Comparative Study on Layout Scheme of High Head Diversion Power Station----Taking the Yamu River-I Hydropower Station as an Example

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Abstract. The small hydropower stations on most tributaries in the middle reaches of Salween River are mostly high-head diversion hydropower stations, and the choice of hub arrangement scheme is an important content of the preliminary construction project. Taking Yamu River-I Hydropower Station as an example, this paper compares and analyzes the layout scheme of the main hub of the project from the aspects of dam site, dam type, regulation scheme, diversion route and site selection, and summarizes the optimization ideas and characteristics of the layout scheme of the main hub of the project, so as to be helpful for the preliminary design of similar hydropower stations.

Keywords. Yamu River-I hydropower station, hub layout, scheme comparison.

1. Introduction
The middle reaches of the Salween River are located in Hengduan Mountain area, with high mountains and deep valleys, fast flowing water, numerous tributaries, large drop and fast velocity, and extremely rich hydropower resources. Most of the tributary rivers have steep terrain and deep valley, and most of them are deep cutting mountain ravines. Most power stations have the characteristics of runoff water diversion type power station with small flow and high head. Hub hydropower station building layout are greatly influenced by topography and geological conditions; comparing and determining the general layout scheme are extremely important for the development scale for power station, engineering cost and difficulty of construction. Therefore, in the preliminary survey and design stage of the project, it is necessary to make a comprehensive comparative analysis and study on the layout scheme of the power station hub, and finally determine the optimal scheme [1]. Based on the case study of the Yamu River-I Hydropower Station in Yunnan province, this paper makes a comparative analysis on the selection of the hub layout scheme from the aspects of dam site, dam axis, diversion line and site selection.

2. Project Overview
Yamu River is located in Fugong, Nujiang State in Yunnan Province, China. It is a first order tributary of the Right bank of Salween River.Located at the junction of Lumadeng Township and Lishadi Township in Fugong City, Yamu River-I hydropower station is the first step to explore Yamu River. It is located on the right bank of the Yamu River. The conditions for building the power station are excellent. This station is about 40 km away from Fugong City, 175 km from Liuku, where the state government located, and 750 km from Kunming, the provincial capital city of Yunnan Province. The
control basin area of Yamu River-I power station is 191.40 km², and the average annual flow rate is 7.95 m³/s. Hub is a fourth-class project, and this project scale is small. The permanent main buildings are first hub, water diversion system, factory hub of three parts.

3. Site Selection

3.1. Dam Site Selection and Dam Types Comparison

3.1.1. Site Selection of the Dam. The development reach of Yamu River is 2500 m long with a concentrated natural drop of about 205.4 m. Yamu River is divided into north and south branches with a length of 19.84 km. In order to make full use of the water head, the dam site was chosen near the intersection of two tributaries. The left bank of Yamu River has a highway from Fugong to Burma at a height of about 1630 m. When selecting the site, the backwater should not inundate the highway during the flood period and facilitate the layout of hydraulic structures.

From the perspective of topographic and geological conditions, the reach between the confluence of the two tributaries and the downstream is about 140 m. The mountains on both sides are strong, and the topography is relatively complete. The bed alluvial layer is relatively thin, and the bed width is about 20 m ~ 40 m. In this section of the river to build a dam, dam foundation, dam abutment can be placed on the bedrock. The scale of the dam is small, and suitable for layout of hydraulic structures. Therefore, the dam site should be chosen within this reach.

3.1.2. Selection of Dam Axis. In the river section of the selected dam site, based on the premise that the backwater will not inundate the existing highway during the flood period after the dam is built, combined with the topographic and geological conditions, and for the convenience of future operation and management, two dam axes are selected for comparison.

The axis of the upper dam is located about 50 m downstream of the intersection of Yamu River. There is a collapse accumulation body on the left bank, which is mainly composed of large soles and chunks of gravel mixed with sandy loam. The excavation and cleaning work is heavy and the abutment stability is poor. The right bank is steep rock and narrow terrain; the layout of hydraulic buildings here is difficult; the construction conditions are poor, and the completion of the operation and management is not convenient.

The axis of the lower dam is downstream of the axis of the upper dam, about 100 m from the axis of the upper dam, and about 20 m ~ 40 m wide. Most of the bedrocks on both sides of the river are bare, and the alluvial layer and the slope colluvial layer on both sides are not thick. The dam foundation and abutment can be placed on the weak to breeze bedrock after the removal, and the bedrock is hard, which can meet the requirements of building a low gravity dam. Moreover, the right bank of the lower dam axis is more open than the upper dam axis, so the layout of hydraulic structures such as flood discharge, energy dissipation, water intake and sand washing is more convenient, and the construction diversion is relatively simple [2].

After comprehensive comparison, the lower dam axis is recommended as the selected dam axis.

