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STRATEGY ON RESERVOIR REGULATION BASED ON SAFETY OF ARCH DAM

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ABSTRACT

Safety of the dam, which is the most important part of the pivotal project, is the core goal of regulation of reservoir for hydropower station. Variation of water level of the reservoir, operation mode of the flood discharge facilities, minimum water level of the reservoir under the worst condition, are all new subjects for a hydropower station in prior stage. The Xiluodu dam is concrete double-curvature arch dam with maximum height of 285.5m, the altitude of the dam crest is 610m.The valley deformation occurred after impoundment of Xiluodu Hydropower Station, which is different from other hydropower station with high arch dam. So it is especially important to carry out reservoir operation scheduling reasonably. For this reason, the monitoring date should be organized and analyzed in time to explore the laws of dam deformation. Finite element inversion analysis can also be used to make the real-time assessment on the behavior of arch dam and predict the trend of monitoring data, which can propose the control indicators and reliable basis for reservoir regulation.

1. BRIEF

1.1 Foreword

The reservoir dispatching of hydropower stations is a systematic project, and the dispatching objectives are multi-dimensional, including hub safety objectives, ecological objectives, water resources utilization objectives, power generation objectives, shipping objectives and so on. It is necessary to coordinate the relationship between dispatching and comprehensive utilization of water resources, water environment, ecological protection, rational allocation of water quantity and control of water level. With the economic and social development of China, the system project of hydropower station on the mainstream of the Yangtze River has become more complex and richer.

How to achieve the optimal allocation of dispatching objectives and maximize the comprehensive benefits of hydropower stations has always been an important topic for us to make unremitting efforts to explore. Because these scheduling objectives are difficult to compare with each other, and there are even contradictions or conflicts among some scheduling objectives, it is difficult to optimize all scheduling objectives. However, it's clear that the goal of hub safety is the basis and premise of all objectives, and dam safety is the core of hub safety. Therefore, in the reservoir operation, in the process of achieving other goals, the impact on dam safety should be fully considered.

The engineering practice shows that through the on-site inspection and instrument monitoring of the reservoir dam and the real-time compilation and analysis of the monitoring data, the abnormality of the reservoir dam can be found in time and the future safety behavior and development trend of the dam can be predicted. Therefore, the state of the dam should be analyzed and evaluated regularly according to the monitoring data, as the basis for operation and dispatching, and the dispatching scheme should be adjusted accordingly if necessary to control the operation of the dam and prevent the occurrence of disasters. In the initial operation period of the hydropower station, in the process of gradually exploring the operation law of the dam, this work is particularly necessary.

1.2 Background

Xiluodu Hydropower Station started to lower the gate to store water on May 4, 2013, and the water level reached the normal water level for the first time on September 28, 2014. As of June 30, 2019, the arch dam has gone through the process of water storage loading of five reservoirs and unloading of five reservoirs. A total of 9 valley amplitude survey lines were arranged in Xiluodu project, and the valley amplitude shrinkage deformation occurred after the impoundment of Xiluodu project. the valley amplitude deformation caused the radial displacement of the dam to be smaller downstream under the condition of normal storage water level. Compared with the same scale arch dam project, the valley amplitude shrinkage of Xiluodu arch dam is relatively larger at the initial stage of impoundment operation. As of June 30, 2019, the VDL04 valley amplitude shrinkage of the 610 m line at the top of the dam is-71.39mm, and the valley amplitude

deformation has gradually converged. For details, see Fig. 1 valley amplitude deformation with reservoir impoundment and fluctuation process line. However, in the process of water storage loading of five reservoirs and fluctuating and unloading of five reservoirs, with the change of reservoir water level, many topics are put forward based on the safe operation strategy of arch dam. What is the development trend of grain amplitude deformation? Is the operation of arch dam safe? Under the present condition, what is the working behavior of the arch dam under the lowest and highest water level of the reservoir? Is there any influence of reservoir water level fluctuation and water storage speed on arch dam?

