Experimental study of ski jump spillway at the Nam Ngiep1 Hydropower Project in Laos

Takuma Takahashi[1,a], Yoshikane Murakami[1,b], Makoto Asakawa[1,c], Shoji Tsutsui[1,d], Yushi Aosaka[2,e]

[1]*International hydropower development group, Kansai electric power Co.,Inc, Osaka, Japan*
[2]*Technical Division, Nam Ngiep 1 Power company, Vientiane, Lao Peoples Democratic Republic*

[a]takahashi.takuma@e4.kepco.co.jp
[b]murakami.yoshikane@e4.kepco.co.jp
[c]asakawa.makoto@b3.kepco.co.jp
[d]tsutsui.shoji@d3.kepco.co.jp
[e]aosaka.yushi@namngiep1.com

ABSTRACT

The Nam Ngiep 1 Hydropower Project in Laos is under construction: two dams and two powerhouses with total installed capacity of 290MW. A 167 m roller compacted (RCC) dam is being constructed in the narrow valley and will be equipped with a ski jump spillway with multiple flip bucket. Hydraulic model tests have been carried out in order to confirm the effect of deflectors and alternative flip bucket geometries which promote increased longitudinal dispersion of the water jets and diving zones downstream in the river course.

1. NAM NGIEP 1 HYDROPOWER PROJECT

The Nam Ngiep 1 hydropower project ("the Project") is located along the Nam Ngiep River, which is a tributary of the Mekong River, 145 km northeast of Vientiane, the capital of Lao PDR and 50 km north of Paksan city as shown in Figure 1.

The Project consists of a main dam and a re-regulation dam. The crest length and dam height of the main dam, an RCC gravity dam, are 530 m and 167 m, respectively. The reservoir created by the main dam will store around 2 billion m^3 of water with an effective storage capacity of around 1 billion m^3 for generating electricity of a maximum output of 272 MW that will be exported to Thailand. The re-regulation dam, which is a conventional concrete gravity dam with labyrinth spillway, is located 6.5 km downstream of the main dam, and its crest length and dam height are 252.6 m and 20.6 m, respectively. The main features of the main dam are shown in Table 1. Major construction works commenced in October 2014 and, as of the end of December 2016, were approximately 60% complete. The aim is to commence commercial operation in January 2019. Salient features of the main dam as of the end of December are as shown in Figure 2.

Figure 1. Location map

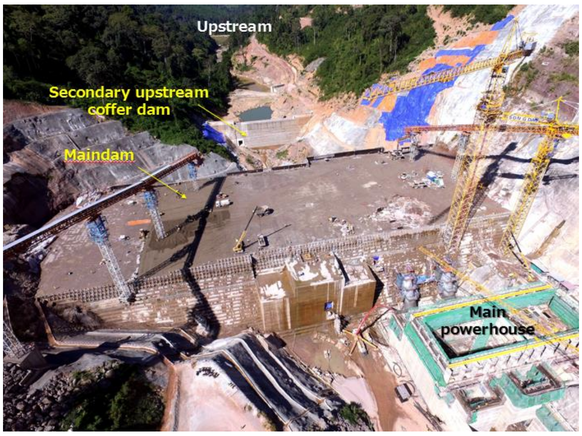


Figure 2. State of Construction Work of the Main Dam (December 2016)

Table 1. Salient Features of Main Dam

Facility	Items	Unit	Specifications
Reservoir	Effective storage capacity	10^6 m^3	1,192
	Catchment area	km^2	3,700
	Average annual inflow	m^3/s	148.4
Dam	Type	-	Concrete gravity dam Roller-Compacted Concrete
	Dam height	m	167.0
	Crest length	m	530.0
	Dam volume	10^3 m^3	2,300
Spillway (Ski jump type)	Gate type	-	Radial gate
	Number of gates	-	4
	Design flood	m^3/s	5,210 (1,000-year)
Turbine and generator	Maximum plant discharge	m^3/s	230.0
	Effective head	m	130.9
	Rated output	MW	272 at Substation

2. PAST STUDY OF SKI JUMP SPILLWAY WITH DISPERSION TYPE OF FLIP BUCKET (PAST HYDRAULIC MODEL TEST CONTENTS)

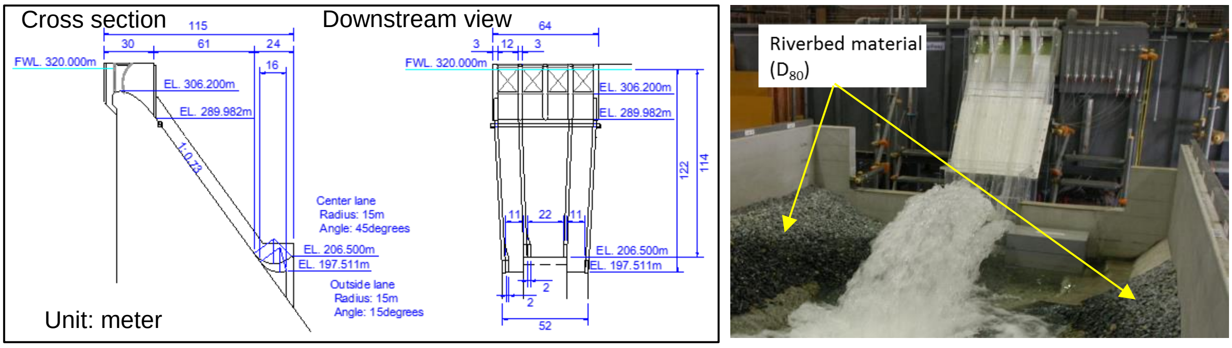
A "hydraulic jump" or "ski jump" is the most adopted type of energy dissipating spillway for concrete gravity dams. While a hydraulic jump spillway requires massive excavation and a huge concrete structure to furnish itself with an energy dissipater, the ski jump type requires less facilities and a smaller volume of excavation. Still, a ski jump spillway can potentially impact riverbed erosion and filling needed to form a plunge pool. The designed flood of a 1,000 year return period is estimated to be 5,210 m^3/s

