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SANAKHAM HYDROPOWER PROJECT

Sedimnet Management

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1 SEDIMENT ISSUES

Sanakham reservoir has the design normal water level of EL.220m, which corresponds to a storage capacity of 827 million m3. As the ratio of reservoir volume to the incoming sediment is 15, it should belong to a reservoir with serious sediment problem. But the sediment concentration of inflow is low (averagely, 0.496 kg/m3); it is a river-like reservoir; dammed water depth is small (about 16 m in the case of mean annual discharge, and about 11 m in the case of mean flood season discharge); and sediment delivery rate is larger when the reservoir is in operation (the yearly average sediment delivery ratio during initial operating stage exceeds 70%, and the average sediment delivery ratio during the first 50 years exceeds 90%). Reservoir sedimentation should be so designed as to keep it well controlled, reduce backwater inundation and inundation extent, and enable reservoir backwater in good connection with the tail water of upstream Pak Lay Hydropower Station. In order to study the influence of operating mode on the reservoir backwater extent under sedimentation, backwater calculation should be carried out under different operating alternatives for the comparison of characteristic water levels. Since the dam has a longer water intake section, and the intakes are low in elevation, sediment flushing outlets should be furnished beneath the intakes to remove the sediments deposited before the intakes, ensuring the safe operation of the project.

2 Sediment Control Measures

2.1 LAYOUT OF MAJOR STRUCTURES AND SEDIMENT PREVENTION AND RELEASE FACILITIES

According to the CNR independent review comments as well as the expert's review comments on the updated Feasibility Study Report in 2016, the general layout of the project structures has been adjusted as follows:

The major structures are arranged in sequence from left bank to right bank as: left concrete auxiliary dam, ship lock dam section, left sluice dam section (13 outlets), riverbed powerhouse dam section (12 units), right sluice dam section (5 outlets), and right concrete auxiliary dam. The dam has the maximum height of 56.2m, and an overall length of 909.90m at the dam crest elevation of 229.50m.

The powerhouse dam section has an overall length of 350.20m, in 8 sub-sections, composed of the auxiliary erection bay dam section, the No.1~No.12 units powerhouse dam section, and the main erection bay dam section in order from left to right.

18 sluice outlets altogether (13 outlets in the opening size of 15m×22m (W×H) arranged at the left terrace and flood plain and 5 outlets in the opening size of 12.5m×16m (W×H) set at the right side), are divided as 11 dam sections, and have an

overall length of 341.50m (left sluice 250m + right sluice 91.50m). The left side of the right flood outlets neighbors the powerhouse dam section, the right side abuts on the fishway outlet dam section, and the 5 outlets would adopt the hydraulic jump energy dissipation method. Among the 13 outlets at the left side, 5 of them against the powerhouse dam section would have the hydraulic jump energy dissipation method, and the remaining 8 flood outlets would apply the surface flow energy dissipation way.

The ship lock is designed as per the single-line capacity of 500t of Grade IV. The effective dimension of lock chamber is 120m×12m×4m (length × width × sill depth). The whole ship lock consists of the upstream approach channel, upper lock head, lock chamber, lower lock head and downstream approach channel. Considering the navigable clearance demand, the dam crest elevation is defined at EL.229.50m.

The fishway arranged on the right bank would have two inlets, respectively at EL.199m and EL.201.3m, and the inlet gate chambers would have a width of 5m. To prevent migrated-upstream fish from being drifted to the dam downstream along the flood discharge, the outlet of the fishway is set at the upstream side 170m away from the dam axis, and considering the minimum reservoir level of EL.219m, the bottom elevation of the fishway outlet is set at EL.217m.

The right sluice dam section (5 outlets) arranged on the right side of the main river channel is designed as a flat-bottomed sluice (No.14~No.18 dam sections) with breast wall, the left side of which neighbors the powerhouse dam section and the No.18 dam section at the far right constitutes a dam block of 38m long with the first dam section of the right concrete auxiliary dam. The opening size of the right sluice outlet is 12.5m×16m (W×H) and the floor elevation of which is 192m. To smooth the flow in front of the sluice, part of the bank slope is excavated within 200m upstream of the dam so as to increase the discharge capacity of the sluice; the bottom of the excavated bank is at EL.208m, which would be lowered to EL.192m (i.e. the floor elevation of the sluice chamber) at 90m upstream of the dam axis with an opposite gradient of 1:4.

