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Sediment Management through Tandem Operation of Dams in Kurobe River

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ABSTRACT:
Kurobe River is one of the steepest rivers in Japan. It produces quite much sediment so that high dams are hardly able to fulfill its whole function long. While, the sediment form alluvial fan downstream where diverse industries have developed. Historically, decrease of sediment discharge which was vulgarly ascribed to dams has caused the problem of coastal erosion. This is the main reason that the recent two dams in Kurobe River had to have sediment discharge gate. This report introduces the ten-year experiences of Unazuki Dam, for mainly flood control, and Dashidaira Dam, for power supply, on tandem operation of sediment discharge.

Keywords: tandem operation, sediment discharge

1. ASPECTS OF KUROBE RIVER

Kurobe River locates at the most eastern part of Toyama prefecture, Japan and has only 85km length, including 13.6km of alluvial fan, which starts from Washibadake, the mountain of 2,924m altitude. 99% of its drainage area is of mountainous one which is mostly covered with weathered granite. Because of much annual precipitation, about 4,000mm/year, and its vulnerable geology, magnificent amount of sediments is produced when flood occurs. These sediments made Kurobe river alluvial fan which runs down with about 1/100 slope from mountain area to sea directly. Annual sediment runoff from mountain area is estimated to about 1.4 million m^3.

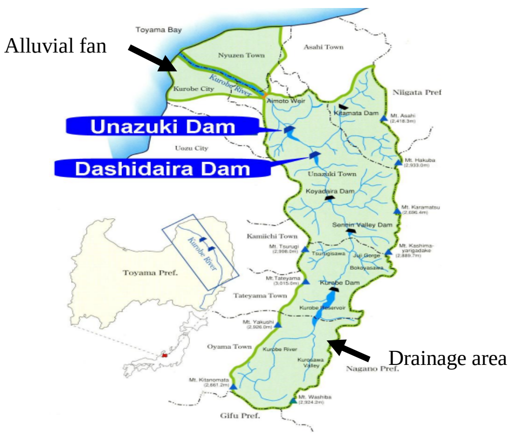
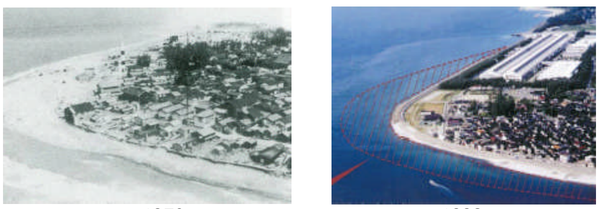


Figure 1. Basin of Kurobe River

The channel of the river has been fixed at present location in its alluvial fan from 18th century though break of the levee had occurred once a several decades.

2. HISTORY OF SEDIMENT TRANSFERENCE

Modern countermeasures against flood have started at the beginning of 1950's mainly with excavation of the channel to enlarge the cross section. At that time, river bed was higher than flood plain, because the sediment production was too much to be flashed to the sea, since the channel was settled. On the other hand, after the settlement of the channel, east side of the shore of Kurobe river mouth is destined to be eroded, because the sediment flow along the sea shore around this area goes from east to west. Meanwhile, the west side has been also eroded continuously. (Fig.2)



1970 1998

Figure 2. Erosion of Sea Shore (west side)

Its cause was ascribed to dams which stored much sediment. But, when we see the sediment amount that is accumulated to every kind of dams and is extracted from the channel (Fig.3), it is obvious that the extraction of sediment from channel has also great influence to the decrease of the outflow of sediment to the sea.

Total amount of checked sediment by dams in recent 6 decades is up to 30 million m^3, while extracted amount is up to 12million m^3 which includes excavated one. For the reduction of the influences of artificial activity, it was natural to be lead to the decrease of sediment extraction from the channel and the sediment discharge from dams. After the decrease of the excavation as public works, extraction of sediment began as commercial act, though it was expected its effectiveness for flood control. The amount of the extracted sediment was so much that the height of the riverbed has fallen down about 2m throughout the alluvial fan.

