SUBMERGED BARRIER AS A SEDIMENT TRAPPER IN A RESERVOIR

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Abstract*— Sediment deposition and accumulation through the reservoir bed causes problems in the shortage and utilization of surface water as well as subsequent decline of reservoir economic and useful lifetime. The economic life time of a reservoir may be defined as the time necessary for aproximately 100% of the initial dead storsge capacity to be filled with incoming sediment. While useful lifetime may be defined as the period in which a reservoir is still functioning even beyond the economic lifetime. The purpose of this study is to investigate the effect of submerged barriers on sediment deposition at the reservoir bed. The barriers placed at reservoir bed affect the inflow pattern and guide the flow to a sediment pool, thus, intensify the increase of volume of sediment trapped before the sediment flow reach the reservoir dead storage. For this purpose, an experiment was carried out which use of Bakaru Reservoir model with high sediment concentration inflow "with" and "without" submerged barriers. The model considers the factors affecting the reservoir sedimentation and trap efficiency. The amount of sediment retained in the submerged barrier as the results of sedimentation was measured and compared with that retained without submerged barrier. The results obtained revealed that the submerged barriers improved the volume of sediment retained and thereby improve the reservoir trap efficiency. Since the sediment retained located outside and upstream of the dead storage, the sediment can be easily removed without interfering the reservoir operation, thus, may increase the economic and the service life of the dam.

Keywords: Reservoir sedimentation, Trap efficiency, submerged barriers, economic life, service life.

I. INTRODUCTION

A reservoir is a vital infrastructure for mankind survival and well being. Its functions are to regulate the variability of surface water flow through control gate and allocate water for various different uses. The main reservoirs purposes are to preserve row water for water supply, irrigation, hydropower, and navigation, as well as to control flood inflows for potential damage reduction. The total storage capacity of reservoirs in the world has been estimated by various sources. Based on the inventory published by the International Commission on Large Dams (ICOLD) and the current rate of dam construction, as of 2000 there were about 45 000 large dams (higher than 15 m) and an estimated 800 000 smaller ones around the world, the vast majority of which were built after 1950 (T.Sumi). Most of these reservoirs, however, have experienced sedimentation problems.

Globally, most of reservoirs, have been affected by sedimentation. Some of them are filled very seriously affected (CT.Yang, 2000). The overall annual loss rate of reservoir storage capacity due to sedimentation is estimated as 1 to 2 percent of the total storage capacity (Yoon, 1992; Yang, 2003). Reservoir sedimentation is the process of sediment deposition formed after a dam construction. The dam causes flow water impoundment, flow velocity reduction, turbulence, and consequently the settling process of sediment carried by the river inflows. As for Bakaru Reservoir case, the sedimentation becomes a serious problem as it decreases the storage capacity and, hence, makes the structure less efficient and delay of the second stage plan of 2x63 MW.

As the useful life of a reservoir directly depends on the reservoir sedimentation rate, estimation of reservoir economic lifetime becomes an important subject within reservoir planning and design. Theoritically, the useful life of a reservoir may be preserved by sediment balance approach through minimizing sediment deposited and maximizing sediment outflow through the reservoir. This paper presents the issue of bakaru reservoir sedimentation control with emphasis on introduction of submerge barrier for sediment handling measure.

II. BAKARU RESERVOIR SEDIMENTATION

A. General

Bakaru Dam is a vital infrastructure for South Sulawesi. The single purpose of the dam is to preserve water for hydropower generation with 2x63 MW installed capacity. Bakaru dam, which was constructed during the period of 1989 –1990, is a concrete gravity dam with four spillways, two sand drains, and two control gates. It was constructed to utilize the Mamasa river flow through the year with a daily pondage reservoir. The original storage capacity was 6.90 million m^3. The daily pondage was designed to accommodate the effective storage capacity to securely supply water during peak time of 6 hour a day. The power plant has been operated since 1990 with an average power production of 990 GWh per annum.

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The dam is located on Mamasa River, South Sulawesi, Indonesia. The study area is characterized by tropical moonson climate, with an average annual precipitation of 2,300 mm. The Mamasa River has a natural darainage area of 1080 km2 and a total length of 126 Km, originating from the North of Mt.Paraleang at Polmas, passing through Pinrang, and joins the Sadang River at Temban, Enrekang most of which are erodible lands. The Mamasa riverbed slopes are; 1:1200 for upstream section, and 1:140 for the downstream of the Bakaru Dam respectively.

