INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

Damage from Typhoon Talas to Civil Engineering Structures for Hydropower and the Effect of the Sediment Bypass System at Asahi Dam

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ABSTRACT: (9 pt)
Typhoon Talas, the 12th typhoon of 2011, hit a wide area of western Japan to cause downpours mainly to Kii Peninsula and triggered landslides and flooding, causing serious human and physical damage. In the area to which the Kansai Electric Power co., Inc. supplies electric power, 17 power plants were damaged. Meanwhile the sediment bypass system at Asahi Dam, commenced its operation in April 1998 and operated during Typhoon Talas, made a significant effect on the reduction of long-term turbidity and sedimentation in the reservoir though it got serious damage to the tunnel invert lining with concrete and steel. This paper reports the actual damage from Talas to our power facilities and the operational result of the sediment bypass system.

Keywords: Typhoon Talas, sediment bypass system, long-term turbidity, sedimentation

1. INTRODUCTION

Typhoon Talas, the 12th typhoon of 2011, hit a wide area of western Japan to cause downpours mainly to Kii Peninsula and triggered landslides and flooding, causing serious human and physical damage, killing 78 people and leaving 16 missing. About 90 percent of human damage was concentrated in three prefectures: Wakayama, Nara, and Mie.

In the area to which the Kansai Electric Power co., inc. (KANSAI) supplies electric power, it caused a power outage in 40,090 houses at the time of the maximum power failure and 196,000 houses in total. Table 1 shows the wide-range damage to our power facilities such as power generation, transformation, power transmission, power distribution, communication, etc. Although the recovery work was hampered by flooded rivers and collapsed roads, we have made an extensive effort to recover damaged power facilities, supported by other power utility companies. [Cabinet Office (2011) and The Japan Society of Civil Engineers Field Survey Team for Earth-flow Disaster by Typhoon No.12 in 2011 (2011)]

Table 1. Damage to the power facilities

Category	Damaged status	Quantity	Notes
Hydropower Station	Inundated	19 stations	7 stations (Nagatono, etc.)
	Collapsed		16 stations (Osato, Nachi etc.)
Substation	Inundated	1 place	Miyai substation (12,000kVA)
Transmission	Impassable	3 lines	Kawarabigawa line (77kV)
Power Distribution	Impassable	259 channels	136 channels (Wakayama branch) 50 channels (Nara branch)
Communication	Impassable	25 sections	Okuyoshino～Uenoji section etc

2. DAMAGE FROM TYPHOON TALAS TO CIVIL ENGINEERING STRUCTURES

2.1 Feature of Typhoon Talas

On August 25, Typhoon Talas was born on the western sea of the Mariana Islands. It moved to the north slowly, growing gradually, and on the 30th developed into a large-sized and strong typhoon whose central pressure was 965hPa with the maximum wind speed of 35m/sec. On September 2 it went to north keeping its storm area, and landed in Kochi Prefecture next day. After that, moving toward the north so slowly, across Shikoku and Chugoku district, in the early morning of the 4th it progressed to Sea of Japan as shown in Fig.1. Because of its size and slow speed, very moist air from the southern sea flowed into the Japanese archipelago for a long time and it made record rainfall especially in the area along the mountain of Kii Peninsula, where the total precipitation from August 30 to September 5 was over 1000mm. At Kamikitayama village in Nara Prefecture, the total rainfall has topped a record breaking of 1,808mm (Fig.2), according to AMeDAS (Automated Meteorological Data Acquisition System) of the Meteorological Agency. [Meteorological Agency (2011)]