3.2. Selection of Diversion Route

Here is the comparison between the left bank diversion scheme and the right bank diversion scheme. The left bank diversion can only be arranged along the river channel, and the left bank has Fugong to Myanmar road through, so the construction will cause traffic disruption. On the right bank of the suborder river mountain is abundant, the terrain is complete, about 600 m in the lower reaches of the sea, to form the "S" type turn of the larger, so tunnel cutoff can be used. Water diversion lines on the right are relatively short with nearly 2 m longer water head being obtained than the left side. The embedded depth of tunnel surrounding rock along the vertical and horizontal buried depth is larger with no big fault through, and the stability of surrounding rock is good; the operation is safer and more reliable than channels. By comparison, the diversion route is arranged on the right bank with tunnel.
In order to avoid a gully in the middle of the tunnel, the tunnel line is arranged as a broken line in the middle gully position.

In the selected right bank diversion line, the two schemes of pressurized and unpressurized water diversion are compared.

The water diversion building is composed of channel, tunnel, pressure front pool and pressure steel pipe. The channel is a rectangular section with a total length of 115 m and a section size of 2.5 m×2.8 m (net width × net height). The tunnel section is in the shape of the gate, with a total length of 1135 m and a section size of 2.5 m×3.52 m (clear width × clear height). The pressure front pool is composed of the front pool, inlet chamber, sluice, overflow weir and discharge channel. The pressure front pool is 94 m long and 10-12 m wide at the top. The main quantities of non-pressure water diversion system are: earth and stone excavation 91501 m$^3$, concrete 13938 m$^3$, steel 1200 t.

The pressurized water diversion building is composed of low-pressure water diversion tunnel, pressure regulating well and pressure pipe. The section of low-pressure water diversion tunnel is in the shape of gate tunnel, with a total length of 1282 m, a clear width of 2.0 m, a clear height of 2.0 m, and a lining thickness of 0.35 m. Pressure regulating well is of the impedance type, the wellbore diameter is 5.0 m, the wellbore height is 39.23 m, and the lining thickness is 1 m [4]. Main quantities of pressurized water diversion system are as follows: earth and stone excavation 53594 m$^3$, concrete 7148 m$^3$, steel 720 t.

By comparison, the pressurized water diversion scheme avoids large area excavation of the front pool on the ground, which is conducive to the stability of the hillside and the reduction of the project area. Moreover, the main quantity of the pressurized water diversion scheme is smaller than that of the non-pressurized water diversion scheme. After calculation, the direct investment in the corresponding project is reduced by about 1.5 million yuan, and the operation and management are relatively simple. Therefore, a pressurized water diversion scheme is recommended.

The arrangement of the pressure steel pipe is divided into two schemes: one is arranged along the ridge, and the other is arranged along the slope. The total length of steel pipe in the linear scheme is 390.4 m, and the slope topography is 41°. The total length of the steel pipe in the broken line scheme is 405.97 m. The upper half of the ridge slope is 28° and the lower half is 39.5°. Although the length of the steel pipe is shorter, the slope slope is relatively steep. There are small gullies on both sides of the pipeline, and the rock mass is relatively broken. The stability of the natural slope is poor. This arrangement of the slope treatment project is large, difficult, after the completion of the operation process there are hidden dangers of landslide. The slope of pipe trench excavation is not high. The foundation of town and abutment is placed on the bedrock. The construction is relatively simple, and the broken line arrangement scheme is adopted after comparison [5].

3.3. Site Selection
There is a terrace on the right bank of The Yamu River near Yaping Village. The slope is about 15°~20°, which can be used for factory buildings and booster stations. There is no large faulted structure development in the factory area, and the entire plant foundation can be placed on the completely weathered bedrock. The hillside behind the terrace is naturally stable. There is a ridge below Yaping Village, where the terrain is complete and gentle, and pressure steel pipe can be arranged along the ridge. In addition, the upper and lower reaches of the reach both sides of the steep terrain, there is no good factory site to choose [6].

4. Selection of Dam Type
At the selected dam site, the designed peak discharge of Yamu River reaches 463 m$^3$/s, and the checked peak discharge is 624 m$^3$/s. The river bed is about 20 m ~ 40 m wide, and the river valley is narrow, so the flood discharge problem is relatively prominent. It is difficult for the local material dam to arrange flood discharge buildings and sand flushing buildings.

According to the topographic, geomorphic and engineering geological conditions of the dam site, the alluvial layer of the riverbed is not thick, and the bedrock on both sides is bare. The gravity dam
can adapt to the topographic, geomorphic and engineering geological conditions of the dam site, the overflow dam can be arranged in the riverbed, and the right bank can be arranged with a sluice, so that the water inlet in front of the dam can be arranged. After comparison, gravity dam is selected as the basic dam type [7].