(106.3 m³/s/m), and the drop height is around 110 m, as shown in Figure 3. (a). Stream power is calculated to be 460 kW/m² according to Schalwyk, therefore this ski jump spillway is big in scale compared to world standards. As part of the process of adopting a ski jump spillway for the Project, hydraulic model tests have been ongoing since 2009 in order to identify the hydraulic characteristics and potential impacts on the downstream river course, both the banks and peripheral facilities.

The dam is placed in a narrow gorge and both banks and the riverbed are covered with thick terrace deposits and river deposits including big boulders of 10 to 15 m in diameter. Considering the above topographic and geological conditions, three chutes with multiple flip buckets were studied to disperse the diving water efficiently and to make a long oval shaped plunge pool that would prevent erosion on both banks. The movable bed was introduced to assess the formation of the plunge pool and so on.

The geological features of the location of the dam are denoted by alternating mudstone and sandstone layers that gently incline in the downstream direction. The syncline is around 8˚. According to Anadle and Schalwyk, the foundation rock below the riverbed, which is mostly categorized as CM or CH class rock based on the classification of the Central Research Institute of the Electric Industry (CRIEPI), is judged to be non-eroded. A scale of 1 to 65 was applied in hydraulic model tests and a Reynold's number (Re) over 10,000 was secured, as shown in Figure 3. (b). Hydrodynamics were adopted as the law of similarity because gravity and inertia force are dominant. The riverbed materials and CL class foundation rock in the model were composed of stones of a diameter of 5 to 15 mm, which is equivalent to D_{80}. Here, D_{80} stands for 1) a particle size of 80% accumulated weight of grain size distribution of riverbed materials (325 to 975 mm) and 2) the expected block size of foundation rock to be cracked by stream power of the diving water in the prototype based on geological survey and drilling core sample observation.

Figure 3 shows the hydraulic model.



(a) Profile of Ski Jump Spillway

(b) Model of Ski Jump Spillway (scale of 1/65)

Figure 3 Model of Ski Jump Spillway

In the original design, the flip bucket angles on the central and outer lanes were set as 45˚ and 15˚, respectively. Regarding the discharge from the outer lanes, the impact energy of discharge from the outer lanes is dissipated by therr water jets' colliding after jumping from the chute. The basic structure of the spillway was determined based on the hydraulic model tests, which can be referred to in the paper of the 25th ICOLD Conference in FY2015, "Q97-1".

At a diving point, however, very large scouring force affected the riverbed, which caused the following issues.

Issue 1); When a big flood is discharged from the spillway, the water level downstream becomes higher due to the filled materials. According to the hydraulic model tests, in the case of the designed flood, 5,210 m³/s is discharged and the water level immediately downstream of the diving point is raised far beyond the ground level of the powerhouse building (EL. 193.3 m), which may adversely impact the powerhouse resulting in a decrease in power generation.

Issue 2); Dredging work may be required to remove sediment deposit influx from the outlet channel.

Issue 3); Since slopes on the right banks are pushing out near the diving point, the discharge may have an adverse impact on the slope stability on both banks.

Issue 4); In case the water flow exceeds 3,000 m^3/s, disturbance of the water flow at the chute significantly affects water discharge.

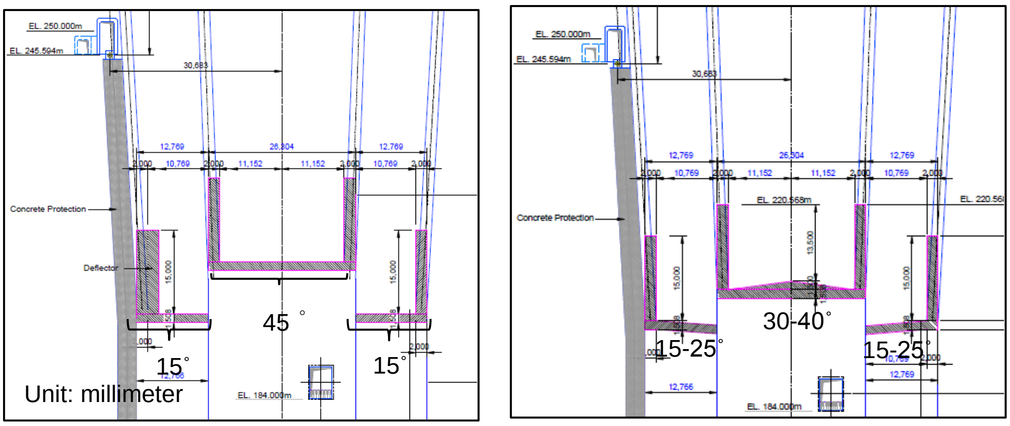
Additional hydraulic model tests were carried out in 2016 to modify the model with changes to the angle of the flip bucket in order to cope with the above issues.

