Sedimentation management utilizing sluicing operation at the Setoishi dam

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ABSTRACT:

The Setoishi hydropower plant on the Kuma River has been operating since 1958 in Kyushu area, Japan. Sedimentation rate of the reservoir is under 10%, but the risk of inundation around the reservoir exists during floods. As countermeasure, excavations with emptying the reservoir have been conducted since 2011. However, this is not sustainable: the amount of sediment to be excavated is too large, and power generation needs to be shut down. With this background, sluicing operation which is draw-down operation during flood to let sediment flow down through the spillway has been studied and the operation rules were aided by numerical analysis.

In 2016 and 2017, the test operations were conducted, and it was found that the rules were effective. In June 2018, the regular operation started, and a large flood took place with a maximum dam inflow rate of 4,450m^3/s in July, equivalent to a 10-year flood. In this flood, 154,000m^3 of sediment, that is 15% of the reservoir sediment, flowed down through the spillway.

The sluicing operation needs improvement to minimize the risk of inundation. We have identified key improvement factors such as modification of the operation rules and removal of large rocks and coarse sediment left in the reservoir.

1 PROBLEMS OF SEDIMENTATION MANAGEMENT IN THE SETOISHI DAM

1.1 *Plant and Dam*

The Setoishi hydropower plant on the Kuma River has been operating since 1958 in Kyushu area, which has the Setosihi dam and regulating reservoir. The Kuma river is called one of the three major rapid rivers in Japan, which has about 1/500 in slope and 3,000,000,000m^3 of annual total inflow at the dam site. These conditions are very useful for Hydropower and the plant has 50GWh in annual total generation. Specification and location of the plant and the dam are on Table 1 and Figure 1.

Table 1. Specification of the Setoishi Hydropower Plant and Dam

Date of operation start	Sep. 1958
Purpose	Power
Maximum output	20,000kW
Maximum water consumption	130m^3/sec
Dam type	Gravity
Dam height	26.5m
Catchment area	1,629km^2
Design Discharge	6,000m^3/sec
Reservoir capacity	9,930,000m^3
Sediment discharge*	840,000m^3
Sediment rate*	8.46%
Specific sedimentation	8.59m^3/year.km^2
Reservoir turnover rate	313
Lifetime of reservoir	709

