Conclusions

- The development law of the surface settlement was different inside and outside the river-affected area. For a single point on the center line, the law of surface settlement over time could be divided into three stages, both inside and outside the river-affected area. When within the river-affected area, there was an asynchronization of the sinking rate and stability of vault settlement and surface settlement.
- The numerical results showed good agreement with the monitoring data, which proves the rationality of the numerical model. Outside the river-affected area, the main factor that influenced the stability of the tunnel face and the development of surface settlement was the excavation of the upper face of the tunnel. Inside the river-affected area, apart from the settlement caused by excavation, the consolidation settlement resulting from the dissipation of excess pore water pressure caused by cofferdam construction above the river was also important, extending the time needed for settlement to converge.
- Outside the river-affected area, the negative excess pore water pressure was distributed mainly in the range of 1.0~3.0 H_t behind the tunnel face, and 1.0~2.0 H_t in front of the tunnel face. Inside the river-affected area, the negative excess pore pressure was distributed in the range of 1.0~2.0 H_t before and behind the tunnel face, which is more concentrated. The construction of the tunnel cofferdam reduced the surface settlement by 30%, and the excess pore water pressure distribution generated by the construction of the cofferdam was more dispersed, which could reduce the tunnel construction risk. To better control the settlement caused by a tunnel undercrossing a river, reinforcements such as a cofferdam and pre-grouting support could be applied.