3. TEST PROGRAM

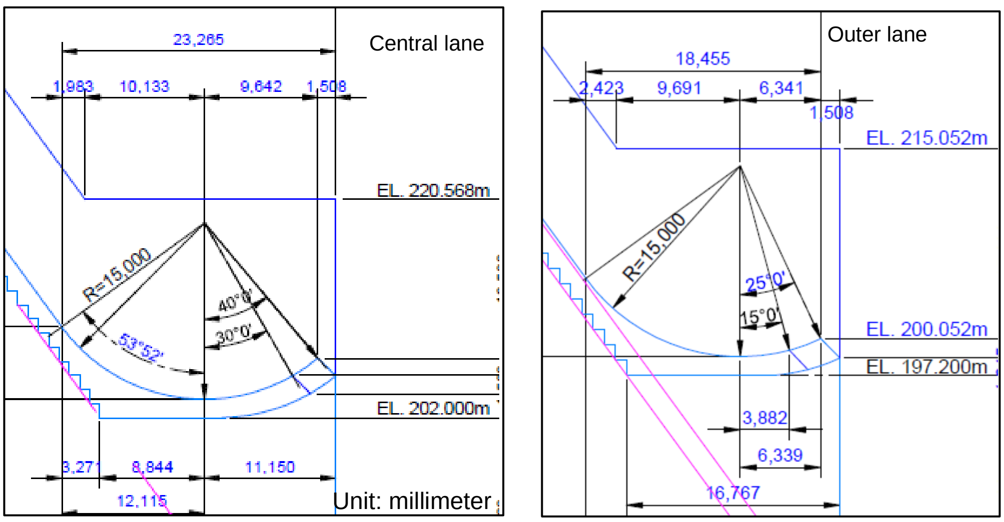
3.1 Flip Bucket with Deflector (Reformation of Flip Bucket)

In order to resolve issues 1) and 2) in Section 2, the following study was conducted.

A range of flip bucket angles on the central and outer lanes were set to 30 to 40˚ and 15 to 25˚ with convex curvature, respectively, as shown in Figure 4, so that the water jets could have a wider trajectory that would expectedly increase the energy dispersion effect at the diving point. In the case of the original flip bucket with a central flip angle of 45˚, the discharged water running out of the chute pours onto the slope on the right bank whereby augmenting the scouring force against the slope. In this test, therefore, as shown in Figure 5, the flying distance of the diving water from the outer lane can be shortened. On the contrary, that from the central lane can be extended to prevent the water from diving near the outlet channel and sediment deposit from inflowing into the outlet channel. In the Aldeadavila Dam (Spain) and Koudiat Acerdoune Dam (Algeria), there are flip buckets of varying angles in the same chute.



Downstream view of Flip bucket (Left; Original, Right; Modified)



Side view of Flip bucket (Left; Central lane, Right; Outer lane)

Figure 4. Detail of Flip Buckets

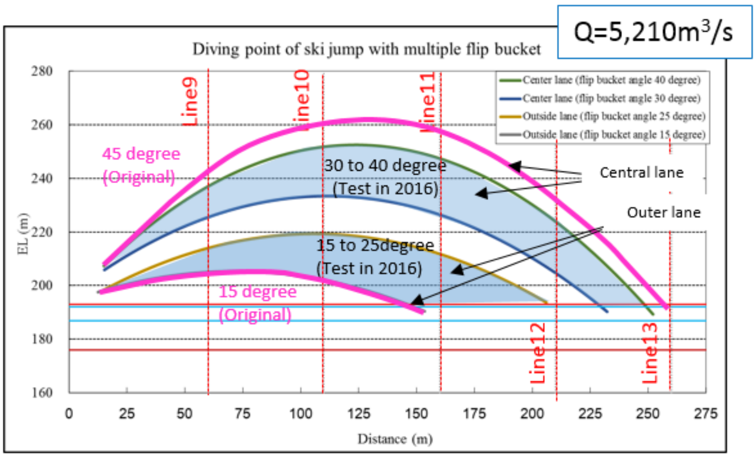
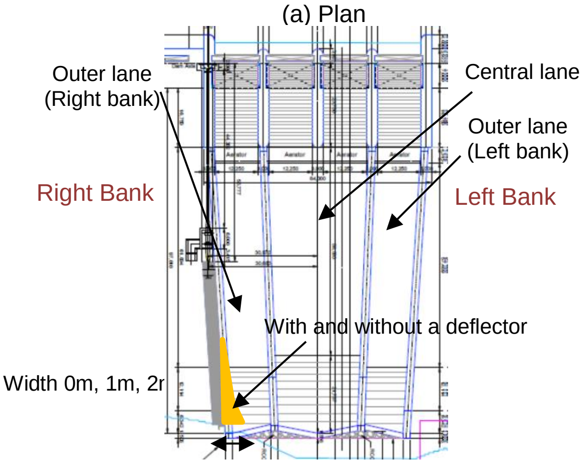


Figure 5. Angle of Flip Buckets and Diving Points

As for issue 3), the topographic features of the site raised the following concern: The slope on the right bank at a point downstream was pushing out over the river and overlapping with the diving point. As for the right outer lane, tests were carried out with the width of a deflator set to 0, 1 and 2 m to confirm the impact on the slope, as shown in Figure 6. (a).

Figure 6. (b) shows the experiment cases for the above issues 1) – 3) and the results of tests. The amount of erosion and filling in each case were calculated by measuring the contour of each section (50 m pitch) of Lanes 9 to 20 before and after the tests. The flow rate was set to the 5,210 m^3/s designed flood, which was large enough to check the impact.