*as of 2018

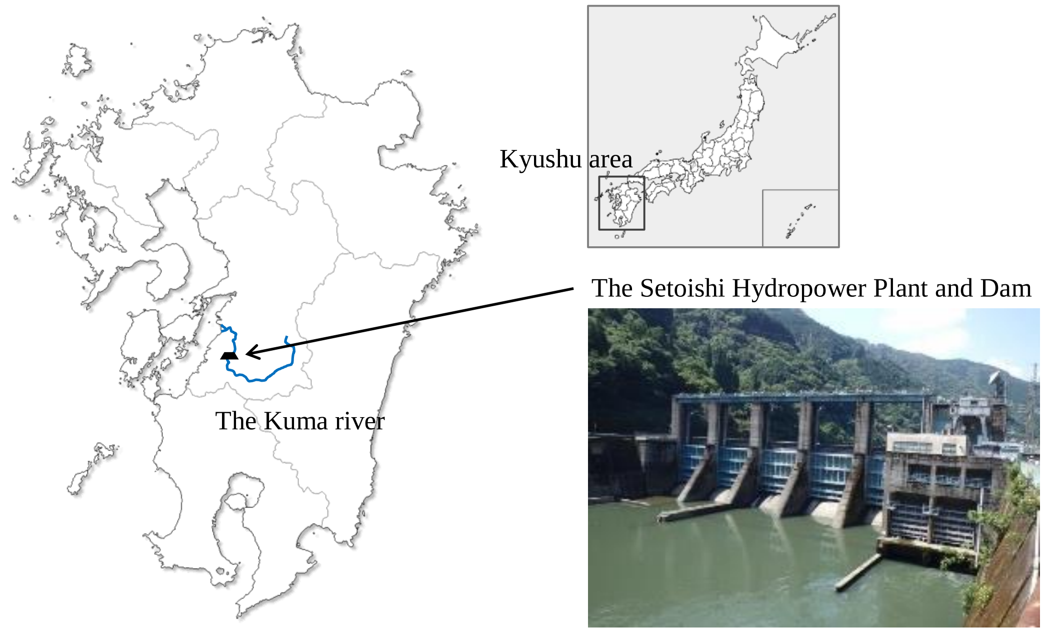

Figure 1. Location of the Setoishi Hydropower Plant and Dam

1.2 *Reservoir Sedimentation*

The Setoishi reservoir has steep topography in the both side, and the cross section shapes are almost same from the dam site to the upstream end of the reservoir which is 10,000m from the dam site. The height of the Setoishi dam is not high, therefore the most of sediment, which flows into the reservoir, flows down through the spillway of the dam. In calculation, 6.39% (48,000m^3/751,000m^3) of the inflow sediment is remained in the reservoir.

Though sediment rate is under 10% which is not high, residences, agricultural lands, roads and bridges around the reservoir are under inundation risk, because the Setoishi reservoir is not located in the mountains but close to people living area. Inundation risk existed before the dam construction, and after the construction the risk has been getting more serious by sedimentation. When a large flood took place with 6,350m^3/sec in July 1982, which is the second largest inflow record, 24 residences and agricultural land were inundated and roads and railways were damaged.

1.3 *Excavation*

As countermeasures against reservoir sedimentation, excavation, lift up of the residences, indemnity contracts for agricultural lands and closing the traffic use of the road under inundation risk during the flood had been considered. Since 2018, the sluicing operation has started progressively. Major countermeasure is excavation, which has started since 2011, shown in table 2. Excavated sediment is transported to temporally disposal area, which is 15km from the reservoir. Volume of excavation has been increasing to get early reduction of inundation risk. Excavation is executed from December to February with emptying the reservoir. During emptying the reservoir, power generation is shut down. At the beginning in 2011, 300,000m^3 of sediment was targeted for excavation, it exists 2,500m to 6,000m from the dam.

But access to the reservoir inside and sediment to be excavated in dry area are limited, then it is difficult to execute excavation as well as plan. Sometimes excavation under water had to be executed shown in Figure 2.

According to the excavation from 2011 to 2018, sediment to be excavated is decreasing from 300,000m^3 to 200,000m^3 and the inundation risk has been getting lower than it was at the beginning. But it is not aspect as we have planed. One of the reasons is the limitation of volume and place for excavation and another is that the rate of sediment inflow has been larger than in our plan.

Table 2. Actual Result of Excavation in the Setoishi Reservoir

2011	10,000m^3
2012	30,000m^3
2013	30,000m^3
2014	31,000m^3
2015	45,000m^3
2016	49,000m^3
2017	63,000m^3
2018	70,000m^3
Total	328,000m^3

Figure 2. Excavation in the Setoishi Reservoir with emptying

1.4 *Problems*

4 kinds of the countermeasures against reservoir sedimentation are noticed in section 1.3, and the countermeasures excluding the excavation have worked for lowering the risk of inundation. Excavation has problems on not only the limitation of volume and place for excavation, but also difficulty of getting temporally disposal area, heavy traffic of transporting sediment, long term shut down of power generation and obstruction against integrated sediment management in river basin. In Japan, the river law changed in 1997 and one of the main projects in new river law is integrated sediment management. In the Kuma river, excavation in river has been regulated for environmental improvement in the sea area by the government, so that excavation in the Setoishi reservoir is against the national project and is not sustainable.

Okumura, H., Sumi, T., 2010, SEDIMENT SLUICING MANAGEMENT BY DRAW DOWN OPERATION IN HYDROPOWER REGULATING RESERVOIRS CONSIDERING PROPERTIES OF SEDIMENTAION AND FACILITY CONDITION, *Annual Journal of Hydraulic Engineering, JSCE VOL.55* (in Japanese)

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2 SLUICING OPERATION

2.1 *Operation Rules*

The sluicing operation is drawing down the dam water level during flood and flowing down sediment through the spillway gate, which flows into the reservoir or remained in the reservoir, shown in Figure 3. This operation solves the problems noticed in section 1.4.