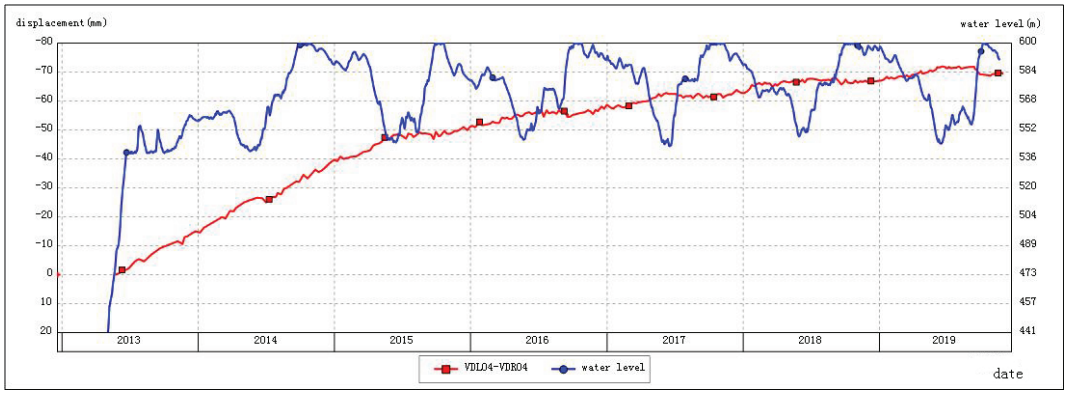


Figure 1 : The process line of Xiluodu VDL04 survey line rising and falling with the reservoir water level

For this reason, the operation and management staff of Xiluodu Hydropower Station carefully carry out dam safety monitoring, check the correctness of the monitoring data and obtain the correct monitoring data. Carry out the analysis of monitoring data, systematically sort out the monitoring data of dam and valley amplitude deformation and evaluate the operation behavior of arch dam from the point of view of monitoring data analysis according to the relevant design codes. The monitoring data are analyzed and evaluated from the aspects of dam body stress and deformation, dam foundation stress and deformation, seepage and seepage pressure, as well as the historical change law of valley amplitude, spatial distribution law, deformation development trend and so on. To provide data support for the study of the working behavior of arch dams. The monitoring data of valley amplitude deformation of Xiluodu arch dam are analyzed by means of statistical regression analysis and empirical formula fitting, and the development trend, convergence time and convergence value of valley amplitude deformation are predicted. Based on the analysis of the monitoring data of arch dam and valley amplitude deformation of Xiluodu Hydropower Station, the cause of formation and convergence value of valley amplitude deformation, and the influence of valley amplitude shrinkage deformation on the static and dynamic working behavior of arch dam, the working behavior and structural safety of Xiluodu arch dam are comprehensively evaluated. A series of dispatching experience has been obtained to ensure the safety of the arch dam. In view of the limitation of space, this paper only focuses on the realization of the dispatching goal, according to the operation monitoring data of many extra-high arch dams in China, combined with the monitoring data of Xiluodu arch dam and the results of finite element calculation and analysis, the working form of the arch dam is reasonably evaluated in the process of loading and unloading.

2. EVALUATION OF WORKING BEHAVIOR OF XILUODU ARCH DAM

Because each arch dam exists in different geological conditions, although the arch dam structure is in an elastic working state, the arch dam-foundation system will show certain initial nonlinear characteristics because of the specificity of the foundation, and the nonlinear displacement of the foundation at the initial stage of impoundment is more timely than that of the general high arch dam, thus affecting the deformation of the dam, so it is almost impossible to emphasize the standard linear elastic curve. According to the operation monitoring data of many extra-high arch dams in China, combined with the deformation monitoring data and finite element calculation and analysis results of Xiluodu arch dam during operation, the dam deformation state is normal during the loading and unloading cycle, and the arch dam structure is in an elastic working state.

2.1 Positive correlation between dam deformation and running water level

The specific performance is as follows: when the reservoir water level rises, the radial displacement of the dam to the downstream increases, while the fluctuation decreases. The law of the increase or decrease of the short-term displacement of the dam is basically the same as that of the short-term water level variation in the same water level interval.

From the first impoundment of the dam to June 2019, the radial deformation of each elevation of the dam section shows a good correlation with the reservoir water level. When the reservoir water level fluctuates, the radial displacement is upstream, and when the reservoir water level rises, the radial displacement is downstream. As shown in Fig 2, the correlation coefficient between the measured deformation and the change of reservoir water level is 0.79-0.85.