The top elevation of the bedrock at the right sluice dam section is lower on the left and higher on the right. To appropriately arrange the right sluice a small quantity of mass constrete should be backfilled at the left side. To avoid affecting flood release, the deck elevation of the access bridge, which is set at EL.221m platform on the tail of sluice pier and connects to the tailrace platform downstream of the powerhouse dam section, is defined as 223.5m.

The right sluice would adopt the hydraulic jump energy dissipation method. The stilling basin with rectangular cross section has a floor elevation of 191.0m, width of 84.5m, bottom plate thickness of 4m and length of 59m, and is designed with anti-floating anchor bars (φ25, L=13.5m, 9m in rock, row spacing 3m×3m) and drain pipe (φ100, 0.5m in rock, row spacing 3m×3m) at the floor. The right side wall of the stilling basin is a load retaining wall with top elevation of 218m, while the end walls of the main erection bay and the service hall are applied as the left side wall (with top elevation of 223m) of the stilling basin since the left side of the stilling basin is within the range of the main erection bay of the powerhouse along the flow direction. To protect the tailrace from disturbance of surplus water or released flood, a 80m long partition wall with top elevation of 213.9m is set between the tailrace and the right sluice. In addition, reinforcement cage apron of 31m long and 1m thick is provided downstream of the stilling basin to reduce the erosion of riverbed by the released water. To smooth the flow at the stilling basin outlet and divert the water into the downstream riverbed, the original riverbed and the right bank slope should be excavated locally within a certain range of the tail channel of the right sluice, the floor elevation of the excavated part is 194m. Reinforced concrete revetment with top elevation of 216.5m should be provided at the right side of the stilling basin outlet, so as to weaken erosion of the bank slope.

Longitudinal partition wall should be arranged between the right sliuce and the power intake, so as to protect the power intake from the influence of sdeiment sluicing. Considering the arrangement of the sand barrier and the apron upstream of the power intake, the top elevation of the longitudinal partition wall is defined as 208m and the length of the wall is defined as 130m.

2.2 RESERVOIR OPERATION MODE

2.2.1 Control of reservoir sedimentation

According to the proposed sand sluicing operation mode of the reservoir and sedimentation calculation, after 10 years of operation, the total inflow sediment would be 703.8 million t, of which the suspended load would account for 690 million t, the sedimentation in the reservoir area would account for 156 million t including 144 million t of suspended load, with an average sediment discharge ratio of 77.8%, which would cause a reservoir storage capacity loss of 15.3%, and the sediment would build up averagely to EL.191.5m in front of the dam. After 50 years of operation, the total inflow sediment would be 3519 million t, of which the suspended load would account for 3450 million t, the sedimentation in the reservoir area would account for 334 million t including 287 million t of suspended load, with an average sediment discharge ratio of 90.5%, which would cause a reservoir storage capacity loss of 31.2%, and the sediment would build up averagely to EL.197.2m in front of the dam.

According to the reservoir operation mode, with Buren Formula, the resultant reservoir's sand trapping rate is 22.9%, and the sand sluicing ratio is 77.1%, which is quite close to the sand discharge ratio (77.8%) obtained based on the mathematical model series, showing that the result is rational and credible. The proposed normal storage level is 220m, after 10 years of operation, the sedimentation in the reservoir area would amount to 127 million m^3, with an average sediment discharge ratio of 77.8%, the average sediment content in the outflow water after sediment settling in the reservoir is 0.386 kg/m^3, about 22.2% lower than the natural scenario, which suggests that the reservoir have no much effect on the river water-sediment movement, especially in case of normal floods which play a bigger role in reforming the downstream riverbed, when the inflow water is greater than a 3-year flood, the reservoir would be released with all gates fully open, basically without altering the natural inflow water-sediment condition, and it would not exert noticeable effects on the downstream riverbed formation and stability; after 50 years of operation, the average sedimentation in front of the dam is about 3 m deep, averagely up to the elevation of 197.2 m, which would be 11 m lower than the elevation (208 m) of the sand barrier in front of the power intake, and 13 m lower than the elevation (210 m) of the bottom of the upper approach channel, so the sedimentation in front of the dam should not bring about threats to the power plant and ship lock safety.