The original sediment rate estimate during the studi period was 133,000 m^3/year. In fact, bathimetric survey in 1996 found the sediment accumulated amount to 6.20 million m3, thus, the effective storage left only aout 700,000 m3. The excess sediment inflow into Bakaru Reservoir has been deteriorating the dam functions for hydropower generation of 126 MW. The sediment also causes deterioration of the metal equipment such as guide van, runner, penstock, and the cooling system components. The figure below shows the current condition of the system.

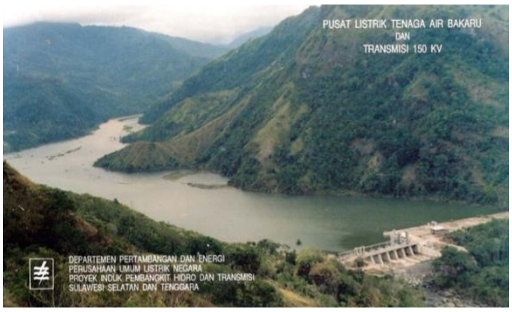

Fig.1. Bakaru Reservoir (1991)

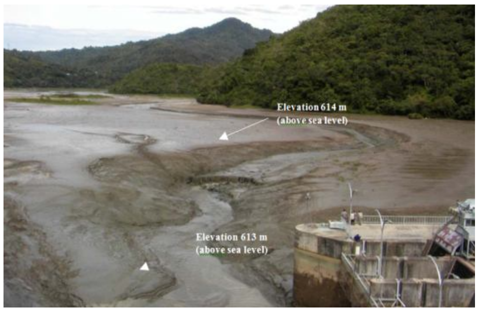

Fig.2. Sediment Accumulation (2008)

Today, average annual sediment inflow is about 700 to 800 thousand m^3. This makes severe reduction on the reservoir storage capacity.

TABLE I

THE CURRENT CONDITION OF THE SYSTEM

Description	Unit	Original Design	Current Condition
− Reservoir capacity	M^3	6.92×10^6	0.8×10^6
− Annual sedimentation	M^3/year	0.13×10^6	0.75×10^6
− Effective reservoir	m^3	4.90×10^6	0.70×10^6
− High water level	m	615.50	615.50
− Low water level	m	612.00	613.00
− Energy production	GWh/yea	999	850
− Installed capacity			
o Stage I	MW	2 x 63	2 x 63
o Stage II	MW	2 x 63	not implemented yet

Source: Completion Report Bakaru 2nd Stage, PLN.

In order to secure the dam functions, both structural measures and proper sediment management measures are required. Flushing and dredging have been performed since year 2000 but little change to the sediment accumulated in front of the dam. The main objective of the study is to introduce submerged barriers method to find the effect of the barriers on sediment deposition on a reservoir bed and to look for effective and economical measures for reservoir sediment reduction and removal. For this purpose, an experiment was carried out by use of Bakaru Reservoir model with highly sediment concentration inflow “with” and “without” submerged sediment barriers.

B. Bakaru Sedimentation Record

Bakaru reservoir sedimentation is the process of sediment deposition formed after the dam construction in 1990. The dam caused the flow water impoundment, flow velocity reduction, turbulence, and consequently the settling process of sediment carried by the Bakaru river inflows. Measurement of the sedimentation in the reservoir were carried out by PT.PLN starting from 1994 to date except in 1998, 2003, and 2004 due to the less of inflow.

TABLE II
Flushing and Dredging of Sediment

Time	Volume (m^3)	Notes
04 February 2000 09 April 2001 05 September 2001 02 May 2002 07 September 2005 16 January 2006 2007 to 2011	893,465 256,840 187,722 543,429 162,000 613,374 200,000-500,000	Year 2003 and 2004 Flushing not conducted due to minimum discharge available. Average

Source: PT. PLN Sul-Sel-Bar, 2012

The following figure shows the Bakaru Reservoir sediment volume accumulated since the start of reservoir operation in 1990.