(b) Results of tests

	Original	Case 1	Case 2	Case 3
Flood	5,210 m3/s			
Width of Deflector (Right Wall of outer lane at right bank)	2.0m	0.0 m	1.0 m	2.0 m
Angle of Flip bucket (Outer lane)	15°	15° to 25°		
Angle of Flip bucket (Central lane)	45°	30° to 40°		
Tailrace water level	196.82 m	193.05 m	192.73 m	192.54 m
Erosion volume	-247,000 m3	-131,700 m3	-170,100 m3	-192,075 m3
Sedimentation volume	136,760 m3	90,900 m3	103,425 m3	128,350 m3

Figure 6. Test Cases

Figure 7 shows the elevation of the riverbed line and the maximum water level on Lines 9 (50 m downstream from the spillway) –20 (approximately 600 m downstream from the spillway) before and after the tests.

Points of improvement for each issue are summarized as follows.

3.2 Concerning Issue 1

- Due to the wider range of the flip bucket angle on each lane as shown in Figures 7 and 9, the energy of the discharge water at the diving point was well dispersed and both the amounts of eroded and filled materials on the riverbed were also significantly decreased. Accordingly, as shown in Figure 7, the water level of Lane 9 near the powerhouse became lower than the ground level of the powerhouse building at EL. 193.3 m.

From the above results, the energy dispersion effect on the discharge water was confirmed.

3.3 Concerning Issue 2

- Due to the change in the flip bucket angle on the outer lane, the water diving point of the discharge water shifted to the downstream as shown in Figure 8, and the inflow of sediment into the outlet channel was not observed in any of the cases.

3.4 Concerning Issue 3

- Since the diving point of the discharge water from the central lane shifted upstream and the range of the flip bucket angle in each lane became wider, the impact on the slope downstream was mitigated.

- It is considered that the amount of eroded material increased in the case where the deflectors were used, because the deflectors narrowed the flow area of the flip bucket thus preventing wider discharge and energy dispersion at the diving point. It is, therefore, believed that tractive force toward the downstream became larger and the water level of Line 9 lowers.

In view of the energy dispersion effect as described above, the deflectors were not required.

When a 5,210 m^3/s flow was discharged, however, the access road to the powerhouse along the left bank still flooded as shown in Figure 10, while the water level lowered in every case.

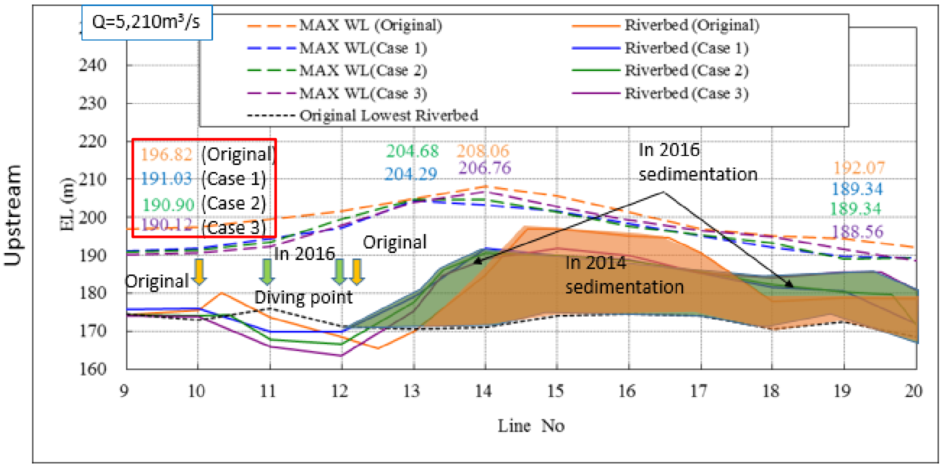


Figure 7. Water Level and State of Riverbed Before and After Test

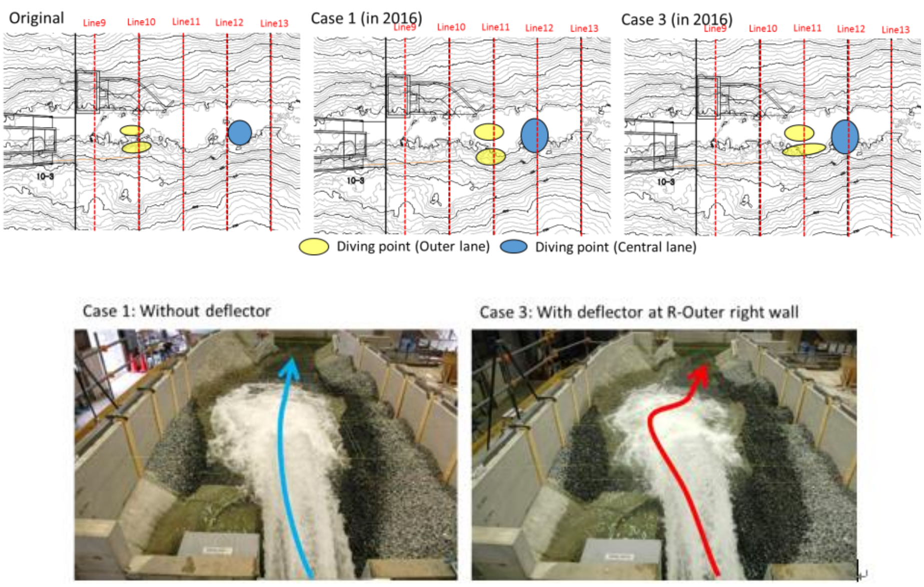


Figure 8. Difference in Diving Points between the Cases with and without a Deflector

