Clear water separation and sediment bypass of the oldest masonry dam in Japan

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Abstract

Kobe City's Nunobiki dam is the oldest masonry dam in Japan. It was completed in 1900. And it had been supplying the world-famous "Kobe Water", which was supplied to vessels stopping at Kobe harbor and to be said to maintain its freshness even if crossing the equator. Off course, it has been supplied to Kobe citizens without dam cleaning more than hundred years. The secret of "Kobe Water" comes from the unique "Clear Water Separation" system. This system is closely linked with By-pass system. As a result, 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, a British water engineer. And the sediment bypass itself was equipped to Karasuhara Dam from the beginning, completed in 1905. The Nunobiki system is the second installation, based on the experience of Karasuhara Sediment Bypass. The author will explore these sediment bypass systems of the classic dam in Kobe and reveal the detail structure and function.

Keywords: reservoir, drinking water, separation, bypass tunnel, bypass channel

1 Introduction

Kobe – a beautiful port city – located on the slope of south side of 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 no deterioration even if it crosses over the equator. Nunobiki dam was constructed in 1900. It was the first masonry dam in Japan. 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 the 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 to downstream of main dam and then mitigate sedimentation inside the reservoir.

Long time has passed. In 1995 a severe earthquake hit upon 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 and water level was low. After this event, the Research Committee suggested that it is effective to attach a concrete filet to dam body itself. Construction works had been done during 2002 through 2005. At the same time 200,000 m^3 of sediment was removed.

By the way there constructed a detached palace in Kobe for the Royal Family, it was called “Muko-Rikyuu”. It was completed in 1914 and water was supplied from the small reservoir, called Tennou-no-ike (Emperor’s Pond). It was an original water system, dedicated to the palace water supply. Here also suffered sediment problem in the reservoir, two years later the bypass tunnel was added to the original reservoir scheme. I will introduce these three examples in Kobe, Karasuhara, Nunobiki and Muko-Rikyuu.

2 History of Reservoir Construction in Kobe

The first modern water system in Japan is Yokohama City in 1887. And Kobe Water system is the 7th water system in 1900. The basic planning and design works for Kobe Water were done by W. K. Burton, a British water engineer hired by Japanese Government. He assisted construction of water and waste water system in Japan in the latter part of the 19C. He wrote a text book of water supply system, which is “Water Supply in Towns and the Construction of Waterworks”. In this book he mentioned about “Works at the Head of the Reservoir”, which contains “Bypass Channel” and another arrangements. 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 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 Mr. Chosaku Yoshimura, skilled water engineer. 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 large leakage was detected, three sediment control dams were buried by a large amount of sand and stones 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.

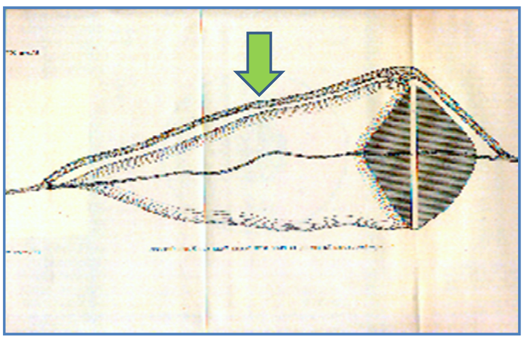

Fig. 1: Bypass channel on the W. K. Burton's text book

The second gravity dam, Karasuhara, was completed in 1905 designed based on these experience and the results from reconnaissance of Indian dams. Main 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 reservoir and paralleled to the reservoir. The end of this channel is an artificial fall at downstream of the main dam.

In both Nunobiki and Karasuhara reservoirs there used to be a sedimentation pond at first, but if flood water would flow 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 Karasuhara reservoir the planning of 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 was adopted and construction started in Feb. 1906 and completed in March 1908. Due to this system the sediment into the reservoir was greatly 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 text book taught in 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” (Figure 1). These are the reasons behind Mr. Sano decided to construct this system.

