Engineering application of power generation technology for adding and reducing silt in multi-sediment reservoir

Heng Zhou¹,², Yongqing Li³, Ruijiao Xing¹,²*, Shengjie Di¹,², Xi Lu¹,², and Haitao Sun¹,²

¹Northwest Engineering Corporation Limited, Power China, Xi’an, Shanxi, 710065, China
²High Slope and Geological Hazard Research & Management branch, National Energy and Hydropower Engineering Technology R&D Center, Xi’an, Shanxi, 710065, China
³State Grid Gansu LiuJiaXia Hydropower Station, Linxia, Gansu, 731100, China
*Corresponding author’s e-mail: xingruiji@nwh.cn

Abstract. The uncoordinated relationship between water and sand is a major technical problem that has not been completely eradicated or resolved in the construction of water conservancy and hydropower in the world [1-2]. In response to the problem of sedimentation, scientific research, design and operation units have carried out research and application of key technologies for the addition of sediment-laden reservoirs to reduce siltation and power generation. The research results have been successfully applied to the Liujiaxia Tao River Mouth Desilting Tunnel and Machine Expansion Project. The Liujiaxia Reservoir has successfully solved the sediment discharge and silt reduction, increased the effective storage capacity of the reservoir, improved the power generation efficiency of the reservoir, improved the water quality of the reservoir, and provided support for the long-term spatial deployment of water resources.

1. Introduction
The Yellow River is the river with the largest sediment content in the world. Due to the lack of water and more sand, the uncoordinated relationship between water and sand is a major technical problem that has not been completely eradicated or resolved in the construction of water conservancy and hydropower in the world [1-2]. In order to eradicate the problem of sediment discharge, carry out the research and application of the key technology research and application of the additional silt-reducing power generation project of the sediment-laden reservoir [3-4]. The research results have been successfully applied to the Liujiaxia Tao River Mouth Desilting Tunnel and Machine Expansion Project [5-7].

The desilting tunnel project is the first phase of the project. Construction was officially started in May 2006, and on September 6, 2015, the underwater rock plug blasting project at the inlet of the desilting tunnel was successfully implemented. The entire line of the desilting tunnel is connected to water, marking the official completion and commissioning of the Taohe Estuary desilting tunnel project, as shown in Figure 1.
The expansion project is the second phase of the project, which started in April 2013. On August 26, 2018, two units (7# and 8# units) were officially put into operation for power generation, as shown in Figure 2.

2. Analysis on the Effect of Sand Discharge of Sand Discharge Tunnel in Taohe Estuary

2.1. Analysis of Sediment Discharge Effect of Density Current

In 2018, the Liujiaxia Reservoir used the Taohe desilting tunnel to discharge the sand 8 times. The discharge situation is shown in Table 1. The water consumption of the desilting tunnel was 23.8% of the water discharged from the reservoir during the same period. Sediment discharge accounted for 75.5% of the amount of sand discharged from the reservoir during the same period. The average water consumption rate for sand discharge is 25.9m$^3$/t. The average sand content out of the warehouse is 38.6kg/m$^3$, which is 9.8 times the sand content of the machine. The average sand discharge ratio is 95.3%. Compared with the use of the discharge channel to discharge sand (1974 to 2015), the sediment content of the machine has been significantly reduced, the water consumption rate of sand discharge has been significantly reduced, the amount of sand passing through the tunnel has been significantly increased, and the effect of sand removal has been significantly improved. Therefore, after the Taohekou desilting tunnel is completed and put into operation, the effect of the reservoir's density flow in desilting is significantly improved and the effect is good.
Table 1. Comparison table of changes in the sediment concentration of the density flow in the Liujiaxia Reservoir in 2018

