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Strategies of Alleviation for Impacts of Sediment Disasters on Hydropower Facilities in Xindian River Basin

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Abstract

The impacts of sediment disasters caused by climate change and extreme weather are closely related to national energy development. Therefore, the strategies for alleviating the impacts to Hydropower, one of the valuable self-produced energy sources in Taiwan, have become important to the operation and management of Taiwan Power Company (TPC).

Through reviews of relevant research projects in recent years, this paper focuses on the impacts of sediment disasters on hydropower facilities in Xindian river Basin, and reveals the morphological changes between the catchment area and the downstream area under the influence of climate change. Furthermore, this paper proposes strategies to alleviate the impacts of sediment disasters on hydropower, including the following: (1) Dredging the alluvium that hinders hydropower generation; (2) Sediment routing with spillway gates operation during flooding period; (3) Assessment of facility renovation plan in response to overflow emergency; (4) Innovative techniques to increase the flushing efficiency. Under the premises of stabilizing power supply and keepingbenefit to public, TPC will ensure the function of hydropower and achieve the important mission of national sustainable energy development.

Keywords: The typhoon Soudelor, Xindian River Basin, Sediment Disasters, Hydropower

1 Overview of geographical context

Xindian river, running a length of 81 km and a catchment area of 921 km^2, is one of the three major tributaries of the Danshui River system in the northern part of Taiwan and is the birthplace of hydropower in Taiwan. The hydropower facilities in Xindian river basin consists of 5 dams and 4 hydropower plants (Abb. 1), having a combined installed capacity of 110 MW and providing an important contribution to Taiwan's early economic development. Among them, the Tsukeng power plant was built in 1909 and is the oldest hydropower plant existing in Taiwan.

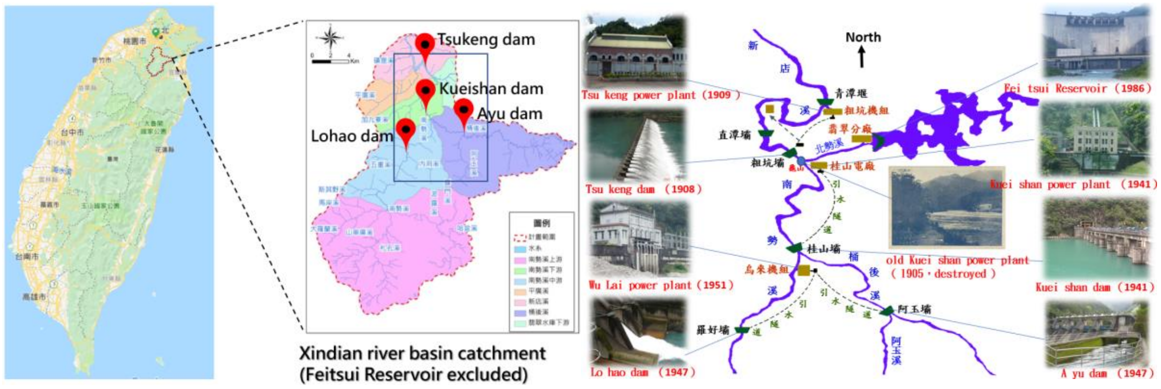

Abb. 1: Xindian river basin, dams and power plants features.

2 Management and operation schemes for run-of-river dams

All hydropower facilities (Feitsui Reservoir excluded) in Xindian river basin correspond to low head run-of-river dams (Barrages) (Tab. 1) which raise the water level to divert the water flow through a headrace canal down to the power plant. Because raising or draining water is completed in a short time, these dams have no water distributing and flood adjusting functions. The sediment management strategies of these facilities differ from those of the storage-based reservoirs used for water resource distributing; because of the trapping effect of a run-of-river dam, the sediment deposition process in the reservoir moves towards equilibrium in the form of 'wedge-shaped deposits' through dynamic processes in river after several years of operation (Abb. 2). After that, the silting ratio varies depending on both the solid fluxes from the catchment area and the bed slope of the river. Under the circumstance of sediment dynamic equilibrium in the dam, spillway gates are dedicated to both flood passage and sediment routing during flood situations to transfer inflowing sediments throughout the reservoir in natural-like flow conditions.

Tab. 1: Low head run-of-river dams in Xindian river basin.