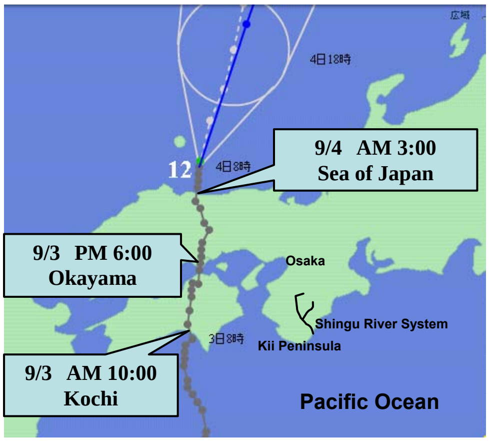


Figure 1. Route of Talas

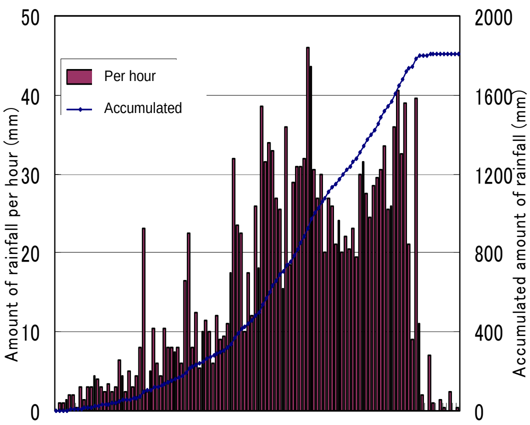
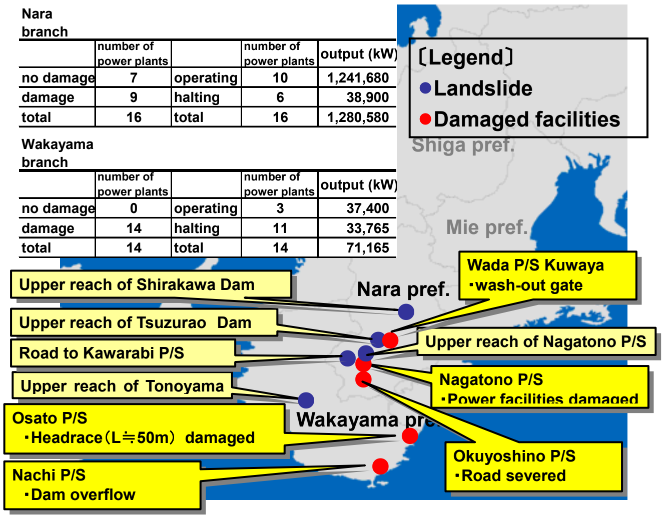


Figure 2. Amount of rainfall in Kamikitayama Village

2.2 Damages of Civil Engineering Structures

Damaged hydropower stations in Nara and Wakayama branch office are shown in Fig. 3, which indicates that 17 out of 30 power plants were damaged to halt their power operation.

Most of them were caused by debris flow or landslides. One of the most serious damage was occurred in the Nagatono power plant (P=15MW, started in 1937). The building and related facilities of the Nagatono power plant, shown in Fig. 4, were totally washed away by a possible flood caused by the landslide which happened at about 1km downstream of this plant. Compared to as it was before Typhoon Talas, the current status of the site has dramatically changed as if a large tsunami hit there. The landslide triggered waves like a powerful tsunami, which spread to upstream from downstream in a form of hydraulic bore, reached heights of up to 30m high from the riverbed according to our site survey of flood trace height along the river. This fact is also explained by the damaged status of the building and related facilities shown in Fig. 5, indicating that an electric pole next to the penstock fell down toward upstream, as oppose to the flow direction of the river. We have studied the restoration plan for the damaged Nagatono power plant with reference to the survey results such as river cross sectional survey, flood trace height, grain size measurement, etc. and by performing numerical simulations for evaluating riverbed variations in the future.



Nara branch

	number of power plants		number of power plants	output (kW)
no damage	7	operating	10	1,241,680
damage	9	halting	6	38,900
total	16	total	16	1,280,580

Wakayama branch

	number of power plants		number of power plants	output (kW)
no damage	0	operating	3	37,400
damage	14	halting	11	33,765
total	14	total	14	71,165

Figure 3. Damage in Nara and Wakayama branch

Figure 4. Collapsed Nagatono power plant

Figure 5. A leaning pole to upstream

We need to manage power facilities with much attention to nature that gives us this kind of unpredictable disasters occasionally.