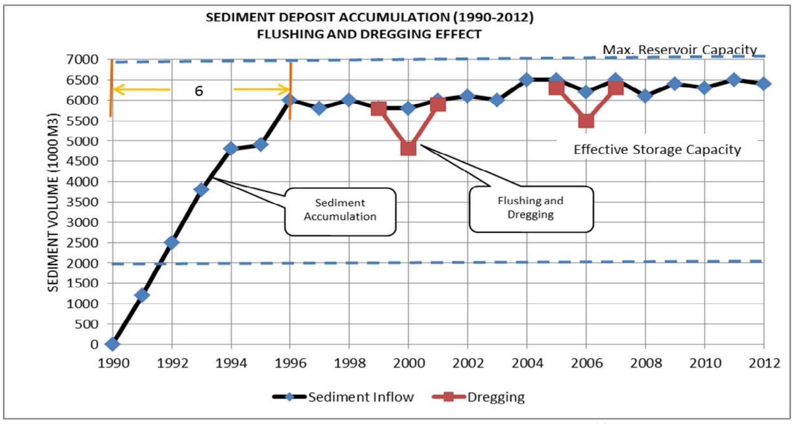

Fig.3. Flushing and Dredging Effect

III. Overview Of Sediment Management Methods

A. *Available Methods*

On the aspect of sediment management practice, the lost of storage capacity due to sedimentation may be recovered by use of sediment-balance strategy. Theoritically, the useful life of a reservoir can be preserved by minimizing sediment deposit and maximizing sediment outflow through the reservoir. The common methods available for managing sediment in reservoir can be grouped into the following four categories:

a. Minimize Sediment Entering Reservoir. This includes Watershed management, upstream trapping, Locate reservoir off-stream, Preserve, Enhance, Restore, and Construct wetlands.
b. Minimize Deposition of Sediment in Reservoir. This includes: Sediment pass-through, Density current venting, Sediment bypass, Hydrosuction bypass.
c. Remove Sediment From Reservoir. This includes: Flushing, Excavation, Dredging, Hydrosuction dredging.
d. Compensate for Sediment Accumulation in Reservoir. This includes: Enlarge dam, Decommissioning of dam, and Construct a new dam.

This paper presents the issue of bakaru reservoir sedimentation control with emphasis on introduction of submerge barrier for sediment handling measure.

B. *Submerge Sediment Barrier Method*

Submerged barrier method is a sediment trapping method to be introduced to sediment management. This paper introduces the use of submerged barrier as a countermeasure to reduce reservoir sedimentation problems, at least, to reduce sediment load to a reservoir dead storage. The barrier consist of excavated channels layed a cross the reservoir bed. The lower end of the barrier is connected to a sediment pool outside the reservoir inundation area. The principal function of the barrier is trapping sediment laden and drain it to a temporary sediment pool. A part of the sediment will accumulate in the pool while the cleaner water flows back to the reservoir. Figure-4 shows the barrier layout.

The main purpose of the system is to reduce the sediment load to a possible level to maintain low sediment accumulation in the reservoir bed or in the dead storage. To attain this goal, the barriers are designed to allow trapped sediment to travel along the channels and deposit in the sediment pool. Since the sediment accumulated in the pool located outside the reservoir the sediment can be easily removed by simple measures such as dredging or hydrosction. The sediment will finally be removed to disposal area

Based on the above categories submerged barrier method may be classified into either minimize deposition of sediment or remove sediment from the reservoir categories.

As for Bakaru reservoir sedimentation case, the submerge barrier method is applied to Bakaru Reservoir model to observe how the barriers control the sediment deposition and extend the useful life of the reservoir and to help sustain the vital benefit from the electric power generation produce by the reservoir