Barrages	Dam height, H (m)	Approx. Crest height, Hc (m)
Ayu dam	17.5	7
Lohao dam	22	10
Kueishan dam	24	7(9)
Tsukengdam	-	6.8

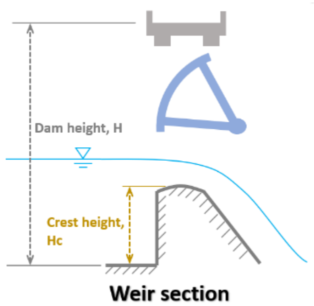

Abb. 2: The sediment equilibrium through dynamic processes. (Lohao dam, before adding the spillway gates, 1950s)

The Sediment management and operation of hydroelectric run-of-river dams in Xindian river Basin is not concerned with reservoir capacity maintenance. Because these dams have no demand for water resource distributing, the amount of water drawn from the water intakes would be returned to the river after passing through the power turbine; as a result, no water loss occurs. Therefore, the main point of sediment management of these dams is not to maintain reservoir capacity, but to avoid accumulated siltation in front of the water intake to affect water diversion in orderto retain the sustainable development of hydropower generation.

The function of the sluiceway of a run-of-river dam is mainly to flush the siltation in front of the water intake. For normal operating conditions, suspended load is deposited in the reservoir due to sedimentation effect (Abb. 3). When the accumulated siltation in front of the water intake affect water diversion, the operators open thesluiceway gates to flush the alluvium in front of the water intake. Due to the small storage capacity of the reservoir, emptying the reservoir by gradually opening thesluiceway gates only takes dozens of minutes. At that time, the flow condition is likely to be equivalent to natural-like flow conditions to flush the siltation in front of the water intake.

During high flow and flood conditions, due to the lack of flood storage capacity of a run-of-river dam, the operators must prepare for flood contingency prevention according to the water level and inflow. When the flow from the upstream river gradually increases, it is necessary to open the spillway gates gradually as a response. At that time, the flow condition in reservoir is similar to natural-like flow condition. In addition to the suspended load that was deposited in the reservoir due to sedimentation effect in normal times, the inflowing sediment laden flow including both bed-load and suspended solids are passed through the spillway gates in natural-like flow condition (Abb. 4).

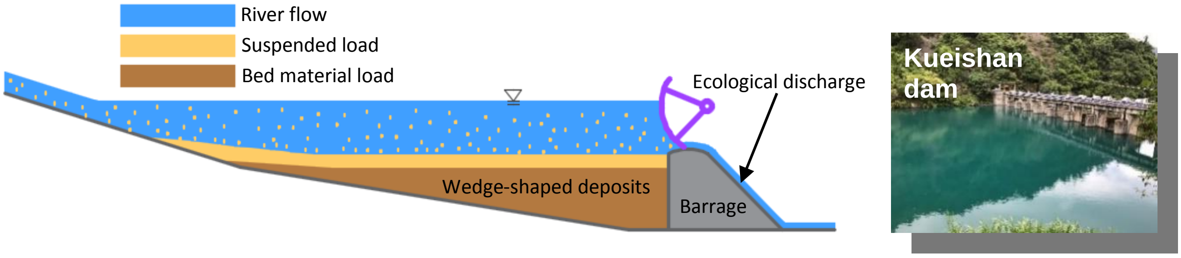

Abb. 3: Sediments in reservoir for normal operating conditions

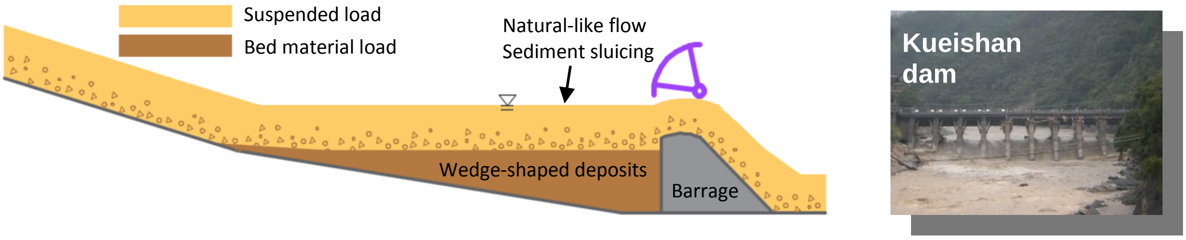

Abb. 4: Sediments in reservoir during high flow and flood conditions.