3. EFFECT of the SEDIMENT BYPASS SYSTEM DURING TALAS FLOOD

3.1 Background of Constructing the Sediment Bypass System

The Asahi dam, which is the lower dam of the Oku-yoshino Pumped Storage Power Plant as shown in the Fig. 6 and Fig. 7, is located in Nara Prefecture, Totsukawa village, part of which is in a national or quasi-national park. From the time of its construction special attention has thus been rendered to preserve the surrounding natural environment and particularly the conservation of water quality downstream of the dam. Accordingly, selective water intake equipment was installed to enable water withdrawal from arbitrary layers inside the reservoir and thereby conserve the water quality in and around the reservoir.

Since a series of typhoons hit the upstream basin of the dam in 1989, a large amount of sediment and turbid water had flowed into the reservoir due to widespread collapses of the mountain slopes, raising a concern that discharge water through the selective intake became severely turbid for a long period of time. In particular, several large-scale runoffs caused remarkable prolonged turbid water in the reservoir lasting over 200 days in 1990, which brought about the fear of creating negative impact on the environment in the downstream river reaches.

Such countermeasures had been undertaken in vain to improve the water quality of the lower reaches of the river as repairing landslide areas within company-owned land adjacent to the reservoir and installing gabion weirs filtering sediment at the downstream of the dam.

Among possible countermeasures the sediment bypass system which can divert a large amount of incoming turbidity as well as sediment flow to the downstream river was selected as the best solution to both the long-term turbidity and sedimentation in the reservoir. The sediment bypass system at the Asahi Dam commenced its operation in April 1998.

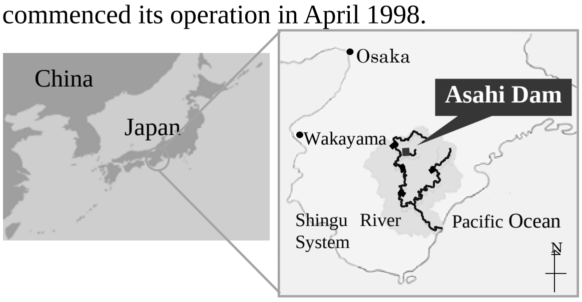


Figure 6. Location of the Asahi Dam

Figure 7. A view of the Okuyoshino Power Plant

3.2 Outline of the Sediment Bypass System

The sediment bypass system consists of four major components, namely, the diversion weir, intake, bypass tunnel and outlet. The inflow water to the reservoir is diverted at the weir located in the backwater area, a certain amount of which passes through the bypass tunnel, 2.35km in length, up to the river downstream of the dam and then joins the original river at the outlet.
The capacity of the bypass tunnel is designed as 140m3/sec, which can practically diminish the number of prolonged turbidity days induced by a flood peak of 200m^3/s equal to the return period of 1-year, and also can sluice more than half of all bed load transported by the design flood of 1,200m^3/s at the dam site.

Main features and general layout of the bypass system are shown in Table 2 and Fig. 8. Rough specifications of the major components were determined by using numerical simulations, and then verified through large-scale hydraulic model tests for observing such a harmful phenomenon in the bypass system as clogging in the tunnel. [Harada, M., et al (1996, 1997, and 1998)]

Table 2. Specifications of the bypass system

Weir	Height	13.5 m
	Crest Length	45.0 m
Intake	Height	14.5 m
	Width	3.8 m
	Length	18.5 m
	Type	Reinforced Concrete and steel Lining
	Gate	1
Bypass tunnel	Height × Width	3.8 m × 3.8 m
	Shape	D-shape
	Gradient	Approx. 1/35
	Max. Discharge	140 m^3/s
	Lining	Reinforced Concrete (with steel lining for inlet portion)
Outlet	Width	8.0 ~ 5.0 m
	Length	15.0 m
	Type	Reinforced Concrete