With the hydrological station at Luang Prabang as the inflow flood water control station (usually the flood water from Luang Prabang would take 1~2 days to reach Sanakham dam site), the desilting operation mode is as blow:

In flood season, when the reservoir inflow water is bigger than the design discharge, surplus flood would be discharged firstly through the 5 flood gates on the left bank with a stilling basin, and then other gates, to maintain the reservoir level at the normal storage water level of EL.220.0m.

In case of a 3-year flood at Luang Prabang, flood release should be started at Sanakham. Firstly, the 5 flood gates on the left bank with a stilling basin, and then other flood gates should be opened, with the outflow less than the 3-year flood peak discharge, the pool level would be drawn down to the gate full opening for flood and sand discharge, and after the flood process, the reservoir would be refilled up to the normal storage level for power generation. When the upstream reservoirs are discharging sand, all gates of Sanakham reservoir should be fully opened for sand discharge accordingly. Based on the sediment monitoring results, backwater at the reservoir should be analyzed. When the backwater due to sedimentation in the reservoir area may affect Pak Lay or the reservoir inundated area, or when the sediment buildup approaches the sand barrier level in front of the intake, all flood gates should be fully opened to draw down the pool level for sand sluicing. In other periods, the plant would operate normally.

2.2.2 Sediment control for power intake

To prevent coarse sediment from flowing into turbine, sediment barrier with top elevation of 208m would be set upstream of the power intake to guide the bed load to the downstream river channel through the gates. The discharge capacity of the gates is fairly large. In flood period, surplus flood would be discharged firstly through the 5 flood gates on the left bank with a stilling basin, and then other gates, to maintain the reservoir level at the normal storage water level of EL.220.0m.

According to the CNR independent review comments, NORTHWEST ENGINEERING CORPORATION LIMITED entrusted Sichuan University to perform sediment deposition calculation of the reservoir area with one-dimensional flow and sediment mathematical model, and sediment deposition calculation and flow velocity - flow regime calculation and study of the river reach within 5km of the dam area with two-dimensional flow and sediment mathematical model. The main conclusions are as below:

(1) Sedimentation at the entrance of upper approach channel is slow since it is affected mainly by the backflow area. The sedimentation occurs mostly in local area inside the outer guide wall of the upper approach channel, while the sand silted outside the outer guide wall could be washed out of the reservoir during full open of the flood gates on the left bank. After 10-year, 20-year and 50-year operations, the maximum sedimentation thickness at the entrance of the upper approach channel is 0.8m, 2.7m and 4.0m, respectively, and the sediment would build up to EL.210.8m, EL.212.7m and EL.214.0m, respectively. The sedimentation at the entrance is unlikely to be flushed out during full open of the flood gates on the left bank, so it is suggested to remove the sand manually.

(2) Sand in the reservoir would be flushed out through the left sluice. Affected by the upstream incoming sediment condition, sedimentation distribution shows a development trend from left to right. After 10 years of operation, the sand would distribute mainly near the No.1 ~ No.2 gates, with the maximum sedimentation thickness of about 0.8m and the maximum silted elevation of EL.198.8m; after 20 years of operation, the sand would distribute mainly near the No.2 ~ No.4 gates, with the maximum sedimentation thickness of about 5.0m and the maximum silted elevation of EL.203.0m; after 50 years of operation, the sand would distribute mainly near the No.3~ No.7 gates, with the maximum sedimentation thickness of about 16.0m and the maximum silted elevation of EL.214.0m.

(3) With low-level outlet furnished at the power intake to remove sediment, the power intake would be free from sedimentation after 10 years, 20 years and 50 years of operation; only a small amount of sediment would deposit outside the sand funnel, having no influence on the plant operation.

(4) The right sluice is located at the talweg of the original river channel. Sedimentation in the first 50 years of operation would occur mostly in the vicinity of the talweg instead of the right sluice. The maximum sedimentation thickness is 4.0m or so, near No.15 ~ No.16 gates, and the silted elevation is about 194.0m.