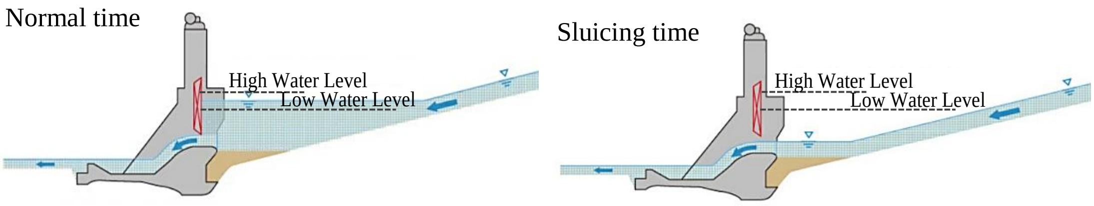

Figure 3. Sluicing Operation (Left: Normal time, Right: Sluicing time)

The most important point of the operation rules is dam water level of sluicing during flood. In order to fix the water level, riverbed change calculation is conducted. One current operation cases and 4 sluicing operation cases are calculated and 4 sluicing cases are different in dam water level during flood which are low water level -2,0m, -4.0m, -6.0m and -8.0m. Sluicing operation is conducted when dam inflow rate is over 1,000m^3/sec and calculation time is 50 years using the record.

The calculation result is shown in Figure 4 and it indicates that not to increase sediment in the reservoir, sluicing water level should be set low water level -4,0m, -6.0m and -8.0m. It is not desirable to change the environment in downstream of the dam by large volume sediment from the reservoir, therefore low water level -4.0m is selected as the sluicing water level. The operation rules including this water level will be feedbacked by experiences.

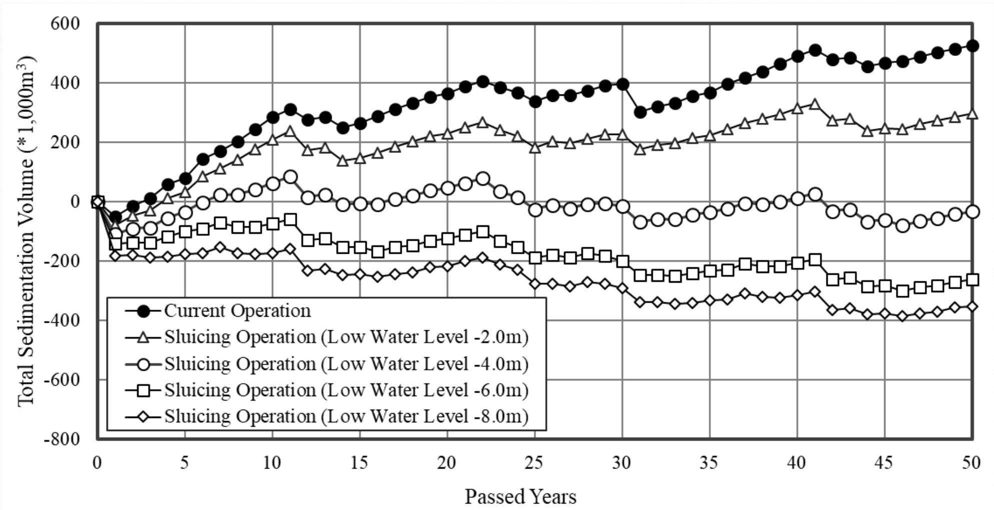

Figure 4. Calculation Result of Sluicing Operation at the Setoishi Dam

2.2 *Test Operation in 2016 and 2017*

To prepare for the sluicing operation, the test operations were conducted in 2016 and 2017 shown in Table 3. During the test operation, environment change in the downstream and sediment behavior in the reservoir are monitored. As the execution judgments of the operation were determined by our own weather forecast system, the system will be feedbacked by the result of the test operations.

Table 3. Test Sluicing Operation

	2016	2017	2018
Operation	Test	Test	Regular
Sluicing	L.W.L.-1.0m	L.W.L.-2.0m	L.W.L.-4.0m

One test operation in 2016 and 3 test operations in 2017 were conducted and they were not in large flood. In the test operations, remarkable environment changes and sediment behaviors were not found and the weather forecast system did work well. Finally, it was determined to start the regular sluicing operation in 2018 as planed.

2.3 ***Regular Operation in 2018***

2 regular operations were conducted in 2018 shown in Table 4. The data of first operation in June are shown in Figure 5.