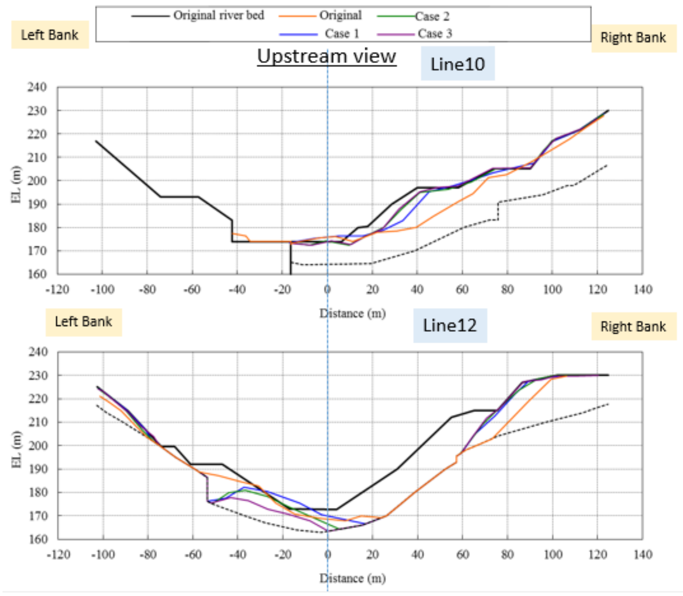


Figure 9. Erosion Downstream (Section)

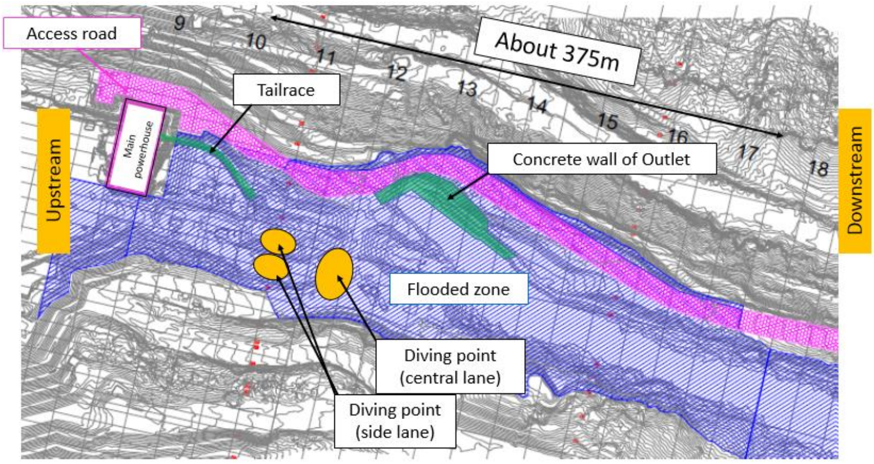


Figure 10. Flooded Area Downstream (Q=5,210 m^3/s)

Figure 11 shows the flow regime during discharge in each case and the original scenario.

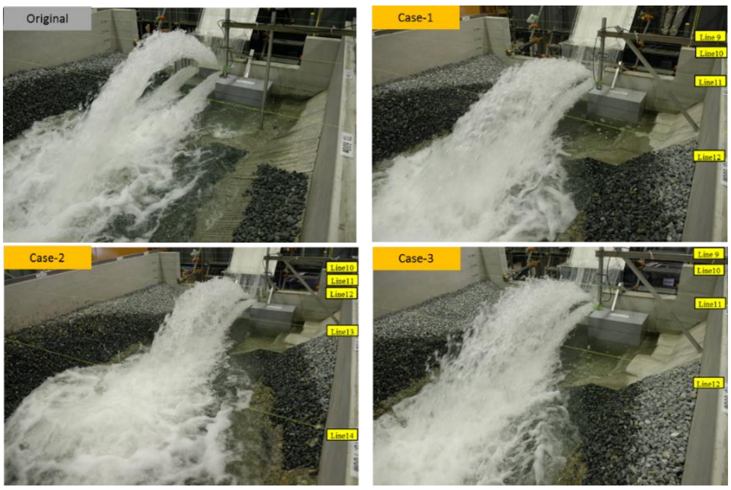


Figure 11. Flow Condition (Downstream View)

3.5 Concerning Issue 4

A study concerning the shape of piers for the outer and central lanes was done in order to improve issue 4) as follows.

In the original plan, if the discharged water flow exceeds 3,000 m^3/s, an imbalance of the water lever is caused at the approach of the outer lane, and a shock wave is generated in the chute as shown in Figure 12. The upstream end of the piers, therefore, were extended toward the upstream to improve such imbalance. Model tests were carried out for two cases that all the piers were extended toward the upstream ("Case 1") and that only the outer piers were extended ("Case 2") as shown in Figure 13.