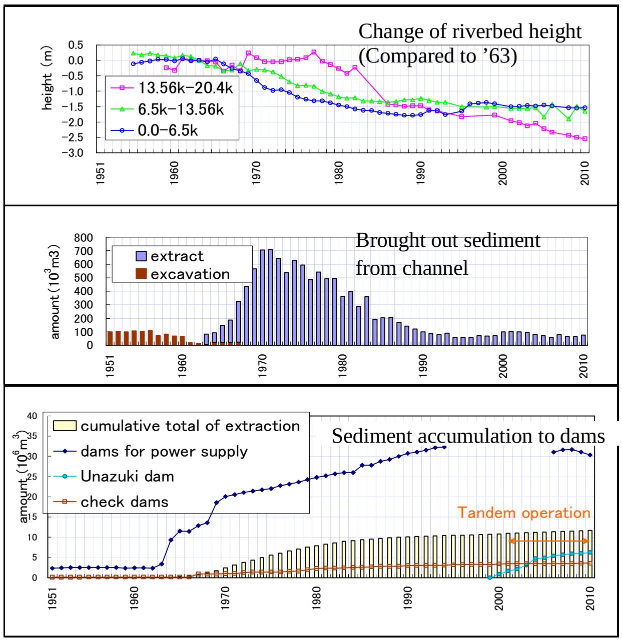


Figure 3. Sediment Balance in Kurobe River

Today, small amount of extraction of sediment from the channel is allowed only in mountain area because of some predicted bad influences. One of the conspicuous influences is erosion of sea shore.

3. DESIGN OF SEDIMENT DISCHARGEABLE DAMS

Undergoing the sediment related problems described above, newly constructed dams in Kurobe river, both for flood control and power supply, were to have sediment discharge gate. For Dashidaira dam, for power supply, has comparatively small capacity of 20 million m3, its reservoir would be filled with sediment in short period without it. Also, Unazuki dam, for flood control, must have too big capacity to be feasible and it make Dashidaira dam not be able to discharge sediment.(Fig.4)

Typical flood control dam has usually flat surface for sediment capacity. Since Unazuki dam has an aim of sediment discharge, expected river bed of reservoir has slope which is based on model experiment. Naturally, sediment surface would not be exactly the same to the result of it. Therefore, through the observation and measurement, it should be adequately monitored and some measures should be taken if necessary.

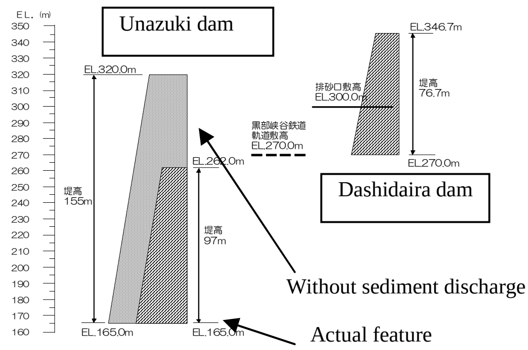


Figure 4. Altitudinal Relation between Two Dams

Longitudinal cross section of river bed of Unazuki dam reservoir is shown in Fig.5. Even it has sediment discharge gate, accumulation of sediment to Unazuki dam has already reached 6.5 million m^3 in 10 years. That is almost half of designed sedimentation.