If the sluiceway gates is opened during high flow and flood conditions, the passing sediment laden flows is likely to cause the sluiceway to wear. According to the results of 3D numerical simulation analysis, during flood conditions accompanied by high flows and high solid concentrations, there is no significant effect on the quantity of sediments deposited in the reservoir irregardless of the sluiceway gate opening or closing [2]. In order to avoid the interruption of hydropower generation caused by the repair of sluiceway abrasion, it is optional to close the sluiceway gate to avoid sluiceway abrasion during high flow and flood conditions. At this point, the spillway gates must be fully opened so as to allow flood and sediment-laden flows to pass through safely, including the suspended load deposited in the reservoir due to sedimentation effect. While the river flow gradually decreases after the flood peak, the sluiceway gate should be opened according to the operation rules to flush the siltation in front of the water intake.

In addition, the results of 3D numerical simulation analysis show that there is no turbid currentin the reservoir of low head run-of-river dam in natural-like flow condition during flood period [2] (Abb. 5). The occurance for the turbid current depends on: (1) highly solid concentrated flow happens in the upstream river channel of high dam reservoir with a certain water depth and (2) the water level of the reservoir is at high before the arrival of the highly solid concentrated flow [3].

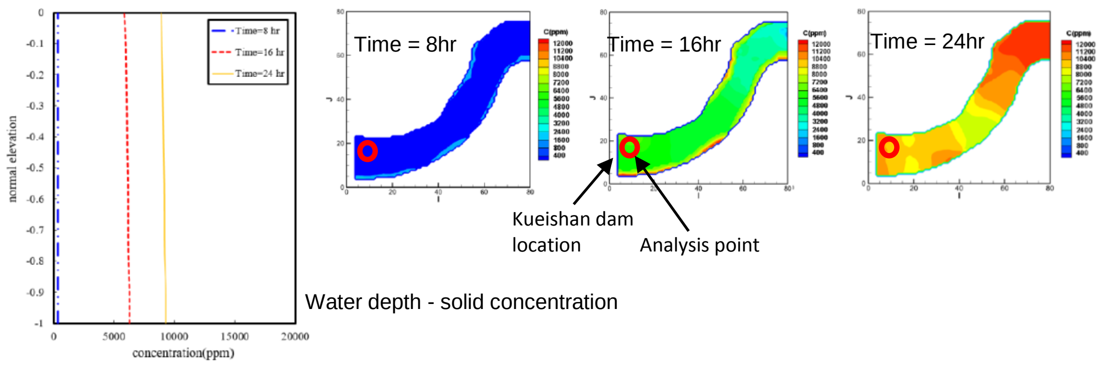

Abb. 5: There is no turbid current in the reservoir of low head run-of-river dam in natural-like flow condition during flood conditions.

3 Impacts of Sediment Disasters on Hydropower Facilities

3.1 Morphological changes between the catchment area and the downstream area

Taiwan is located in the western Pacific subtropical region and is vulnerable to heavy precipitations caused by typhoon and tropical depression in the period from summer to autumn. In 2015, the typhoon Soudelor, which brought a maximum accumulated rainfall of 792mm, devastated northern Taiwan, causing numerous landslides in upstream parts of mountainous Xindian River Basin, road collapses, dammed lakes and floods, as well as damaging hydropower-related facilities. According to the evaluation of morphological changes in upstream Xindian river basin, the area of mountain landslide went up from 0.38 Mm^2 (landslide ratio 0.1%) to 2.185 Mm^2 (landslide ratio 0.6%) after the typhoon event. A huge amount of sediment from the landslide moved downstream and accumulated in the river channel, elevating the level of riverbed. A recent survey revealed that the volume of landslide in upstream catchment area is 4.75 Mm^3, the volume of sediments accumulated in the river channel is 2.73 Mm^3, and the volume of sediments drained away from the basin is 2.02 Mm^3 (Abb. 7) [4].

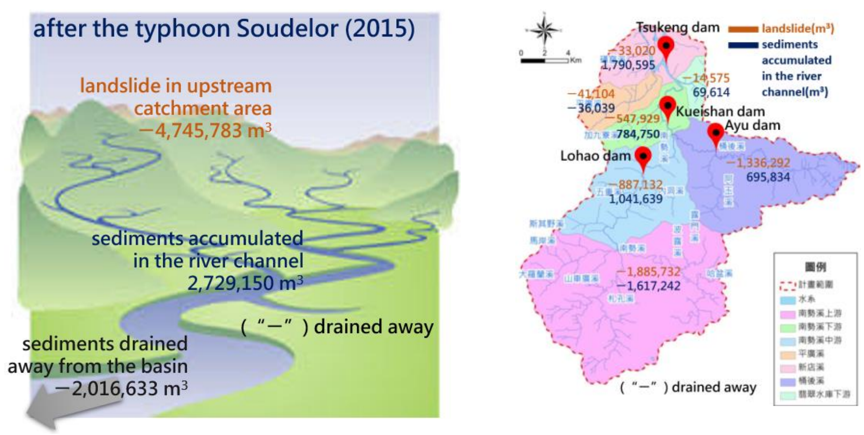

Abb. 6: Morphological changes between the catchment area and the downstream area after the typhoon Soudelor (2015) [4].