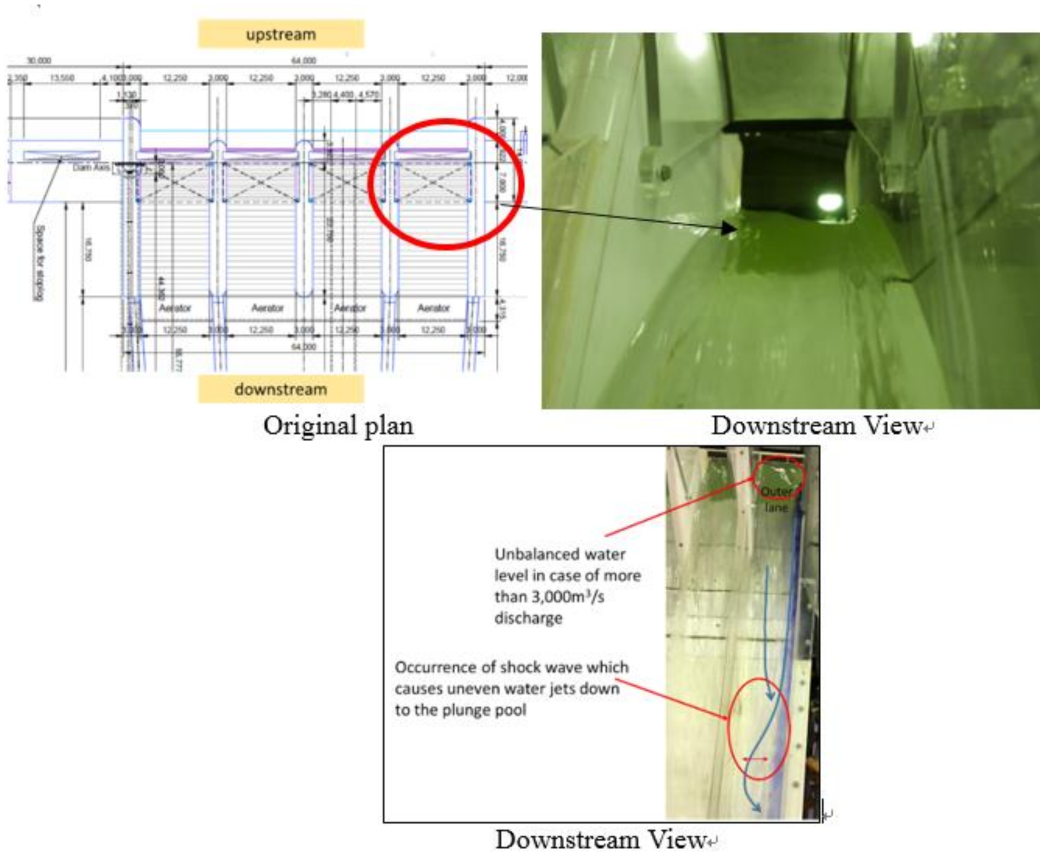


Figure 12. Imbalance Water Level and Shock Wave in Original Case

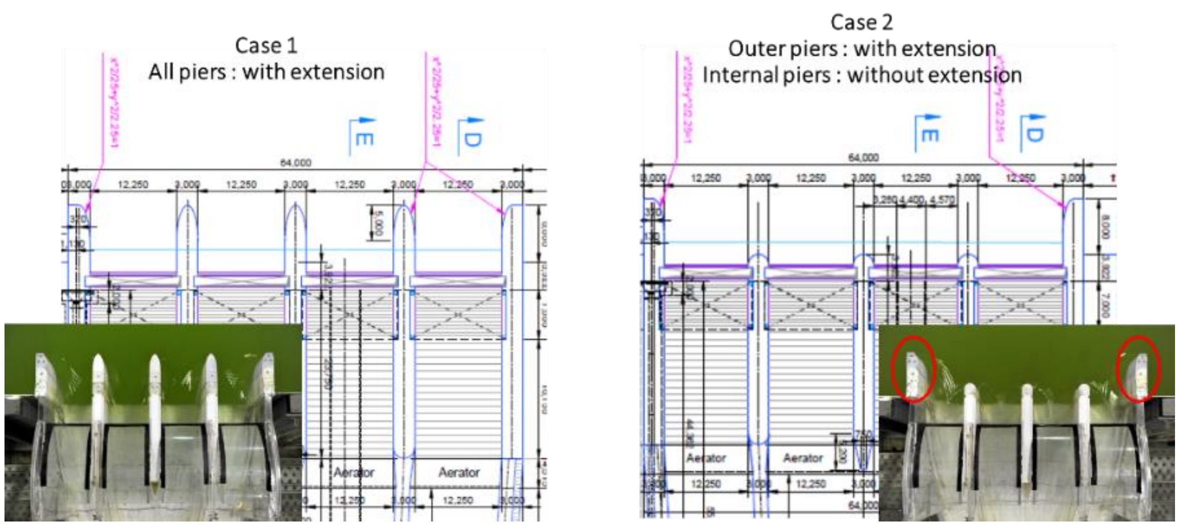
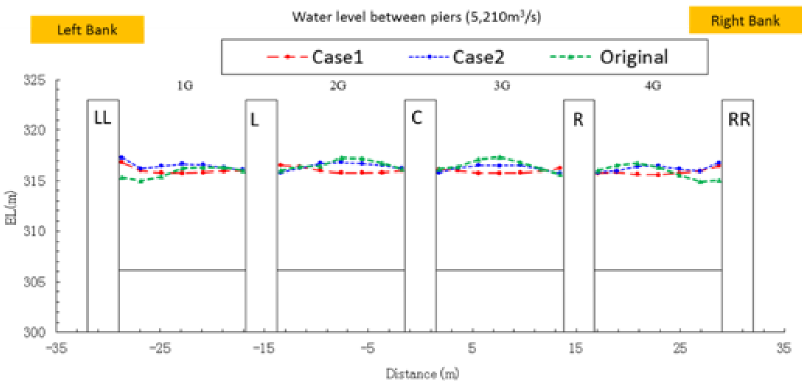
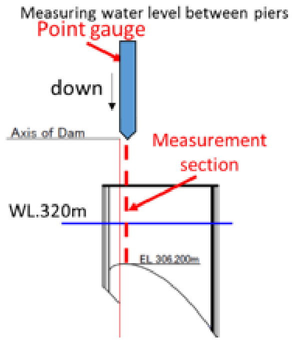


Figure 13. Extension of Piers Upstream

The tests were conducted under the designed flood of 5,210 m³/s, and the water level data at the approach between each pier was measured by point gauges. The imbalance of the water level in both cases was rectified to a flat line, though they still fluctuated slightly, and the shock wave disappeared as shown in Figure 14. There was no significant difference in the degree of improvement between Case 1 and 2.



