising speed of sediment surface from 1908 to 2001 is lower than the speed from 1900 to 1908. (Fig. 16)
Construction work of Resiliency upgrading started in 2001. It was the first time for the dam to remove sediments after 101 years after the dam completion. The sediment volume was 300,000m^3. In this reinforcement work, 200,000 m^3 of sediments were removed from the reservoir. It was transported to Kobe Port and it was used for the construction of Port Island and Kobe Airport. In the Nunobiki dam, sediment transport was difficult because the south side of the dam is very steep, and there was no road beside the hiking road to carry the sediments. So it was forced to construct a new road tunnel upstream of the dam, which is dedicated to carrying out the sediments from the reservoir.

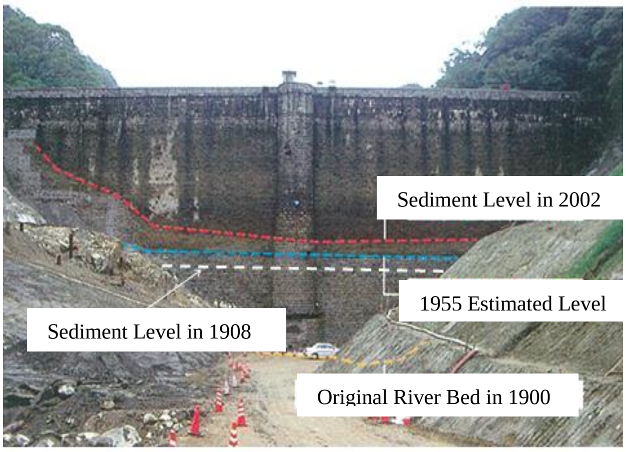

Fig. 16 Sedimentation during 100 years (Courtesy by Prof. Sumi, Kyoto University)

8. EVALUATION OF CLEAR WATER SEPARATION AND SEDIMENT BYPASS

Clear Water Separation system was effective in mitigating the sedimentation of the reservoir. Bypass channel and tunnel can carry sediments to the downstream of the dam. It is a short cut route and has a gradient of 1/75. At the end of the bypass, there is a waterfall which created a beautiful landscape beside the dam. This Nunobiki Valley has been a scenic spot for more than 1000 years, and many intelligent persons visited here and made poems with inspiration from this landscape. In both the Nunobiki and the Karasuhara reservoir, Clear Water Separation system was installed with this Sediment Bypass system. This system took power to avoid sedimentation in a reservoir. The filter system captured organic matters adhered to soil particles and reduce water-soluble organic matters. One sampling (Dec. 22, 2016) has shown that river turbidity 0.22 went down to 0.16 in the intake well. Through these facilities Kobe City Water could send it to water purification plant, and users, including sailors, could enjoy wonderful “Kobe Water.”

9. CONCLUSION

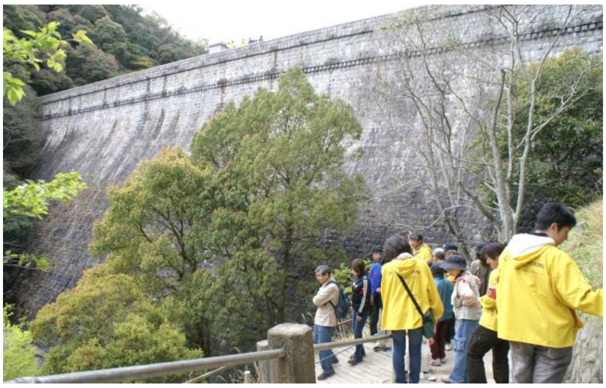

Fig. 17 Dam hiking is very popular in Kobe

Clear Water Separation system mitigates sedimentation inside a reservoir and Sediment Bypass can carry sediments directly to the downstream of dams. As a result, the Nunobiki dam and the Karasuhara dam could survive for more than 100 years without removing sediments. Thus these installations are beneficial for prolonging its lifetime. At the same time, the separated clear water turns to be a world-famous "Kobe Water." Kobe Port was open to the world in 1868 and many ships visited from European countries and US. They took clear water at Kobe Port and then set sail for the other part of the globe. Sailors said that Kobe Water is sustaining its freshness even if it crosses over the Equator. The secret of "Kobe Water" is using this Clear Water Separation system and slow sand filtration in Kitano Purification Plant. In addition, the Bypass system has been playing an important role in protecting good water quality.

After that, it was recognized that the contribution of this dam to the modernization of Kobe and the prevention of water-borne diseases. Nunobiki dam was designated as the "The Important Cultural Heritage" which is still an important role in supplying water to Kobe City. Now "Nunobiki" is the keyword of "Good Drinking water" and be a civic pride. This Nunobiki dam is located along the Hiking course from Downtown Kobe and familiar with the tourists and Kobe citizens. Because of easy access and easy to get knowledge about civil structures, the Nunobiki dam and reservoir appeals how it contributes to the modernization of Kobe.

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