3.2 Impacts of sediment disasters on hydropower facilities

The landslides in the catchment area yielded a large amount of sediment depositing into the river, causing the level of riverbed to elevate. The reduction of the capacity of water conveyance in river channel raised the water level and caused severe damages such as flooding. The accumulated sediments in the river obstructed the headrace not only affected the function of water intake and discharge but also hindered the sedimentation function of the grit chamber. The intake water without sedimentation would wear out the headrace canal and hydro turbine at a speedy rate. The resulting increased frequency of maintenances would affect power supply stability (Abb. 7).

Abb. 7: Impacts of sediment disasters on hydropower facilities.

In addition to a large amount of sediments, the landslides caused huge amount of woody debris to fall into the river channel and drift downstream along with the flood. When these woody debris cannot pass through the dam discharge facilities smoothly, it would accumulate and block the spillway gates and reduce of the flood discharge capacity, and even cause flood overflow. Although the concrete gravity barrage should be able to withstand a flood overflow event [5], the large amount of woody debris brought by flood would cause serious damage to the power generation facilities (Abb. 8).

Abb. 8: Serious damage caused by woody debris.

4 Strategies to alleviate the impacts of sediment disasters on hydropower

Since the management issue of sediments in the reservoir cannot be solved with a single solution, it is necessary to consider various options that are economical. There are some strategies and ways of working to alleviate the impacts of sediment disasters on hydropower facilities in Xindian River Basin.

A. Recover the capacity of water conveyance in river channel

To alleviate the impacts of sediment disasters on hydroelectric facilities, long-term strategies to tackle the high-potential landslide area of upstream catchment area and the potential soil that downward movement should be formulated and implemented by authorities, with considerations of the characteristics of soil production and its movement. The reservoir management agency should take active measures to prevent sediment disasters which may affect the security of the dam and the water intake and operation of power generation. River and waterway dredging to recover power generation should be completed in shortest time (Abb. 9).

Abb. 9: Recover the capacity of water conveyance in river channel.

B. Enhance the flood prevention ability of power generation related facilities

After the typhoon event, a large amount of soil from catchment area fell into the river, causing the riverbed to rise and the flooding risk to increase. The reservoir management agency continuously take active measures, such as heightening the flood wall (Abb. 10) to prevent flooding, ensuring the function of drainage facilities, ensuring the protection of important devices from flooding. Such measures improve the flood prevention capacity and lower the risk of power generation related facilities being flooded.

Abb. 10: Heighten the flood wall to prevent flood.

C. Innovative techniques to increase the flushing efficiency

The waterintake of Guishan Dam is located on the inside bend of river so thatdeposition occurs easily due to slower flow. The bedrock outcrop in front of the waterintake also hinders the flow path and reduces the sediment flushingefficiency of the sluiceway. By building a diversion wall of the sluiceway, hydraulic head makes the ditch in river channel when opening the sluiceway gate, and the water flow can be directed straight to flush the sediment that deposited in front of the water intake(Abb. 11, 12, 13). The effects are: (1) improved sediment flushing efficiency, reduced the span of flushing time to increase power generation revenue. (2) reduced the ingress of sediment that cause hydro turbine wear.

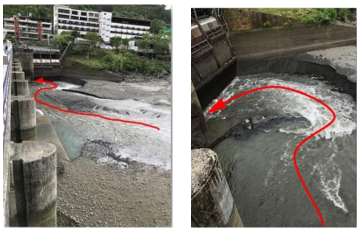

Abb. 11: The previous hydraulic behavior

Abb. 12: Build the diversion wall of the sluiceway

Abb. 13: (1) (2)Hydraulic head makes the ditch in river channel when opening the sluiceway gate. (3) Water flow can be directed straight to flush the sediment in front of the water intake.