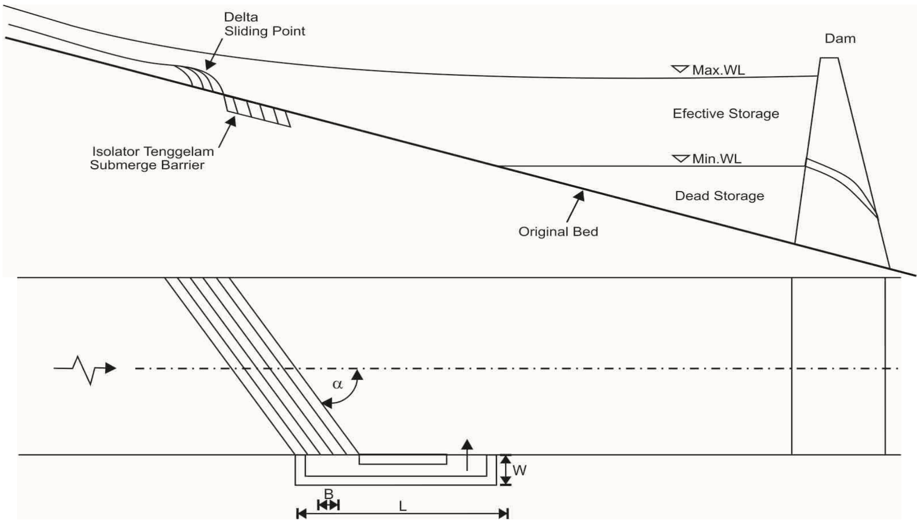

Fig.4. Submerge Barrier Layout

IV. MATERIAL AND METHOD

This study is designed to simulate the relationship between sediment inflow and the sediment retained by submerge barrier with use of Bakaru Reservoir model. To attain the purposes, an effort was made to collect existing background data pertaining to the study area, Bakaru Reservoir, and Bakaru Dam Site. Data Mining consists of data collection, preparation, and modelling. The major source of recent bathymetry data was the 1996-2011 survey of the River System by the State Electric Company (PLN) and Hasanuddin University (UNHAS). Hydrologic and Sediment data were obtained from PLN. Daily flow basis data record are available at Bakaru Dam Control Office.

In order to obtain favourable results from the hydraulic modelling, a physical model of Bakaru Dam was made. Parts of the prototype reproduced in the model were the dam, spillway, intake, and their parts and were made according to the survey results. The similarity in shape, dimensions and roughness of the material in the prototype were observed. The shape and measurements reproduced in the model are the shape and hydraulic measurement that influence the surface flow pattern. The model of weir, outlet gate, and their parts were made considering common designs. The similarity in shape, dimensions and roughness of the material in the prototype design were simplified.

V. RESULT AND DISCUSSION

A. *Results*

Bakaru reservoir has been developed in undistorted model with a scale of n:150. The model includes Mamasa river portion, Bakaru Dam, intake gates, drain inlet gates, and the submerge barriers. Preliminary tests were conducted. The first stage was to test how sediment distributed along the reservoir bed and the volume of sediment trapped without submerge barriers.

Fig-5. Reservoir Model and Sediment Deposited At Submerged Barriers

The second stage was to test how the submerge barriers affect the sediment deposition. The two experiments showed promising results. Observation obtained from the run-tests showed that the effect of series submerged sediment barriers on sediment trapping has been very good. The test with submerged barriers trapped about 10% more sediment compared to the test without barriers.

B. ***Discussion***

In the case of this experiment, the effectiveness of the submerged barrier may defined as the ratio of the sediment trapped before and after the set up of the barriers. Since the results showed an increase on sediment trapped after the set up of the barriers, it can be expected that the series submerged barriers decreased the inflow velocity and hence, increase the fall velocity of the sediment particles. Accordingly, more sediment deposited at the barriers area compared with that have accumulated before the set up of the barriers.

In summary, the submerged barriers affect the inflow pattern and the sediment deposition on the reservoir bed by trapping more sediment and, hence, reduce sediment inflow to the dead storage. Therefore, there is potential measurement to remove the sediment from reservoir without interfering the reservoir operations. Accordingly, it may be expected that the sediment removal will be inexpensive and economical and the useful lifetime of reservoir may be preserved.

In order to optimize the barrier performance and to trap as much sediment as possible, more tests are required to evaluate the sediment inflow characteristic and its parameters, the sizes, numbers, and dimensions of the barriers, as well as the best fitted location for the barriers system plan. This may significantly improve the system adequacy.

PRELIMINARY CONCLUSION

The effect of submerged barriers on sediment deposition was evaluated in Bakaru Reservoir Model. The preliminary key findings of the experiment are as follows:

a. The series of submerged sediment barriers increased the volume of sediment trapped.
b. The sediment trapped accumulated at the barriers and, therefore, the volume of sediment deposited in the dead storage has been less.
c. Since the sediment deposit accumulated at temporary sediment pool, outside the reservoir inundation area, the removal of the sediment would be simple and more economical.

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