Upstream View



Cross Section

Difference between Maximum Water Level and Minimum Water Level (m)

	Case 1	Case 2	Original
difference	1.0	1.0	1.7

Standard Deviation of Water Level (m)

	Case 1	Case 2	Original
1G	0.3	0.3	0.5
2G	0.3	0.3	0.5
3G	0.2	0.3	0.6
4G	0.3	0.3	0.7

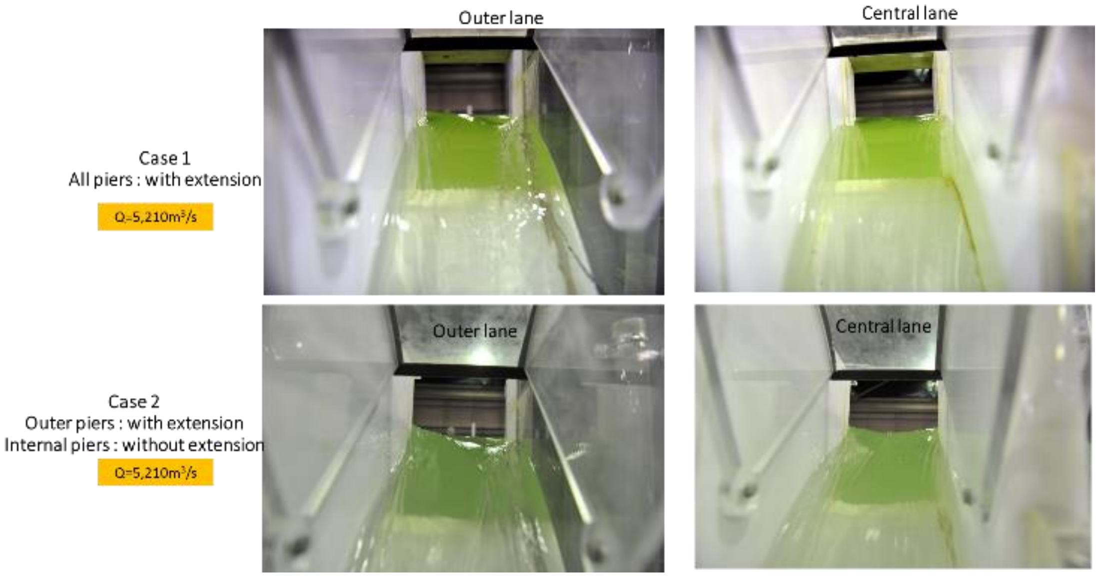


Figure 14. Effect of Pier Extension Upstream

The water flows of Chutes No. 2 and No. 3 collided with each other at the lower part of the central chute and the discharged water was disturbed as shown in Figure 15. The extension of the downstream end of the pier between Chutes No. 2 and No. 3 was studied to make their confluence smooth for cancelling the disturbance of the discharged water. In reference to U.S. Army Corps of Engineers (USACE), it is expected to extend the pier downstream by 5 m or more (Case 1) and by 15 m (Case 2) as suggested by the third party, Dam Safety Review Panel (hereinafter referred to as “DSRP”).

The flow regime of the central chute was improved in both Case 1 and 2 as shown in Figure 16, and the double peak of the water jet as seen in the original scenario was eliminated. No apparent difference in the degree of improvement by the extension of piers downstream between Cases 1 and 2 could be seen.

At the same time, operation of some gates was tested, and when the opening height of the gates exceeded 2 m, vortexes with less air-entraining formed frequently at the approach of the gates in both the Case 1 and Case 2. However, when the next gates were closed a bit, the event reduced. This kind of event has sometimes happened with intake gates of hydropower plants owned by Kansai Electric Power. However, since less air is entrained, the gates have been properly operated without any issues so far. The formation of vortexes with air-entraining will be monitored quantitatively through hydraulic model tests, and measures will be considered if necessary.