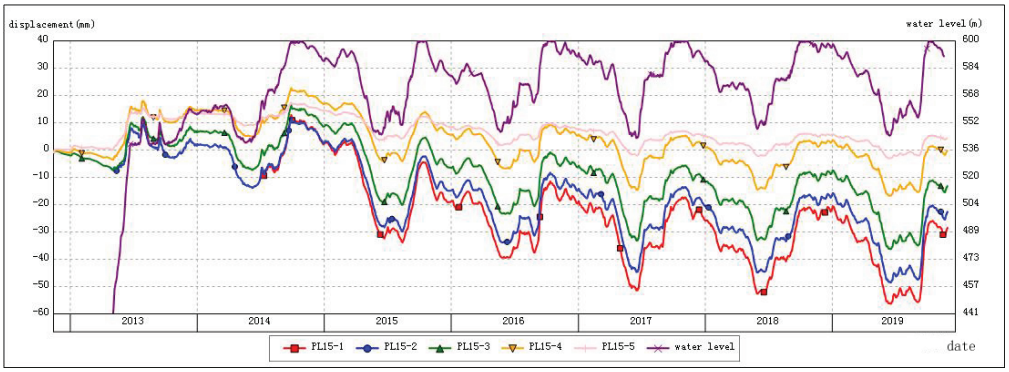
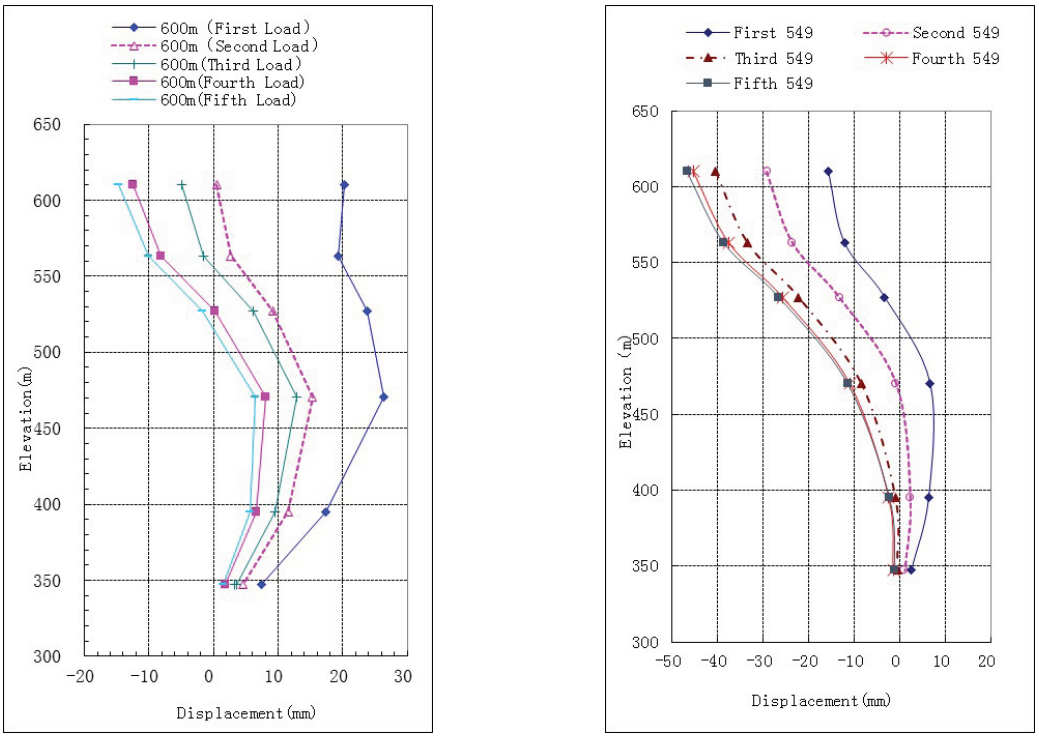


Figure 2 : Radial displacement process line of No. 15 dam section of Xiluodu arch crown beam

2.2 When the reservoir water level rises or falls to a stable water level, the dam deformation has stable convergence

The reservoir-arch dam-foundation system is a complex system, and the dam structure is a statically indeterminate structure. Under the action of load, the adjustment of deformation and load distribution of the dam has a certain timeliness but short, and has the ability of fast convergence. The foundation system is a complex structure formed in the long-term historical years, which has not only structural nonlinearity such as faults and fissures, but also material nonlinearity such as weak interlayer and interlayer dislocation zone, therefore, it has more obvious early nonlinear characteristics under load, and the deformation convergence has a certain timeliness, and the convergence is slow. The reservoir water is not a complete surface force load for the whole arch dam foundation system. Due to the infiltration and infiltration of water to the foundation, it will form a seepage force and change the load distribution, there will also be a process of adjustment, and it will also show the timeliness of load distribution. Considering the timeliness of the above three aspects, it is reasonable to lead to a certain nonlinear aging deformation in the initial impoundment process of the reservoir. However, a large number of monitoring data show that this kind of nonlinear aging deformation has obvious but slow convergence characteristics. When the water level of the reservoir rises or falls to a certain stable water level, the deformation of the dam foundation system will gradually tend to be stable. This is also an important distinguishing feature to judge the early plastic-elastic deformation of the system in the normal working state and the elastic-plastic deformation in the case of failure.