2.2.3 Sedimentation at the approach channel

The river channel where the power station is located is a navigable channel. Ship lock is arranged at the terrace on the left bank of the headwork structure, and the approach channels are set both at the upstream and downstream sides. As flow velocity in the approach channel is relatively small, the flow usually appears at the entrance of the approach channel in the form of backflow, which often caused massive sediment deposition. The deposition is mainly located at the inlets and outlets of the upstream and downstream approach channels.

At present, the Sediment State Power Corporation Ministerial Key Laboratory, a well-known sediment laboratory in China, and Ministry of Education Key Laboratory for Water and Sediment Sciences (joint) of School of Water Resources and Hydropower Engineering of Sichuan University have been commissioned to carry out calculation of the plane two-dimensional mathematical model of the complex area. According to the calculation of two-dimensional mathematic models, the research results and countermeasures on the sediment deposition in the approach channels at the upstream and downstream are shown as follows:

(1) The silting situation in the entrance area of upper approach. After the reservoir runs, there would be accumulative deposition in the entrance area of upper approach. At the end of the 10th year, the depositing elevation would reach 210.74 m, and the navigation can't be intercepted, the maximum depositing thickness is only 0.74 m. The navigable depth is far above the navigation condition while the minimum navigation depth is 4.0 m. As time goes on, if water depth in the entrance area of approach doesn't satisfy the navigation condition for the whole year, and the dredging projects measures should be taken.

(2) The silting situation in the entrance area of lower approach. After the reservoir runs, there would be accumulative deposition in the entrance area of lower approach. After 10 years, the maximum depositing thickness near the entrance area of lower approach is 0.3m~1.3m. Under the lowest navigation discharge, the channel width in the approach channel and the velocity of backflow near the entrance area can still satisfy the navigation condition, but there is navigation obstruction trend. If water depth in the entrance area of approach doesn't satisfy the navigation condition for the whole year, and the dredging projects measures should be taken.

After completion of the power station, monitoring the sediment deposition of the approach channel should be strengthened. The sediment at the entrance of the approach channel should be flushed by opening the sand-sluicing gate in the case of lower flow and larger head differences between the upstream and downstream. For the parts with poor flushing effect, artificial or mechanical dredging measures should also be taken to clear the deposits.

2.2.4 Erosion of downstream river channel

The sediment issue of Sanakham HPP is not severe. According to the similar project experience, after the power station is constructed, there would be some influence on downstream channel. The sediment concentration of inflow is low in Sanakham reservoir, and the reservoir is a river-like reservoir with small dammed water depth, and sediment delivery rate is larger when the reservoir is in operation, so the construction of the power station would not basically change the conditions of incoming water and sediment, no serious erosion would occur at the downstream channel. For safety purposes, downstream river channel and bank slopes should be included in the reservoir sediment monitoring system, in the case of slope collapse or deformation, appropriate engineering measures should be taken for protection.

2.2.5 Bank slope erosion

Water level fluctuation of the reservoir caused by impounding and operation may have a certain impact on the stability of the bank slopes of the upstream and downstream channels, so a sediment monitoring system including the monitoring of bank slopes is designed for Sanakham HPP. After putting into operation of the power station, especially in the early years of operation, monitoring of the bank slopes should be conducted carefully. In case unstable rock block is found in partial bank slope, engineering measures such as cement laid stone masonry or gabion protection should be taken accordingly. It is recommended that the Employer should reserve certain treatment fees for bank slope protection.

2.2.6 Environmental protection

Strong consideration should be given to environmental protection during operation and sand sluicing of the power station and the detailed requirements on sand sluicing are as below:

(1) Time for sand sluicing

Study shows that most of the fishes lay eggs from March to June, therefore, sand sluicing should not be performed during this period and silt carrying flow that may affect egg laying should be prevented from flowing into the downstream river channel. From this consideration, the gates should be opened gradually and in sequence according to the site condition so as to avoid sudden increase of sand content in the water. The outflow sediment content should be monitored during the sand sluicing and the downstream river channel and the condition of the fishes should be monitored and investigated in the meantime, so as to provide information and experience for rational determination of outflow sand content. In addition, considering navigation and regular life of downstream inhabitants, the gates should be opened gradually to avoid sharp change of upstream and downstream water levels.