Table 4. Regular Sluicing Operation in 2018

	First one (June)	Second one (July)
Duration	June 19th 4:00 – 23rd 14:00	July 2nd 19:00 – 10th 8:00
Total Rainfall	220mm	570mm
The Maximum Dam Inflow Volume	3,051m^3/sec	4,450m^3/sec
The Lowest Water Level during Sluicing	L.W.L.-3.9m	L.W.L.-3.9m
Change in Reservoir Sediment Volume	First one + Second one = -153,724m^3	

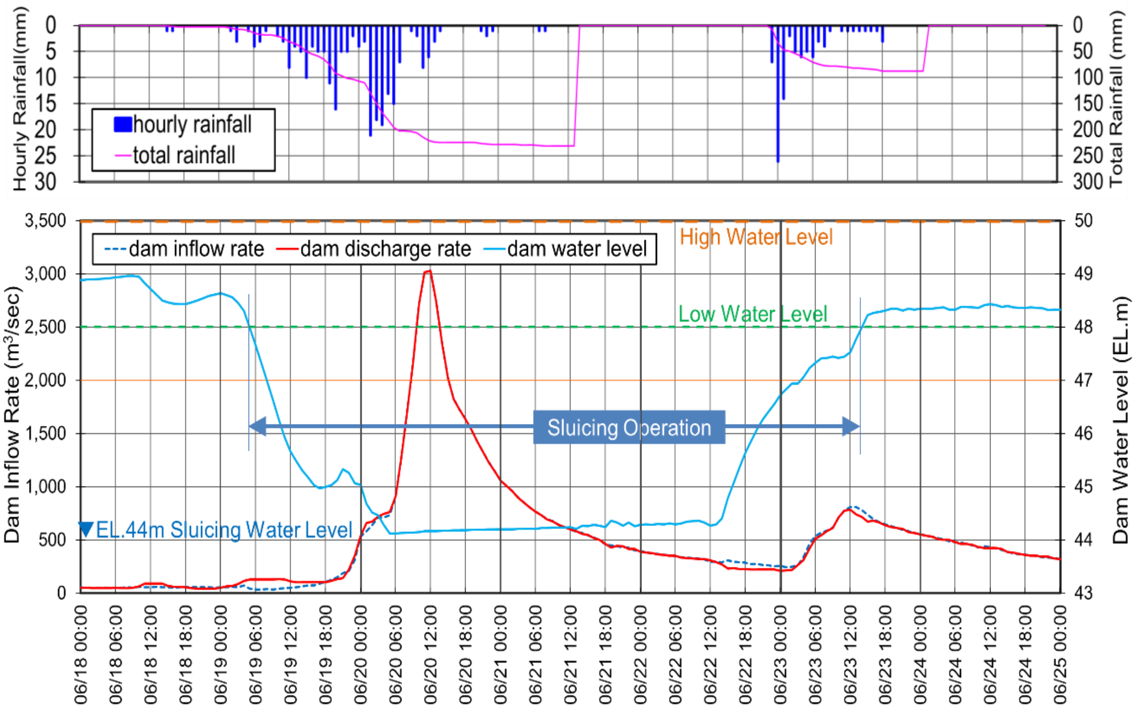

Figure 5. Operation Result of Sluicing in June 19th 4:00 – 23nd 14:00

Contour of riverbed change during 2 sluicing operations in June and July is shown in Figure 6 and Table 5. It indicates that 114,767m^3 in153,724m^3 of decreasing sediment in the reservoir was existed near the dam. In this area, fine sediment is remained in usual operation. The sluicing operation changes this area's water flow condition from like a lake to like a river and fine sediment was flushed in the sluicing.

In the middle area of the reservoir, where is 2,500m to 6,000m from the dam, riverbed was generally degraded by the sluicing, but in some parts, where is 3,000m, 4,000m and 5,500m from the dam, riverbed was aggraded. The aggraded riverbeds are corresponded to excavation areas. This indicates that excavation area is easily refilled by sediment in next flood. In the viewpoint of long term, 258,000 m^3 sediment was excavated and 65,000m^3 sediment was refilled, then excavation is still effective.

The riverbed was aggraded in 1,000m and 2,000m from the dam. In this 2 places, river width in downstream of them is narrowed by the deposits from the bank in Figure 7.