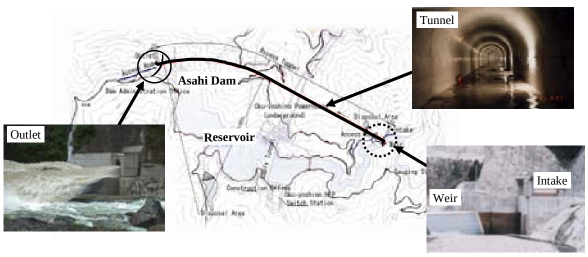


Figure 8. General layout of the bypass system

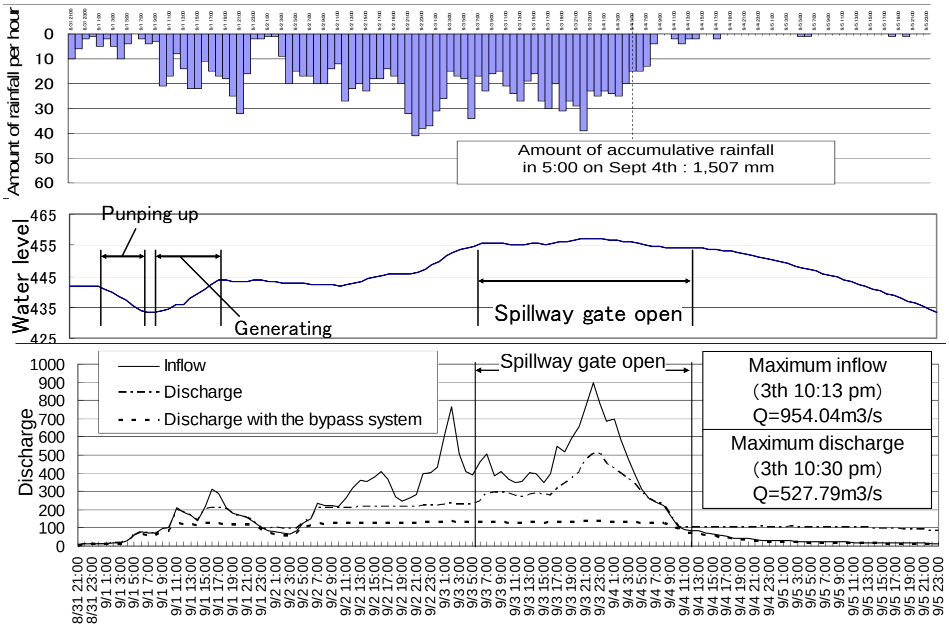


Figure 9. Operational results of Asahi Dam and the bypass system during the flood

3.3 Operational Results of the Asahi Dam during Talas Flood and Effects on the Turbid Water with the Bypass System

Fig. 9 shows the operational results of the Asahi dam and the bypass tunnel during the flood of Typhoon Talas. The cumulative rainfall in the Asahi dam reached over 1,500mm and the maximum inflow to the dam amounted to 954m^3/s, which surpassed by far the previous maximum inflow of 537m^3/s. The sediment bypass system, which is represented as the dotted line in Fig. 9, had been operating throughout this flood period.

Fig. 10 represents the measured data on turbidity at two gauging stations located upstream and downstream from the dam. The turbidity at the upper gauging station, which is located about 4.3km upstream from the dam, dropped to 5ppm on Sept 6th. And a week later, the turbidity in the lower gauging station, located about 1.5km downstream from the dam, became less than 5ppm on September 13th. The number of long-term turbidity days was similar to those in the past floods although this flood was far larger-scale.

Fig. 11 illustrates that the number of prolonged turbidity days has decreased dramatically from some 50 to 9 days on an annual average basis since 1998. [Harada, M., et al (1996), Kataoka, K. (2000), Kataoka, K., et al (2005), and Doi, H. (2005)] As for the definition of the long-term turbidity days, the daily data on SS over 5ppm are deemed as a day which is used for the evaluation of the prolonged turbidity and then the difference in days between the two stations is defined as the number of days that stands for the prolonged turbidity to the downstream reaches.

It is clearly demonstrated that diverting a large amount of turbid water by using the bypass system is highly effective for a decrease in days for long-term turbid water discharge to the downstream area.