In the gravity dam, the masonry dam and concrete gravity dam are compared. Although there are more stone materials available in the project area, and the quality is better, the stone materials needed for the construction of the dam need to be processed manually. The project amount is large, and the construction period is long. As for the concrete gravity dam, the raw material selection requirements are not high, and the construction technology is simple, so it is not necessary to process the stone material. Adding proper amount of buried stone in the dam makes temperature control measures simple, and can accelerate the construction progress. Concrete gravity dam is selected as the dam type by comparison.

5. Adjustment Scheme Comparison and Selection
The comparison between the regulated scheme of reservoir and the non-regulated scheme of low dam is made during the layout of the head hub.

5.1. Adjusting the Layout of Head Hub
According to the calculation of water energy, in order to obtain the incomplete daily regulation capacity in the dry season, the storage capacity needs to be adjusted to 80,000 ~ 90,000 m$^3$, and a dam with a height of 30 m or more should be built. If the lower dam axis position is selected and the dam body is raised, the backwater will flood the highways and Bridges, and the highway diversion and bridge construction works will be large. Therefore, according to the geological and topographic conditions, the dam axis of the adjustment scheme shall be 100 m downstream of the selected lower dam axis position. This location has complete topographic bedrock exposed, and the riverbed overburden is 5~6 m thick. The dam body can be placed on the bedrock, which is suitable for the construction of gravity dam. In order to reduce the leakage of the reservoir, a vertical impervious curtain was made along the upstream side of the grouting corridor. The maximum depth of impervious curtain was 33.8 m.

The first hub is composed of non-spillway dam, spillway dam, sluice gate, water inlet and other buildings. The total length of the top of the dam is 84,879 m, and the maximum height is 35.3 m. According to the calculation of hydraulic energy and hydraulics, the dead storage capacity of the reservoir is 30,000 m$^3$, and the regulated storage capacity is 93,000 m$^3$.

The maximum dam height of non-spillway dam is 33.79 m, the crest width is 5m; the crest elevation is 1624.800 m; the upstream slope is 1:0.15, the downstream slope is 1:0.78, the maximum dam bottom width is 27.75 m. The height of the overflow dam is 26.30 m, and clear width of the overflow front is 12 m. The elevation of the overflow weir is 1615.800 m. The upstream dam slope 1:0.15, and downstream dam slope 1:0.78, the crest adopts the WES curve. The way of energy dissipation is flow-lifting energy dissipation. The radius of the reverse arc is 12 m, and lifting degree is 30°; the maximum lifting distance is 47.28 m, and the depth of the tapping pit is 7 m. The tapping pit is far from the dam site, which does not affect the safety of the dam body. In order to ensure the adjustment of storage capacity, two 6 m×8 m (width × height) arc gates are set on the overflow dam, and corresponding arc door lifting and closing machine room is set.

The sluice is arranged on the right bank adjacent to the overflow dam, with the top elevation of 1624.800 m and the bottom elevation of the orifice of 1600.000 m. Set a 3 m×3 m working gate and a 3.5 m×3.5 m maintenance gate with the size of orifice. The inlet sluice is located on the right bank close to the dam body. Top elevation of sluice is 1624.800 m, the bottom elevation of sluice mouth is 1606.800 m. There is a 2 m×2 m working door and a 2.5 m×2.5 m maintenance door with the size of sluice mouth on the top.
5.2. Layout of Hub at the Head without Adjustment Scheme
Along the selected dam axis, the first pivot building is non-spillway dam, spillway dam, sluice gate and water inlet successively from left bank to right bank. The layout of the bow hub is shown in figure 1.

![Figure 1. Head hub layout.](image)

The overflow dam is an open type, arranged in the middle of the riverbed. The upstream dam slope is 1:0.18 and the downstream dam slope is 1:1. The maximum height of the dam is 14.50 m. The non-spillway section is a buried concrete gravity dam with its end embedded in left bank bedrock. The maximum dam height is 15.0 m, the crest length is 10.50 m, the width of the crest is 3.00 m, the elevation of the crest is 1619.500 m, the upstream face is vertical, and the downstream dam slope is 1:0.75.

The sluice is arranged on the right bank of the overflow dam and adopts the front sand flushing method. The height of the sluice pier is 10.50 m, the thickness is 1.50 m, and the thickness of the bottom plate is 1.00 m. The hole size of the punching gate is 2 m x 2.5 m. The inlet sluice is arranged in front of the right bank dam, and water is drawn directly from the head of the right bank dam by way of drawing water from the front side of the dam. The gate body is constructed of C20 reinforced concrete, with a height of 10.80 m, a thickness of 1.50 m, and a floor thickness of 0.8 m. The sand guide bar is cast in C15 concrete, and the top of the gate is 2.5 m higher than the bottom of the sluice.