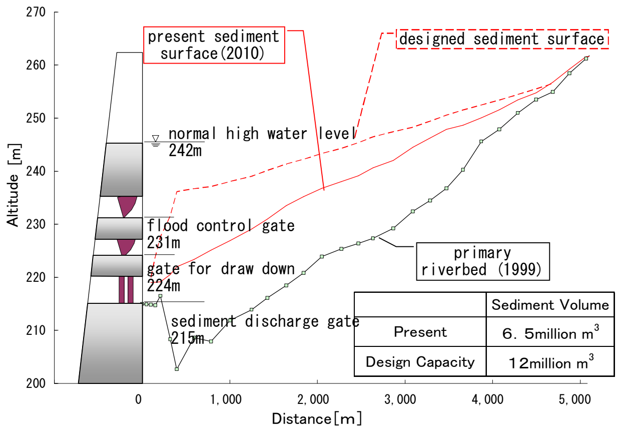


Figure 5. Longitudinal Cross Section of Unazuki Dam

4. WORK OF SEDIMENT DISCHARGE

4.1 Sole Operation by Dashidaira Dam

Dashidaira dam was constructed in 1985 beforehand of Unazuki dam construction, 2001. Therefore, until then, sediment discharge was done solely. The first operation was done in December of 1991. At that time, the sediment was so dirty and stinky that every participants wondered and soon after the event the accusation was made by fisherman. Actually, beforehand, nobody was worried about the quality deterioration of the sediment, because the water quality of Kurobe river is one of the clearest one in Japan. After the wide spread of the problem throughout the region, Evaluation Committee was established by Kansai power co. ltd., owner of Dashidaira dam. Consequently, the committee asserted that contented biomass was the cause of the deterioration and the sediment discharge should be done every year.

After several times of the discharge as experiment or from necessity and some discussion with stake holders, such as fishermen and farmers, the term of the discharge was set between June and August, rainy season in Japan.

4.2 Tandem Operation by Two Dams

Tandem operation has started at 2000 after Unazuki dam was constructed. The sediment discharge operation is done at the end of a flood when discharge is gradually decreasing. During the operation, at least once, even a short time, these two dams have a moment of no reservoir at the same time. That is, from upper stream of Dashidaira Dam to down stream of Unazuki Dam, water flows with free surface, no obstruction by gates.

Essentially, Dashidaira dam has to discharge whole sediment during the flood so that any excessive sediment would not to be accumulated, while sediment discharge gate of Unazuki dam is closed shortly after the end of free flow of Dashidaira dam.

Because the operation is done from June 1st to August 31st, sedimentation occurs at the rest of the year. To prevent the long sediment storage, the first discharge is done at rather smaller flood than as literally called flood. On the other hand, after the first operation, the trigger of the operation is bigger than the first. Typical example of the operation of Unazuki dam is shown in Fig.6.

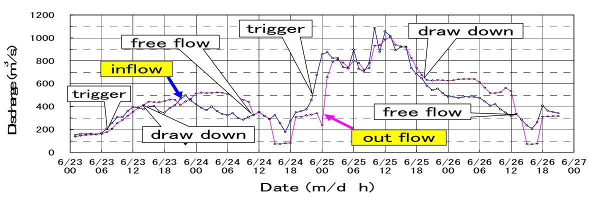


Figure 6. Example of the Operation of Unazuki Dam

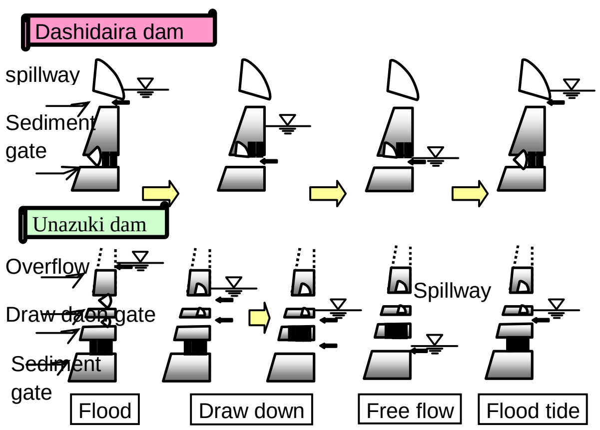


Figure 7. Condition of the Gates at Flood Stage

Also, the condition of the gates of two dams at each stage during flood is shown in Fig.7.Since the sediment discharge gate of Unazuki dam is not allowed to open when water level of the reservoir is higher than 235m, draw down gate has to be used after the outflow became bigger than the inflow so that the water level goes down fast. On the other hand, the operation of Dashidaira dam is done only using sediment discharge gate. The aspect of tandem operation is shown in Fig.8 by water level of two dams.