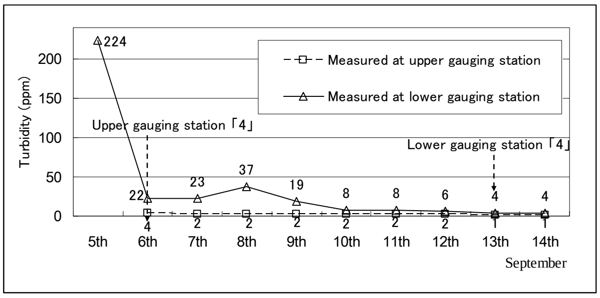
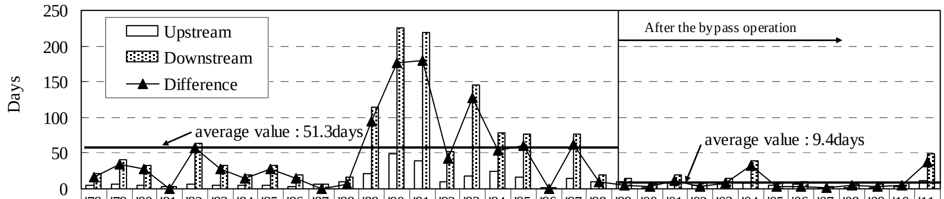


Figure 10. Data on turbidity at two gauging stations

3.4 Sedimentation in the Asahi Reservoir after Talas Flood

In 1998 when it took 20 years after the commercial operation, the ratio of the sediment to the total storage capacity of the Asahi reservoir was only 4.3%, which can be computed by dividing by the planned sediment volume of 2.51 million m^3 (for 100-year) into the present volume of 0.67 million m^3 in 1998. However, the riverbed shape of 1998 had nearly reached the power intake/outlet as shown in Fig. 12, and further development of sedimentation would harm the safe operation of the power plant without any effective countermeasure. [Kataoka, K. (2000)] Since the bypass operation started in 1998, it is likely that the riverbed shapes inside the reservoir have been relatively stable



	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11
Upstream	5	6	5	4	6	5	5	5	4	6	10	21	49	40	9	18	25	16	1	14	10	9	2	8	5	6	8	5	6	2	1	2	3	12
Downstream	22	41	32	4	63	33	19	33	19	6	17	115	226	219	52	146	79	76	1	76	19	14	6	19	8	14	40	8	10	4	6	6	8	49
Difference	17	35	27	0	57	28	14	28	15	0	7	94	177	179	43	128	54	60	0	62	9	5	4	11	3	8	32	3	4	2	5	4	5	37

Figure 11. Number of days with turbidity over 5 ppm

though the riverbed of 2011 as shown in Fig. 12, which was formed in the record flood triggered by Talas, rises higher than before. In particular this flood developed the sedimentation downstream of the Se Bridge at near the L.W.L. of 430 as shown in Fig. 13.

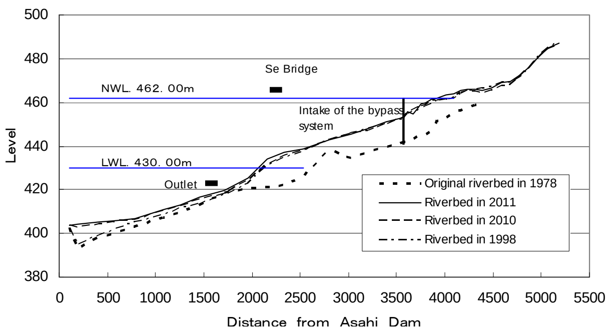


Figure 12. Longitudinal profile of the riverbed in the Asahi reservoir

Figure 13. Sedimentation in Asahi Dam

Meanwhile, annual measured and estimated sedimentation volumes are illustrated in Fig. 14, in which the estimated volume with the bypass operation is computed through a numerical simulation model, and the measured one is obtained through periodical bathymetric surveys. [Fukuroi, H. (2009)] Fig. 14 reveals that a range of 80 to 90 % of incoming sediments is discharged to the downstream reaches via the tunnel, and the remaining amounts deposit in the reservoir overtopping the diversion weir.