(2) Control and monitoring of sand sluicing

The sediment monitoring system of Sanakham reservoir involves the monitoring of inflow and outflow sediment content. Through the monitoring, the discharged flow and the sand content in the process of sand sluicing could be controlled so as provide a proper survival condition for the fishes.

Sediment measurement with tour gauging method is applied by the hydrometric stations in Laos, with insufficient measurement duration and less measurement frequencies, the measurement accuracy is relatively poor. Currently, NORTHWEST ENGINEERING CORPORATION LIMITED is performing sediment measurement in the vicinity of the dam site to get more detailed data. It is suggested that after the power station is put into operation, water-sediment monitoring should be paid with special attention and the sluice gates should be opened rationally according to the actual condition so as to avoid sudden change of upstream and downstream water levels.

During sand sluicing, shipping should be suspended and the downstream inhabitants should be informed to pause the work with high-pressure flow, so as to avoid the risks of bank slope deformation caused by high-pressure flow, violent flow or water level variation.

2.3 MONITORING AND MANAGEMENT

Main contents of the Sediment Monitoring Program of Sanakham Reservoir are as follows:

(1) Monitoring of reservoir inflow and outflow water and sediment volumes;

(2) Monitoring of reservoir water surface profile;

(3) Monitoring of reservoir sedimentation;

(4) Monitoring of dam site area sedimentation;

(5) Monitoring of sedimentation in upstream and downstream approach channels;

(6) Monitoring of downstream river channel erosion;

(7) Monitoring of reservoir bank scouring/ sedimentation change and collapse.

All the monitoring data should be collected and analyzed, so as to provide detailed and rational guidance to sediment management and control.

Following engineering measures corresponding to different sediment issues should be taken:

(1) According to the sediment characteristics of Mekong River, the sediment volume is mainly concentrated in the wet season, especially when flood occurs, when the incoming flow is more than rated flow 5801 m^3/s, bottom hole, sediment flushing gate and the flood gate opened gradually, reservoir water level maintains at 220m.Flood occurs from June to November, when Luang Prabang hydrological station on upper stream is encountered with 3-year-and-above flood (before the

completion of Pak Beng Hydropower Station) or Pek Beng project on the upper stream is encountered with 3-year-and-above flood and begins to discharge flood with all gates opened, Sanakham HPP would carry out the preliminary discharge, and the preliminary discharge rate would be controlled at 17800 m^3/s (peak discharge of 3-year flood at Sanakham dam site), and the water level in reservoir would begin to reduce. The time spent for the flood from upper reach (Luang Prabang station or Pak Beng project) to Sanakham HPP is about one to two days. Therefore, the preliminary discharge time is also one to two days. As the water level in reservoir decreases, more flood gates would be opened gradually so as to maintain the discharge rate at 17800 m^3/s; when the water head is less than 4m, the power plant would be shut down; when the water level in reservoir further reduces to 213.85m, all the gates would be opened for discharging flood and sediment. When the inflow exceeds 17800 m^3/s, the ship lock would go out of service and the reservoir operates in ungated pattern.

(2) After Sanakham HPP is put into operation, monitoring of sedimentation in front of the dam should be strengthened and based on the monitoring results the gates for sand sluicing should be opened irregularly to reduce the sedimentation at the power intake and protect the power intake from being blocked by sediment, water plants or other foreign matters. Sediment silted at the sand barrier would be discharged to the lower reach through the gates, and the area where the effect of sand sluicing is unsatisfactory would be dredged by manual or mechanical means.

(3) Monitoring of sedimentation at the approach channels should be strengthened after Sanakham HPP is put into operation to ensure the safety and normal operation of the navigation channel. According to the sedimentation calculation of the approach channel, the sediment accumulation rate is small and the sand sluicing efficiency is relatively low. It is suggested to dredge the channel by manual or mechanical means if shipping is influenced by the deposited sediment.