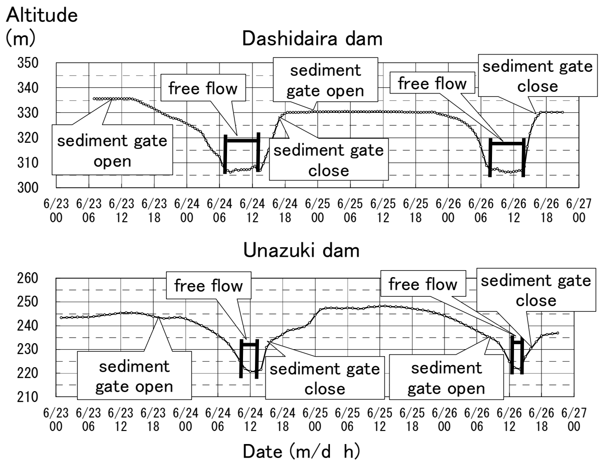


Figure 8. Example of Tandem Operation of Two Dams

5. RESULTS OF SEDIMENT DISCHARGE

To prevent the erosion of sea shore and tide overtopping, several offshore dikes were constructed around the river mouth of Kurobe river.

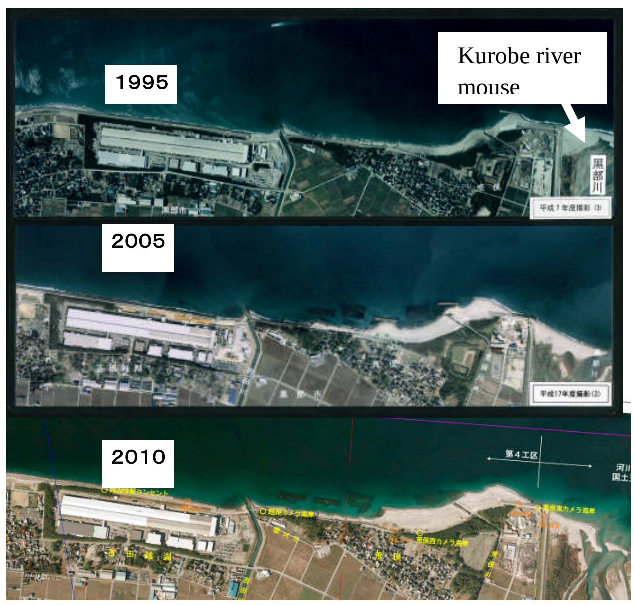


Figure 9. Change of the Shore

Fig.9 shows the change of the west side shore of the river mouth. It can be seen that the shore was small in 1995 though the first offshore dike had been there for two years. It reveals that at the time of construction of two dams a little sediment was flown out from the river to the sea. After beginning of tandem operation, the shore grows year by year so as to the offshore dikes had to be lowered because of too much sedimentation. Though it cannot be observed as the proof of the effectiveness of tandem operation, it is obvious that two dams do not check sediment transference.

Fig. 10 shows the remained sand at the lower end of sediment discharge gate of Unazuki dam. It can be seen that the diameter of the discharged sediment is maximum several centimetres.

Figure 10. Remained Sediment at the Lower End of the Gate

As to the amount of discharged sediment, it seems to be enough to maintain the seashore, if it would adequately flow along the shore.

6. SUBJECTS HEREAFTER

6.1 Supply Cobble to Downstream

As it is written above, the discharged sediment consists of sand. On the other hand, the diameter of the reached sediment to the middle of the reservoir is about 30 to 50 centimetres. Essentially, it is necessary to discharge these cobbles to maintain the channel downstream. Actually, the decrease of the amount of cobble made the cause of destruction of some facilities.

Figure 11. Destruction of the Ground Sill

Fig.11 shows the destruction of ground sill of the river, which locates at the top of the alluvial fan at 13.4k apart from the river mouth. Though the weight of each cubic concrete block is about 60 tons, many of them were flashed. The cause of the damage was ascribed to the descent of the river bed which has fallen about 2 meters during a flood. For the prevention of this kind of damages, enough amount of sediment including cobbles should be supplied from the upper stream. However, it appeared that it might be difficult to discharge cobbles from Unazuki dam.