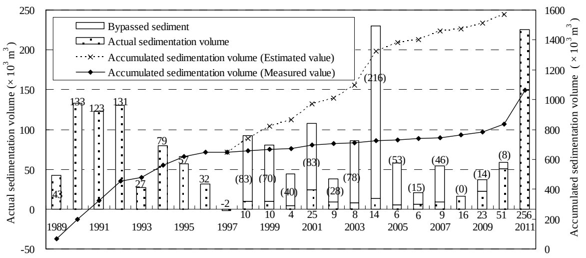


Figure 14. Measured and estimated sedimentation volume in the Asahi Dam

In the aftermath of this record flood, the annual sedimentation volume inside the reservoir measured more than 200,000 m^3, which was the largest volume since the start of the bypass operation. Bypassed wash load and bed load during the flood period could be roughly estimated by using Fig. 15 which was developed based on the results of a numerical simulation model at the design phase. This figure indicates that about 75% of all bed load and 25% of wash load were routed thorough the bypass tunnel to the downstream reaches.

In reaction to the trend of the riverbed shape formed by Talas and the actual measured volume in the reservoir, the verification of the ratio of bypassed sediment to all incoming sediment to the dam is underway with one-dimensional simulations of riverbed variations to confirm the effects of the sediment bypass system.

3.5 Damage to the Bypass Tunnel

In the course of flooding from Typhoon Talas, a large number of reinforcement bars in the tunnel invert were severed in places and also the tunnel invert lining with concrete was deeply eroded by a maximum of 60cm. This eroded volume of concrete was much larger than the cumulative volume counted up to the previous floods since considerable amounts of bed load passed through the bypass tunnel.
Fig. 16 shows the damaged tunnel section lining with steel sheets (length=19m), a portion of which was torn off due to tremendous debris flows.

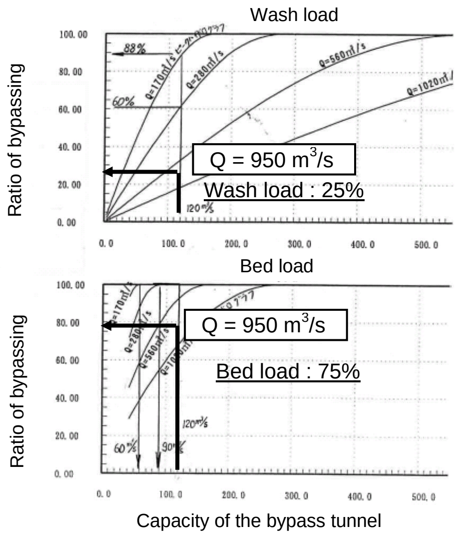


Figure 15. Bypassed wash load and bed load according to inflow volume

Figure 16. View of the damaged tunnel section lining with steel sheets

4. Conclusion

The actual damage from Typhoon Talas to the civil structures owned by KANSAI and the operational results of the sediment bypass system at the Asahi Dam are as follows:

・In Nara and Wakayama branch office, 17 out of 30 power plants were damaged to halt their power operation.

・The building and related facilities of the Nagatono power plant were totally washed away by landslide triggered waves which spread to upstream from downstream in a form of hydraulic bore.

・At the Asahi Dam, the maximum inflow reached 954m^3/s, which surpassed by far 537m^3/s of the previous maximum experienced inflow.

・The sediment bypass system had the effects of reducing long-term turbidity days and of routing a large part of incoming sediment through the tunnel, though sedimentation in the reservoir developed.

・A large number of reinforcement bars in the tunnel invert were severed in places and also the tunnel invert lining with concrete was deeply eroded by a maximum of 60cm.

In the aftermath of Typhoon Talas, we have studied a rehabilitation plan for the collapsed Nagatono power plant and the effects of the bypass system on discharged sediment amounts through the tunnel during this flood. Further we continuously collect relevant survey data for verifying long-term operational effects of the sediment bypass system on environmental conservation of the downstream river, focusing on analyzing trends of water quality and sedimentation in conjunction with changes in the ecosystem of the downstream river.

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