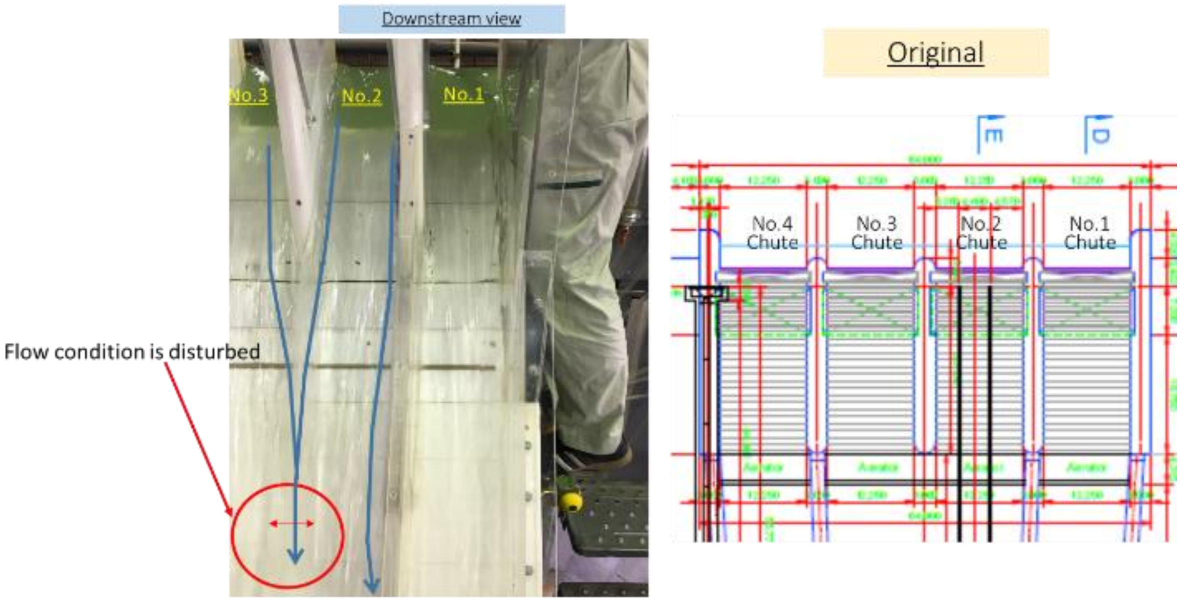


Figure 15. Disturbed Water Flow in Chute in Original Case

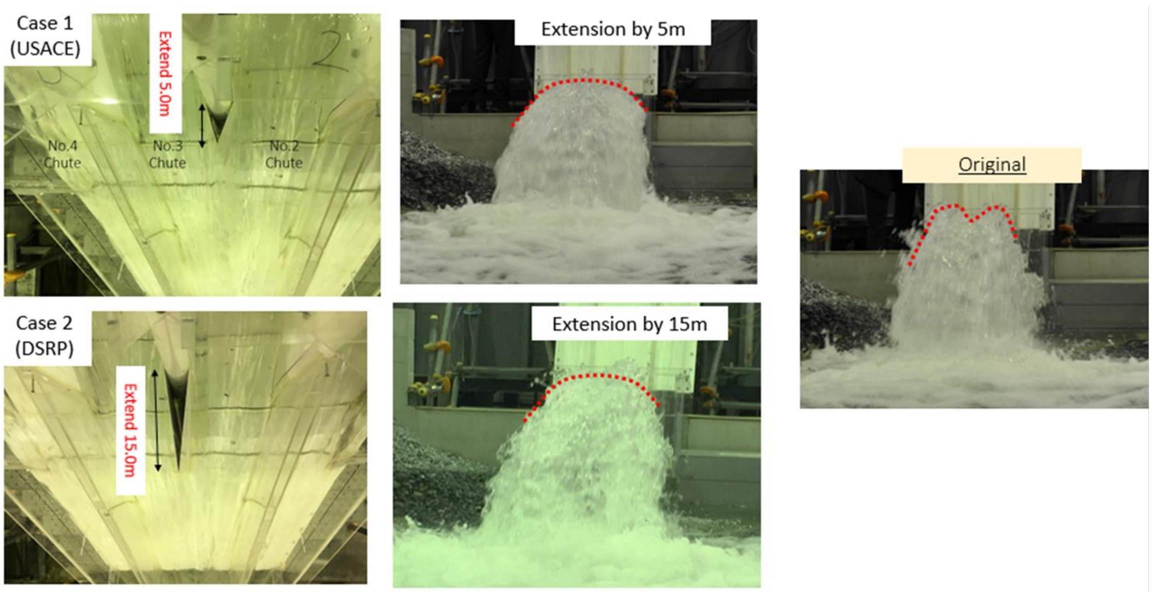


Figure 16. Effect of Pier Extension Downstream

4. CONCLUSION

The main purpose and method of the hydraulic model test are

1) To promote increased longitudinal dispersion of energy by changing an angle of flip buckets, and 2) To improve the flow regime by changing shape of a pier to prevent generation of shock wave in the case of large flood.

This hydraulic model test provided the following result.

- Thanks to the wider flip angles, the energy dispersion effect at the diving point was improved. Accordingly, the amount of erosion and filling in the riverbed and both banks could be significantly decreased and the water level dropped below the ground level of the power house building.
- Thanks to the modification of the flip angle in the outer lane and the diving point shifting to the downstream, the inflow of sediment into the outlet channel could be prevented.
- For the same reason above, the adverse impact on slope stability downstream was mitigated. In view of the effect as described above, it was concluded that a deflector would not be necessary.
- Due to the change in the shape of the piers at the spillway gate, the flow regime was improved as compared with the original plan in every case.

As for the flooding along the access road, it is considered acceptable in view of the current situation of the project site, that 1) an access route for people to the powerhouse other than the access road will be secured; 2) an Emergency Action Plan in case of disaster is being established by NNP1 one year before the start of reservoir impounding; and 3) the access road from the Paksan District has been frequently flooded by high water under the present conditions, so, in the event of damage to the access road in the vicinity of the powerhouse, it will be urgently recovered with heavy machinery.

Future discussion may be, however, required.

It was found that, even if there were a large drop height, large flow rate and topographic features of a narrow valley like this project, it would be possible to properly control and disperse the energy of the water discharged from the ski jump spillway, while maintaining the necessary functions by improving the chute structure of the ski jump spillway.

5. ACKNOWLEDGEMENTS

The authors would like to express thanks to KANSO Technos who handled the hydraulic model test and to the Central Research Institute of the Electric Power Industry and NEWJEC who gave us apt advice on implementation. In addition, we would like to give special thanks to DSRP who gave us advice and guidance frequently and in a timely manner, on the implementation of the second stage of hydraulic model test that was needed to improve the remaining complicated situations for the smooth commencement of the Project slated for January 2019. At the site, our staff and contractors continue efforts to equip facilities of the ski jump spillway by considering the impacts on surroundings.