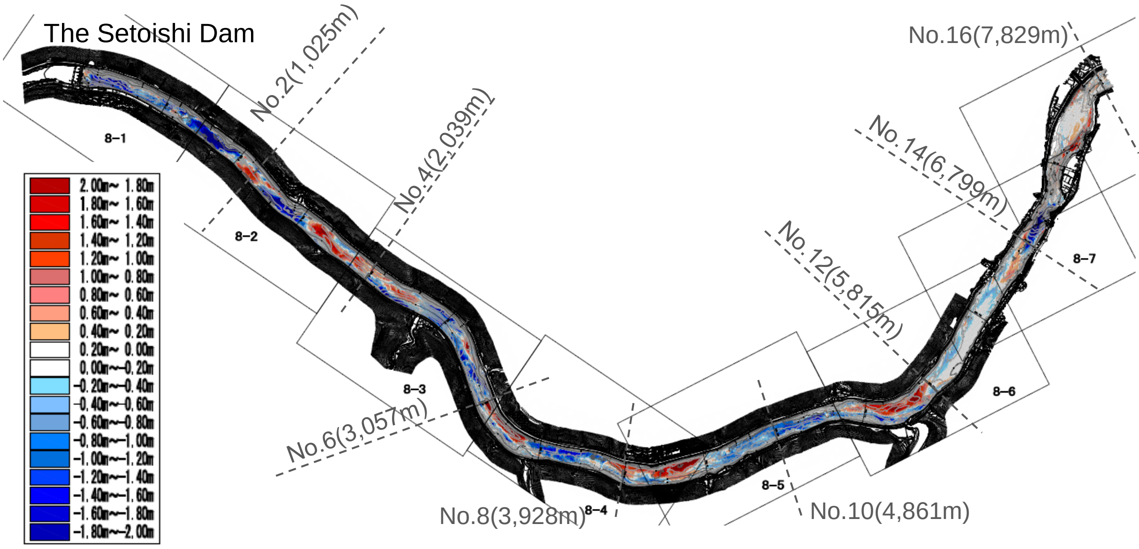

Figure 6. Reservoir Bed Level Change Contour between May and July in 2018

Table 5. Change of Sedimentation Volume between May and July in 2018 (m^3)

No.	Change of Sedimentation Volume		
0~1	-33,863		
1~2	-49,137		
2~3	-29,559	No.0~No.5 -114,767	
3~4	15,512		
4~5	-17,720		
5~6	-26,832		
6~7	20,210		
7~8	-17,953		
8~9	25,198	No.5~No.12 -17,544	No.0~No.16 -153,724
9~10	-18,546		
10~11	-19,868		
11~12	20,247		
12~13	-7,220		
13~14	-822		
14~15	-32,046	No.12~No.16 -21,413	
15~16	18,675		

Figure 7. Deposits from the Bank at 800m(left) and 1,500m(right) from the Setoishi Dam

3 IMPROVEMENT

In order to execute a better sluicing operation, the regular operation should be improved by experiences. Though the sluicing operation in 2018 was succeeded and amount of sediment in the reservoir was decreased, there is still inundation risk and it still needs excavation in the reservoir. It has identified that the key factors for improvement of the sluicing operation are modification of the operation rules, sediment replenishment and removal of large rocks for smooth water and sediment flow in the reservoir.

3.1 *Modification of the Operation Rules*

It did not find that sluicing operation in 2018 influenced on river environment in the downstream of the dam, even though 53,727m^3 sediment flew out through the spillway. Considering Figure 3, the lower the sluicing water level is, the more effective the sluicing is. Therefore it is rational and effective that the sluicing water level is set lower, and it should go with in gradual way, monitoring the influence on the reservoir and the downstream of the dam.

3.2 *Sediment Replenishment*

Coarse sediment tends to be remained in the reservoir even under the sluicing operation because the dam causes water level to rise comparing for no dam situation. Especially relatively large grain size sediment is likely to be remained. It is inconvenient that there is less supply of coarse sediment in downstream of the dam.

As countermeasure against the less coarse sediment in the downstream of the dam, it is effective to execute the sediment replenishment, and coarse sediment excavated in the reservoir is transferred to the downstream of the dam and restored in the river. In 2018 test sediment replenishment was executed in just downstream of the dam, shown in Figure 8. Amount of it was 500m^3, and it flew down in flood and no sediment was left. It is planed that 5,000m^3 will be replenished in 2019 and amount of the sediment replenishment will be larger gradually.