| Time     | Incoming sand content (kg/m³) | Sand content of the machine (1#~5#) (kg/m³) | Sand content of the tunnel (kg/m³) | Times ratio (Passing hole/passing machine) |
|----------|-------------------------------|--------------------------------------------|----------------------------------|--------------------------------------------|
| 2018.7.19 | 146.0                         | 8.87                                       | 89.5                             | 10.1                                       |
| 2018.8.3  | 28.1                          | 3.22                                       | 17.2                             | 5.3                                        |
| 2018.8.4  | 17.2                          | 1.15                                       | 10.4                             | 9.0                                        |
| 2018.8.8  | 20.9                          | 2.42                                       | 14.1                             | 5.8                                        |
| 2018.8.10 | 21.3                          | 5.10                                       | 20.3                             | 4.0                                        |
| 2018.8.13 | 18.8                          | 1.58                                       | 12.7                             | 8.0                                        |
| 2018.8.15 | 41.2                          | 3.55                                       | 21.0                             | 5.9                                        |
| 2018.8.21 | 36.9                          | 3.54                                       | 22.9                             | 6.5                                        |
| Average   | 48.2                          | 3.93                                       | 38.6                             | 9.8                                        |

2.2. Changes of Sandbank Elevation in Taohe Estuary
The changes in the elevation of the sand sills of the Tao River are related to the inflow and sedimentation of the Tao River, the inflow of the main stream, and the changes in the operating water level of the reservoir. At present, the highest siltation in the Shakan River section is only upstream of the Tao River entrance gate between Huang 3# and Huang 4# sections. The siltation is still mainly formed by the spread of Tao River sand in the estuary, and the erosion is mainly caused by water from the main stream. The performance is scouring along the way. The erosion and deposition changes of Huang 3# and Huang 4# sections are shown in Figure 3 and Figure 4.

![Figure 3. Schematic diagram of erosion and deposition changes in Huang 3# section](image)

Figure 3. Schematic diagram of erosion and deposition changes in Huang 3# section
Figure 4. Schematic diagram of erosion and deposition changes in Huang 4# section

It can be seen from Figure 3 that a deep trough with a width of about 50m to 80m and a depth of about 25m appears on the left bank, which becomes part of the funnel in front of the Taohekou desilting tunnel, which is conducive to the stable flow of the density current into the desilting tunnel and lift. The sand removal effect of the high sand discharge hole. As can be seen in Figure 4, the siltation during the flood season in 2015 and 2016 was about 0.8m, and the erosion during the non-flood season was about 0.5m. After the formation of the main scour channel at the Taohe Estuary, the density of the Taohe River returned to the trough, and the spread at the estuary weakened. The erosion and siltation changes of Huang 4# section have been reduced. In 2017 and 2018, the siltation during the flood season was less than 0.3m. After the completion and operation of the Taohe Estuary sand drainage tunnel, it will be beneficial to control the elevation of the Taohe Estuary sand sill.

2.3. Siltation changes in front of the dam
The Huang 2# section is 730m away from the dam, and about 400m upstream is the entrance of the Taohe estuary sediment discharge tunnel, which is less affected by the water discharge in front of the dam and the discharge tunnel. This section analyzes the changes in sediment erosion and deposition in front of the dam. As shown in Figure 2.3-1, after the Taohe River Sand Drainage Tunnel is completed and put into operation, an erosion funnel is formed in front of the mouth of the cave, and a 20m deep scouring trough is formed at the mouth of the Taohe River, intercepting and draining most of the incoming sand from the Tao River, and the siltation in the front section of the dam is obviously slowed down. Reducing the threat of sedimentation in front of the dam to the safe operation of the gate.

Figure 5. Schematic diagram of erosion and deposition changes in Huang 2 section

2.4. Analysis of Influence on the Sediment Concentration of Unit Passing Units in Front of Power Station Dam
In 2018 and 2019 at the same time, the comparison of the sediment content of the machine is shown in Table 2 and Table 3.
Table 2. The comparison table of the sediment content of the unit in front of the dam and the expansion unit of the sand tunnel at the same time in 2018