Table 1. Movable Amount of Sediment (10^3m^3)

diameter range (mm)	200～500	70～200	20～70	7～20	2～7	0.7～2	0.2～0.7	0.05～0.2	0.005～0.05	0.002～0.005
dam site	0.00	1.16	14.51	7.12	8.51	10.56	58.37	9.38	46.46	16.32
20.8K	0.00	0.90	14.08	6.67	8.14	10.06	56.03	9.35	46.24	16.33
21.0K	0.00	0.13	6.63	3.10	4.14	8.78	48.61	8.62	44.58	15.97
21.2K	0.00	0.39	9.17	3.84	4.92	9.22	48.43	8.79	44.94	16.11
21.4K	0.00	0.40	9.21	3.72	4.44	9.32	46.88	8.60	41.25	14.35
21.6K	0.00	0.15	6.14	2.69	4.25	9.43	45.34	7.93	39.00	14.08
21.8K	0.00	0.18	5.35	2.52	3.66	9.26	42.06	7.35	37.28	13.53
22.0K	0.00	0.33	5.10	3.11	4.24	9.03	39.99	5.59	34.40	12.76
22.2K	0.00	0.25	5.48	3.20	4.22	8.17	39.01	5.19	33.23	12.37
22.4K	0.00	0.42	6.08	3.53	5.96	8.18	39.50	5.21	32.35	11.96
22.6K	0.00	2.69	5.61	3.07	6.66	8.45	39.82	5.21	32.36	11.97
22.8K	0.00	3.09	4.64	2.76	6.30	8.46	38.76	5.21	32.36	11.97
23.0K	0.00	3.44	4.90	3.03	6.10	8.43	38.57	5.21	32.36	11.97

Table 1 shows the estimation of the movable sediment amount during a flood in the reservoir of Unazuki dam after 30-year operation. The estimation was made for each classified sediment diameter. Depending on the calculation, it seems that sediment can be discharged over thousand m^3 on each flood in total. But, in the middle of the reservoir, it decreases to 0.2 thousand m^3 which is rather small not only in amount but its diameter than expected. So, some measurement should be taken to transfer cobbles to the downstream of the dam.

6.2 Prevention of Deterioration of Sediment

As mentioned above, at first, sediment of Dashidaira dam was deteriorated by long restoration. Instead, water quality, including its smell, discharged from Unazuki dam was in the spotlight in 2011.

Table 2. Water Quality of Outflow

Date	amount of discharged sediment (10m3)	SS		BOD	
		Dashidaira dam	Unazuki dam	Dashidaira dam	Unazuki dam
2001/6/20	590	90,000	2,500	5.8	2.6
2001/7/2	—	29,000	3,700	2.9	2.5
2002/7/14	60	22,000	5,400	5.6	5.4
2003/6/29	90	69,000	17,000	39	17
2004/7/17	280	42,000	6,800	6.0	7.7
2004/7/19	—	16,000	17,000	3.6	14
2005/6/29	510	47,000	65,000	5.8	22
2005/7/4	—	90,000	29,000	30	5.2
2005/7/13	—	40,000	21,000	4.5	5.2
2006/7/2	240	27,000	22,000	7.2	20
2006/7/14		12,000	10,000	3.3	5.8
2006/7/18	160	27,000	16,000	8.9	8.0
2006/7/24		7,400	5,900	2.3	4.5
2007/6/30	120	25,000	37,000	7.0	18
2008/7/1	350	62,000	22,000	9.4	12
2009/7/10	370	50,000	30,000	11	12
2009/7/19	20	17,000	13,000	4.9	8.5
2010/6/28	160	52,000	14,000	6.7	16
2010/7/13	50	6,000	4,300	3.8	3.3
2011/6/24		47,000	51,000	23	38
2011/6/26		30,000	59,000	13	27

Table 2 shows maximum value of water quality during a flood at each dam. Data of 2011 at Unazuki dam seems to be singularly bad except of 2005. Though the reason is on study now, some measures might be necessary in the near future.