Figure 8. Sediment Replenishment at Downstream of the Setoishi Dam in 2018

3.3 ***Removal of Large Rocks for Water Flow***

Riverbed aggradation was found around 1,000m and 2,000m from the dam after the sluicing operation in 2018, shown in Figure 9. The figure indicates that the river width is narrowed by the deposits from the bank, as is noted in section 2.2. The deposits are obstacle against water and sediment flow and should be taken away or broken into small pieces.

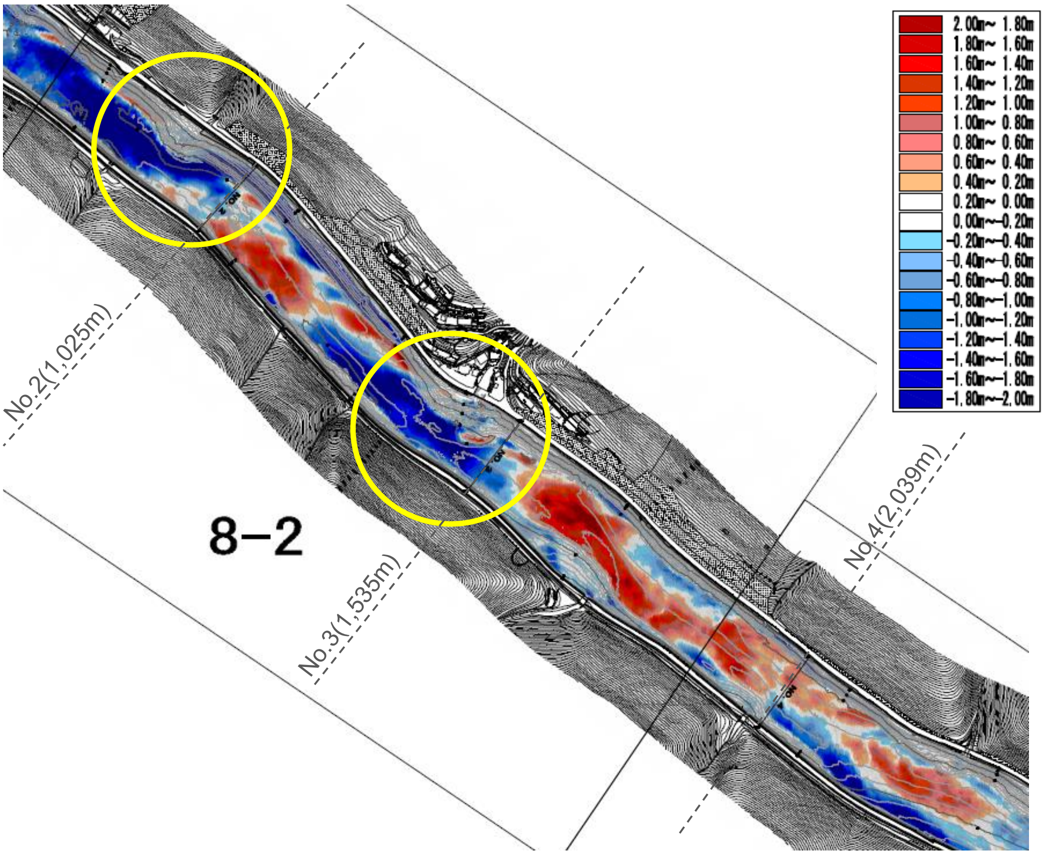

Figure 9. Reservoir Bed Level Change Contour around Dam Distance 1,000m-2,000m

4 CONCLUSIONS

The sluicing operation in the Setoishi dam was started in 2018 after test operation in 2016 and 2017. In 2018 a large flood took place with a maximum dam inflow rate of 4,450m^3/s in July, equivalent to a 10-year flood. It is found that operation rules are functional and it needs more couple of years to estimate the effect of the operation. It is useful and necessary to prepare the improvement to get the better effect of the sluicing operation more quickly in river basin, coastal area and hydropower supply.

REFFERENCES

OKUMURA, H., SUMI, T., 2010, SEDIMENT SLUICING MANAGEMENT BY DRAW DOWN OPERATION IN HYDROPOWER REGULATING RESERVOIRS CONSIDERING PROPERTIES OF SEDIMENTAION AND FACILITY CONDITION, *Annual Journal of Hydraulic Engineering, JSCE VOL.55* (in Japanese)

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