| Time (Month, Day, Hour, Minute) | Sand content (kg/m³) 4# unit | Sand content (kg/m³) 4# unit | The ratio of sand content of unit 8# to unit 4# |
|--------------------------------|-----------------------------|-----------------------------|-----------------------------------------------|
| 7.20 9:00                     | 1.88                        | 9.83                        | 5.2                                           |
| 7.21 17:00                    | 1.75                        | 2.46                        | 1.4                                           |
| 7.21 20:00                    | 1.49                        | 1.4                         | 0.9                                           |
| 8.8 15:00                     | 2.36                        | 11.9                        | 5.0                                           |
| 8.13 20:00                    | 1.05                        | 3.07                        | 2.9                                           |
| 8.14 15:00                    | 1.3                         | 1.46                        | 1.1                                           |
| 8.16 9:00                     | 2.32                        | 2.27                        | 1.0                                           |
| 8.17 9:00                     | 2.37                        | 5.77                        | 2.4                                           |
| 8.17 15:00                    | 1.52                        | 2.24                        | 1.5                                           |
| 9.2 16:00                     | 0.69                        | 1.81                        | 2.6                                           |
| 9.26 20:00                    | 0.79                        | 0.49                        | 0.6                                           |
| Average                       | 1.59                        | 3.88                        | 2.4                                           |

Table 3. Comparison of the sediment content of the unit in front of the dam and the expansion unit of the sand tunnel in 2019

| Time (Month, Day, Hour, Minute) | Sand content (kg/m³) 4# unit | Sand content (kg/m³) 4# unit | The ratio of sand content of unit 8# to unit 4# |
|--------------------------------|-----------------------------|-----------------------------|-----------------------------------------------|
| 6.23 10:30                     | 0.2                         | 0.38                        | 1.9                                           |
| 7.8 9:30                       | 0.2                         | 1.03                        | 5.2                                           |
| 7.15 23:30                     | 0.1                         | 0.33                        | 3.3                                           |
| 7.22 9:40                      | 0.1                         | 0.38                        | 3.8                                           |
| 7.25 9:30                      | 0.2                         | 0.46                        | 2.3                                           |
| 7.28 22:30                     | 0.7                         | 3.12                        | 4.5                                           |
| 7.30 9:0                       | 0.2                         | 0.25                        | 1.3                                           |
| 7.30 16:0                      | 0.1                         | 0.2                         | 2.0                                           |
| 8.1 17:50                      | 0.1                         | 0.46                        | 4.6                                           |
| 8.1 23:20                      | 0.1                         | 0.51                        | 5.1                                           |
| 9.3 9:0                        | 0.1                         | 0.59                        | 5.9                                           |
| Average                        | 0.19                        | 0.7                         | 3.7                                           |

From Table 2 and Table 3, it can be seen that the sand content of the expansion unit of the Taohekou Desilting Tunnel is significantly higher than that of the unit in front of the dam, which is 2.4 times on average in 2018 and 3.7 times on average in 2019. In 2018, the large flow and long duration of scouring and desilting, the Taohe estuary scouring main trough was fully formed, which was conducive to the sorting of the Taohe estuary sand into the trough, and improved the sediment carrying effect of the Taohe estuary desilting tunnel. The sediment content of the Taohe estuary in 2019 Times ratio increased.
3. Conclusion

(1) The sand discharge tunnel at Taohe Estuary was completed and put into operation. The sediment content of the machine was significantly reduced, the water consumption rate of sand discharge was significantly reduced, the amount of sand passing through the cave was significantly increased, and the sediment discharge effect was significantly improved.

(2) Before the full density flow is discharged, the siltation is raised by about 0.8m. After the project was repaired, the siltation elevation was only about 0.3m in the two flood seasons. Considering the erosion effect in the non-flood season, the annual average siltation elevation value was smaller, and the siltation and elevation momentum of sand sills was basically controlled.

(3) After the Tao River sediment discharge tunnel is completed and put into operation, an scouring funnel is formed in front of the cave entrance, and an scouring trough about 20m deep is formed at the Tao River mouth, which intercepts and discharges most of the incoming sand from the Tao River. The amount of sand entering the front section of the dam is significantly reduced, and the siltation in the front section of the dam is significantly slowed. This has reversed the passive situation of continuous accumulation of sediment in front of the dam, and reduced the threat of sediment deposition in front of the dam to the safe operation of the gate.

(4) The sand content of the expansion unit of the Taohe Estuary sand discharge tunnel is significantly higher than that of the unit in front of the dam. The average sand content in 2018 was 2.4 times and the average in 2019 was 3.7 times. Due to the large flow and long duration of scouring and desilting in 2018, the Taohe Estuary scouring main trough is fully formed, which is conducive to the sorting of the incoming sand from the Taohe River into the trough, and improves the sediment carrying effect of the Taohe estuary desilting tunnel.

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