In Nunobiki Reservoir it was damaged by some floods, especially 1939 and 1968 floods are very famous. There is no report how much volume of soils were removed after these events. From 2002 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 sediment was removed from the reservoir by using newly constructed road tunnel at the back side of the reservoir. Hereafter, the author will describe the detail structure of these three cases – Karasuhara, Nunobiki and Muko Detached Palace.

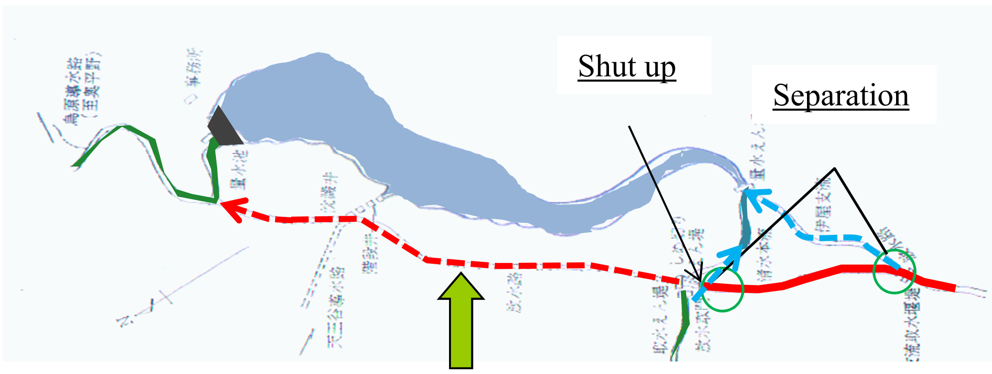

Fig. 2: Karasuhara Reservoir Bypass Channel

3 Karasuhara Sediment Bypass Channel

3.1 Overview

In the 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 regain 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 was.

Fig. 3: Karasuhara scheme - Separation dam (a, b) and meeting place (c) of two rivers.

3.2 Bypass Structure

In the head of the reservoir flow 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. Clear Water Separation facility consists of 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 which are 132.72 m, 139.39 m and 78.78 m, and open channel, 333.09 m, separation dam, shut up dam and the Clear Water Separation system.

3.3 Clear Water Separation

Separation dam is located at Karasuhara River, which dams up water and made it easy to flow into stone chamber through perforated pipe under the filtering layer made of stones and soils. Separation dam takes water through the sand layer beside the dam. Separated water flows into the well within the limit flow rate which finally enters to the reservoir. In case of flood, excess water is diverted to the bypass route. As a result, reservoir stores only separated clear water which containing less sediment than usual water. The structure of filter system is a set of sand layers which is remaining on the old drawing of “Suido-shi-fuzu”. Figure 4 shows bypass open channel and tunnel sections, and the filter and well of intake facility. These systems are working to keep water quality flowing into the reservoir in a good condition.