Because the dam body of the project is not high and the water depth downstream of the dam in the flood period is relatively deep, it is difficult for downstream energy dissipation measures to dispose the energy dissipation of the flow [8]. Therefore, the energy dissipation scheme of the bottom flow is adopted to make the end of the dam produce submerged hydraulic jump and concentrate energy dissipation, so as to achieve the purpose of protecting the dam toe and the downstream riverbed.

5.3. Scheme Selection
Suborder river belongs to the alpine valley, so river natural slope is big, and the valley is narrow. The regulation scheme above the dam site of natural slope was 8%, and the valley is 20 ~ 60 m wide, so building more than 30 m high medium dam only adjust the capacity of 93000 m³ (not completely daily
regulation). All quantities of the project increase, and only the first hub in direct engineering fees is 15.053 million yuan, nearly 8 million yuan more than the low dam diversion scheme.

On the other hand, the water flow of Yamu River is evenly distributed, with a guaranteed flow of 3.6 m$^3$/s ($P=90\%$) during the dry period. There are two rainy seasons in the year, and the precipitation from February to May accounts for $50.08\%$ of the annual precipitation. At this time, other power stations in the grid except Fugong and Gongshan are in the dry period.

Yamu River dam site has an average sediment yields amount of 256400 tons with 192300 tons of suspended load sediment and 64100 tons of bedload sediment. A reservoir flood overflow surface will fill below, so sluice can only guarantee the water inlet "door". Although the flood can open arc door sand washing, the suborder river bed load size is big, so bed load will be back in the reservoir accumulation, occupying the part of the regulating capacity.

Therefore, the construction of a middle dam at a height of more than 30 m in the first part of Yamu River to obtain limited regulated storage capacity has a high cost and cannot guarantee storage capacity effectively for a long time. Thus, the operation and maintenance of the reservoir is complex. The non-regulating scheme of low dam diversion water was selected.

6. Layout Characteristics of the Project Hub

(1) According to the characteristics of annual rainfall distribution and sediment content in Yamu River basin, the first hub adopts to an unadjusted scheme of low-dam water diversion; (2) According to the topographical and geological conditions, the 2 m head of the tunnel can be obtained more than that of the open channel by making use of the characteristic that the tunnel can be cut and bent and taken straight, with high safety and reliability in operation; (3) Pressurized water diversion system can avoid large-scale surface excavation and save 1.5 million yYuuan of project investment (direct cost); (4) According to geological conditions, the pressure steel pipe lines are arranged in broken lines instead of unconventional straight lines; (5) In this project, a tail canal with a length of 103.975 m is set up to make use of 7 m head. The tailgate of the two units respectively enters the tailgate and the main tailwater channel is discharged into the Subu River. Therefore, the design of the long tailwater channel can make more use of the head, so that the power station can obtain more benefits [9].

After comprehensive comparison, considering the geological and topographic conditions and the backwater not to inundate the existing highway during the flood period, the dam site was selected in the river section between the confluence of two tributaries and about 140m downstream of The Subu River at 19.84 km. Considering the adaptability of the river width to the layout of the junction buildings at the head and the geological requirements of the abutment of the dam foundation, the lower dam axis is superior to the upper dam axis. Compared with topographic conditions, head loss and engineering quantity, the pressurized water diversion scheme on the right bank is better. There is a terrace on the right bank of Sub-Mu River near Yaping Village, with a gradient of about 15°~20°. It is the only suitable place for the layout of workshops and booster stations. The hub building consists of three parts: the head hub, the low-pressure diversion system and the plant hub [10].

The water diversion system is arranged on the right bank of Yamu River and consists of pressure diversion tunnel, pressure regulating well and pressure steel pipe. The pressure tunnel passes through the strong mountain along the right bank to the pressure regulating well arranged on the front ridge of Yaping Village. From the pressure regulating well, it leads out the concrete buried pipe and steel lined concrete pipe with the inner diameter of 2.0 m, which is connected with the pressure steel pipe. The pressure steel pipe is arranged in a broken line along the ridge and enters the main workshop on the ground after bifurcating in front of the workshop.

The hub of the factory is located on the riverfront platform near Yaping Village on the right bank of Yamu River (figure 2). It is about 2.5 km away from the first hub along the river road. It consists of the main factory building, auxiliary factory building, tailgate canal, outdoor booster station and other main buildings.
7. Conclusion
In Salween River tributary at all levels, high head and small flow rate diversion power station is very common. In the process of general layout, it is important to optimize the layout of the building from the dam, the dam axis, water diversion lines, with or without regulation, site selection and scheme comparison, hub layout aspect to make the arrangement more reasonable and the investment more economic. The design process of hub layout should go through repeated calculation, layout and adjustment according to the characteristics of the project to achieve the purpose of optimal design. It is of great significance to summarize the comparison and selection of the layout scheme of Yamu hydropower station for the layout and design of hydropower station in the topography of high mountains and valleys in Yunnan.

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