D. Dredge the alluviumthat hindershydropower generation

Dredging the alluviumby mechanical excavation to create artificial flow path. It can improve the flushing effects by ditch erosion and piping (Abb. 14, 15).

Abb. 14: Dredge by mechanical excavation.

Abb. 15: Longitudinal or Lateral Erosion Enhancement.

E. Strengthen the protection of waterintake facilities

During the flood period, the water flow condition in the reservoir of a barrage issimilar tonature-like flow condition, the inflow is about the same as outflow and the hydrological behavior is similar to river. As a result, the debris booms used for storage-based reservoirs are not suitable for barrages(Abb. 16). It’s more feasible to protect the waterintake facilities of the barrages by setting up barriers(Abb. 17).

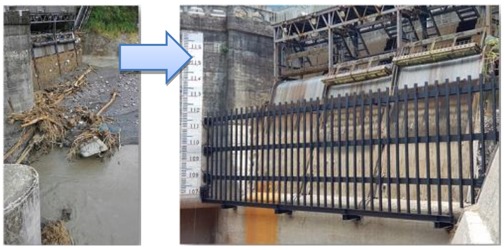

Abb. 16: The failed debris booms in barrages.

Abb. 17: Waterintake barriers of Guishan Dam.

F. Dam retrofitting works

Under the condition that the debris boomscannot effectively intercept the driftwoods carried by the flood, the woody debris may block the spillway gates, reduce the flood discharge capacity and cause the overflow. Although the concrete gravity barrage should be able to withstand a flood overflow event [5], some severe damages to power generation related facilities may still occur.After the relevant assessment, the dam retrofitting work regarding emergency overflow facility is a feasible solution[6], and the additional flood discharge capacity attributed by retrofitting can reduce the risk of flood overflow(Abb. 18).

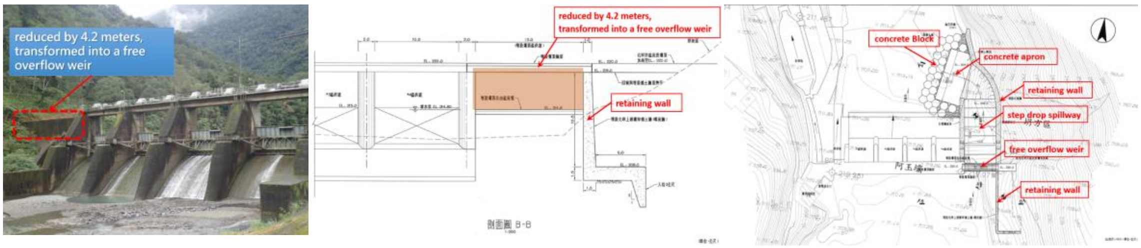

Abb. 18: Ayu dam retrofitting work regarding emergency overflow facility.

G. Revitalization of local community with dams

Sediment disaster not only causes damages to related facilities but also affects local tourism development. TPC is a government-owned enterprise that should take the responsibility to keep benefit to public; dredging can restore local scenery and enhance tourism development (Abb. 19), which not only enhance company image but also increase the company’s intangible benefits.

Abb. 19: Desilting in reservoir of Tsukeng damrestore local scenery.

5 Conclusions

Climate change is one of the greatest challenges of our time. In recent years, the intensity and frequency of global extreme weather events caused by climate change, such as severe droughts, extreme rainfalls, flash floods, and heat waves, have increased and resulted in many concentrated disasters. These concentrated disasters have widespread impacts on homeland security, water resources utilization, ecological conservation, social and economic development, etc.. The extent of these impacts has not only caused human lives and property damages, but also affected humanity's goal of achieving sustainable development.

98% of Taiwan's energy source depends on importation, which exposes Taiwan's power supply to considerable risk of relying primarily on the volatile world energy market. The national energy development is also closely related to national security, social economy, and environmental sustainability.

The impacts of sediment disasters caused by climate change and extreme weather are closely related to national energy development. Therefore, the strategies for alleviating the impacts to Hydropower, one of the valuable self-produced energy sources in Taiwan, have become important to the operation and management of Taiwan Power Company (TPC).

The strategies of alleviation for impacts of Sediment Disasters on hydropower facilities still need to consider the schemes that are economical regarding the cost of facilities repair, hydrogeneration loss and dam retrofitting work etc..Under the premise that the economic benefit assessment is appropriate, TPC will continue to take active action to ensure the function of hydropower and achieve the important mission of national sustainable energy development.

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