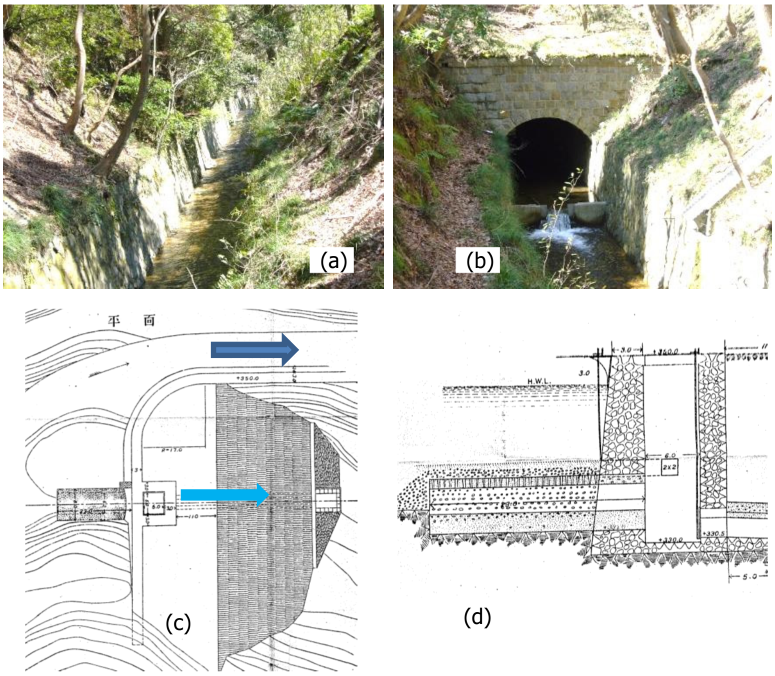

Fig. 4: Karasuhara Bypass Channel – Channel (a), Tunnel (b) and Filter to Separation dam (c, d)

4 Nunobiki Sediment Bypass Tunnel

4.1 Overview

Based on the experience of heavy sedimentation in Nunobiki dam, Karasuhara dam was equipped with the sediment bypass system from the beginning. After completion of the Karasuhara sediment bypass, it had begun an additional construction of the Nunobiki dam sediment bypass.

From the beginning, Nunobiki Reservoir had some small sediment control dams in upstream of the reservoir. These dams, however, were soon filled with sediment due to the heavy erosion of Rokko Granite Rocks. Dr. Sano felt some fear about being buried the dam with sediment in a few years. This was also the theme when he went to India to investigate possible solutions from the preceding dams. In Nunobiki dam, this system was put on the original reservoir in 1909. The design and construction was based on the Karasuhara reservoir such that Clear Water Separation and Sediment Bypass are in one-set. In upstream works, a small separation dam was constructed, which has a sand filtration system besides the dam where only clear water through the filtration is collected in the well and flows into the clear water tunnel, and then into the reservoir. Reservoir water is very clean and keeping its quality.

4.2 Bypass Tunnel

The system of the bypass structure is consisted of Shut-up dam, Separation dam and Bypass tunnel as shown in Fig.5. Shut-up dam stopped original stream. Water is taken from Separation dam and Intake facility. The detail of Intake facility is described below. With filtration system and a shut out gate, water quality into the reservoir is kept clean.

Fig. 5: Nunobiki Reservoir Bypass Tunnel

Fig. 6: Nunobiki Sediment Bypass Tunnel – Inlet (a), Inside (b) and Outlet (c)

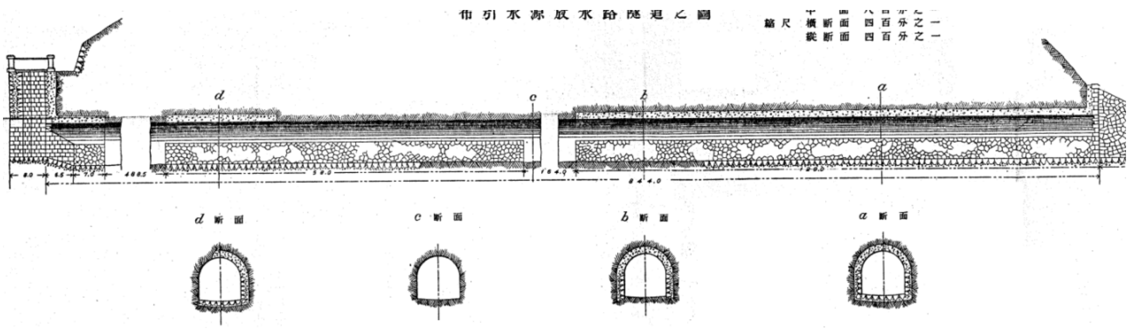

Fig. 7: Cross Section of Nunobiki Sediment Bypass Tunnel

4.3 Clear Water Separation

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

Fig. 8: Nunobiki Separation dam (a), Intake (b) and Shut up dam(c)