(4) After reservoir impoundment, fluctuation of the reservoir levels may exert certain effect on the stability of the upstream and downstream bank slopes, therefore, the bank slopes should be monitored after the power station is put into operation, especially in the initial operation period. In case unstable rock block is found in partial bank slope, engineering measures such as cement laid stone masonry or gabion protection should be taken accordingly.

3 CONCLUSIONS AND SUGGESTIONS

Main sediment problems of Sanakham HPP include: sedimentation in the reservoir area, sedimentation in the approach channel, sediment control before water intake, scouring of the downstream channel, deformation of the channel and bank slope, etc.

(1) According to study sediment occurs mainly in rainy season, especially in the case of flood. The right sluice would be opened to release water when the inflow discharge is

greater than the design discharge of 5801 m^3/s. Flood occurs from June to November, when Luang Prabang hydrological station on upper stream is encountered with 3-year-and-above flood (before the completion of Pak Beng project) or Pek Beng project on the upper stream is encountered with 3-year-and-above flood and begins to discharge flood with all gates opened, Sanakham HPP would carry out the preliminary discharge, and the preliminary discharge rate would be controlled at 17800 m^3/s (peak discharge of 3-year flood at Sanakham dam site), and the water level in reservoir would begin to reduce. The time spent for the flood from upper reach (Luang Prabang station or Pak Beng project) to Sanakham HPP is about one to two days. Therefore, the preliminary discharge time is also one to two days. As the water level in reservoir decreases, more flood gates would be opened gradually so as to maintain the discharge rate at 17800 m^3/s; when the water head is less than 4m, the power plant would be shut down; when the water level in reservoir further reduces to 213.85m, all the gates would be opened for discharging flood and sediment. When the inflow exceeds 17800 m^3/s, the ship lock would go out of service and the reservoir operates in ungated pattern.

(2) Sanakham HPP is designed as a run-of-river power station. Sedimentation is not severe. Considering the sand retaining effect of the upstream cascade hydropower stations, the inflow sand content would be decreased significantly and the particle size of sediment flowing into Sanakham reservoir would be small, therefore, sedimentation in front of the power intake is slight. To prevent coarse sediment from flowing into turbine, sand barrier would be set upstream of the power intake to guide the bed load to the downstream river channel through the gates. Dredging by manual or mechanical means should be conducted to the area with unsatisfactory sand sluicing effect.

(3) Sedimentation at the entrance of upper approach channel is slow since it is affected mainly by the backflow area. The sedimentation occurs mainly in local area inside the outer guide wall of the upper approach channel, while the sand silted outside the outer guide wall could be washed out of the reservoir during full open of the flood gates on the left bank. Dredging by manual or mechanical means should be conducted to the area with unsatisfactory sand sluicing effect.

(4) With low head, Sanakham reservoir features small sand trapping rate and large sand sluicing ratio; most of the inflow sediment would be discharged into the downstream river channel through the gates, so the difference between the natural water-sediment relation and the water-sediment relation after sand sluicing is small. No serious erosion would occur at the downstream river channel.

(5) Water level fluctuation of the reservoir caused by impounding and operation may have a certain impact on the stability of the bank slopes of the upstream and downstream channels, so a sediment monitoring system including the monitoring of bank slopes is designed for Sanakham HPP. After putting into operation of the power station, especially in the early years of operation, monitoring of the bank slopes should be conducted carefully. In case unstable rock block is found in partial bank slope, engineering measures such as cement laid stone masonry or gabion protection should be taken accordingly. It is recommended that the Employer should reserve certain

treatment fees for bank slope protection.

(6) Environmental protection: Spawning of the fishes generally lasts from March to June, therefore, sand sluicing should not be performed during this period and silt carrying flow that may affect egg laying should be prevented from flowing into the downstream river channel. Therefore, the gates should be opened gradually and in sequence according to the site condition so as to avoid sudden increase of sand content within a short time. The outflow sediment content should be monitored during the sand sluicing and the downstream river channel as well as the condition of the fishes should be monitored and investigated in the meantime, so as to provide information and experience for rational determination of outflow sand content. In addition, considering navigation and regular life of downstream inhabitants, the gates should be opened gradually to avoid sharp change of upstream and downstream water levels.