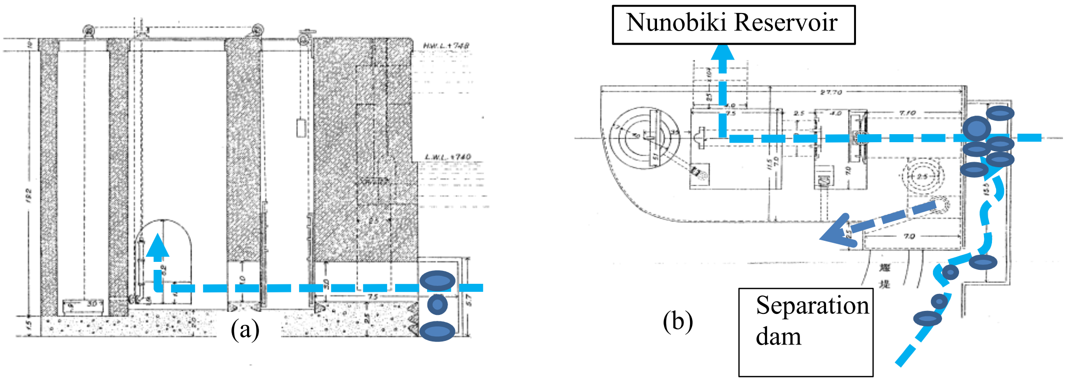

Fig. 9: Cross Section (a) and Plan View (b) of Nunobiki Intake to Separation dam

5 The Other example in Kobe – Muko-Rikyuu and Tennou-no-Ike

In 1910, Muko-Rikyuu, the Emperor’s Detached Palace, was planned and started to construct in Suma Village, close to Kobe City. At that time there was no detached palace in the western part of Japan. So Japanese Government decided to construct it in Kobe area. The problem was to secure the clean water. The nearby spring was utilized and it was called “Tennou-no-Ike”, the Emperor’s Pond. To reserve an enough volume of water it was constructed small dam just downstream of the spring. And it was to be a small pond “Tennou-no-Ike”. The detached palace was completed in 1914. Tennou-no-Ike was buried in a mean time with sediment from Rokko Mountains delivered by the heavy rain. Palace managers decided to put **a small sediment bypass tunnel** besides the pond. In this process, some discussion was supposed to have with Kobe Water Engineers, because they had experienced sedimentation of Karasuhara and Nunobiki Reservoir. Works started in 1916 and completed in the same year. The spring was completely separated and protected from the flood. Unfortunately Muko-Rikyuu, Detached Palace, was completely burned out by bombing in Kobe during World War II. However, a small sediment bypass tunnel is still remaining.

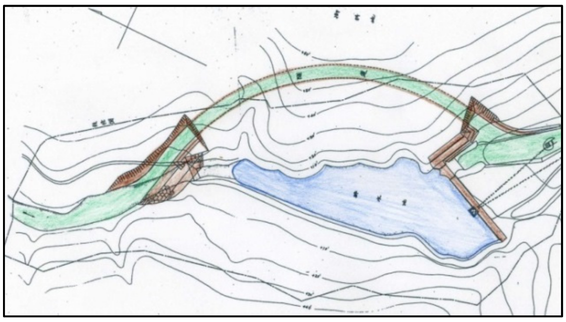

Fig. 10: Plan view of Muko-Rikyuu SBT

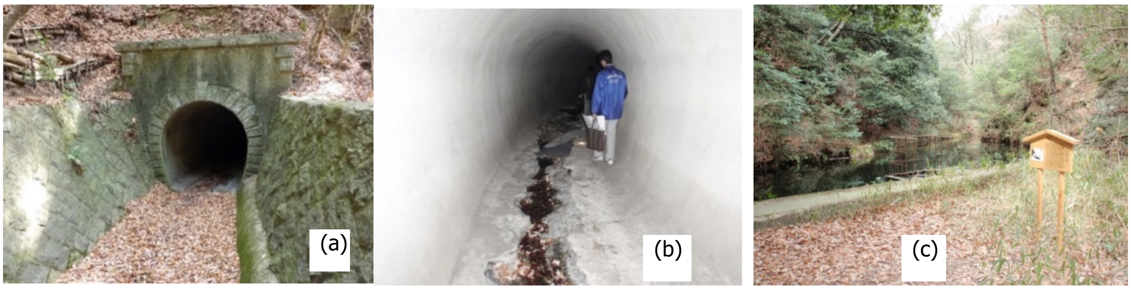

Fig. 11: Muko-Rikyuu Sediment Bypass Tunnel (a, b) and Tennou-no-Ike (c)

6 Sediment Removal from Nunobiki Dam after 100 years

Kobe City was attacked by a strong earthquake in 1995. Kobe's water system was devastatingly destroyed and water supply was suspended more than three month in the most damaged area. Nunobiki dam itself caused some concrete cracks in the dam body and small leakage was seen on the surface of the dam. It was fortunate that dam did not fill with much water due to the drought. So the water level was rather low and strong impact was not added to the dam body. After the 1995 earthquake, the committee which investigates the earthquake impacts to the dam started to discuss its improvement method in 1999. As a result, the best way of reinforcement is putting a small concrete **filet** to the upstream side of dam. For this purpose, dam should be emptied and it was a good opportunity to remove sediments in a Nunobiki Reservoir. Construction works started in 2001. It was the first time for the dam to remove sediments after 101 years after the dam completion. Sediment volume was 300,000 m^3. In this reinforcement work, 200,000 m^3 of sediments was removed from the reservoir, which was transported to Kobe Port and used for the construction of Port Island and Kobe Airport. In Nunobiki dam, sediment transport was very difficult because south side of dam is very steep and there was no road access besides hiking road to carry the sediments. So it was forced to create new tunnel road behind the dam, which is dedicated to carry out the sediments from the reservoir.

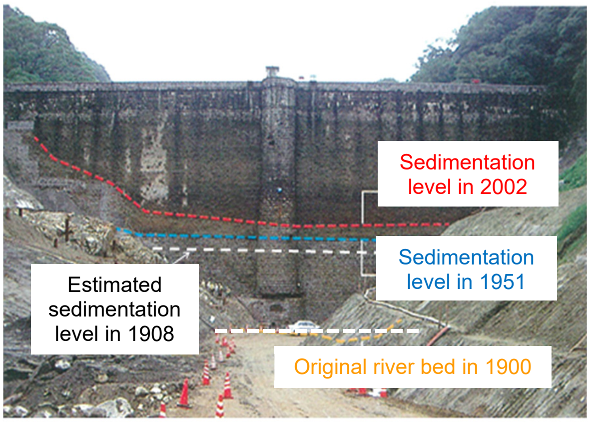

Fig. 12: Sedimentation during 100 years (Courtesy by Prof. Sumi, Kyoto University)

7 Evaluation of Clear Water Separation and Sediment Bypass

Clear Water Separation system was very effective to mitigate reservoir sedimentation. Bypass Tunnel which provides short cut route with a gradient of 1/75 is able to carry sediments to the downstream of Nunobiki dam. At the end of the bypass, there is a natural fall which created a beautiful landscape besides the dam. This Nunobiki Dale is very famous more than 1000 years where many intellectuals visited and made poets with inspiration from this landscape. In both cases of Karasuhara and Nunobiki reservoirs, Clear Water Separation system was installed with the Sediment Bypass which effectively avoids reservoir sedimentation. The filter system captured organic matters adhered to soil particles and reduce water-soluble organic matters. One sampling in 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 users including foreign sailors could enjoy wonderful “Kobe Water”.

8 Conclusions

Clear Water Separation system with Sediment Bypass can mitigate reservoir sedimentation and carry sediments directly to the downstream of dams. As a result, Nunobiki and Karasuhara dams could survive for more than 100 years without removing sediments. Thus these installation is very effective for prolong their lifetimes. At the same time, the filtered and preserved 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 take clear water at Kobe port and then set sail for the other part of this globe. Shipmen 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, Sediment Bypass has been playing an important role for protecting good water quality.

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