After five times of loading and five times unloading of the dam of Xiluodu Hydropower Station, the measured radial displacement of the typical dam section of the dam tends to be stable, and the displacement increment caused by the same water level increment (reduction) is basically stable, as shown in Figrue 3, which shows the convergence of dam deformation.



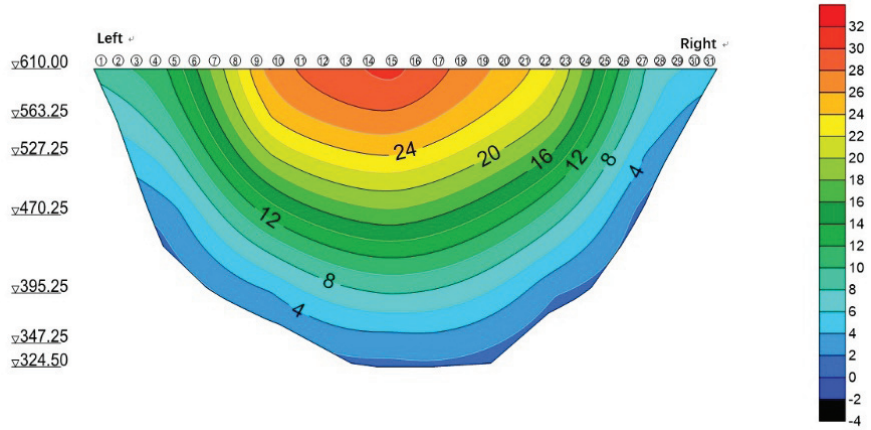
(a) High water level conditions (b) Low water level conditions

Note: "+" represents the downstream direction; "-" represents the upstream direction

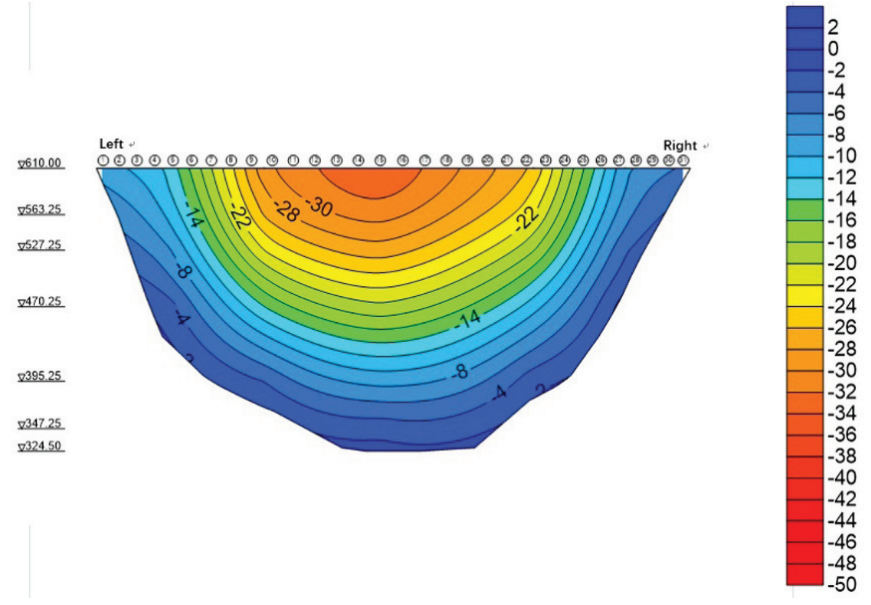
Figure 3 : Distribution diagram of radial displacement along elevation of 15 # dam section at high and low water levels

2.3 The incremental monitoring value of dam deformation caused by incremental water level is consistent with the results of elastic finite element calculation.

Due to the time difference of all kinds of monitoring instruments to bury and obtain the initial value, the influence of the early construction process of the dam and so on, it is objectively difficult to evaluate the structural deformation characteristics of the dam by the total deformation, so it is reasonable to use incremental evaluation. In the period of rapid impoundment or fluctuation of the water level of the reservoir, the nonlinear deformation of the foundation lags behind the deformation of the dam structure, and the displacement increment produced by the dam can better reflect the elastic characteristics of the dam structure itself. Under this premise, the dam deformation along the river and the increment of the cross-river deformation show obvious regularity. A large number of monitoring feedback analysis shows that as long as the monitoring feedback parameters are close to the actual engineering parameters, the monitoring increment value is in good agreement with the calculated increment value. Although the valley amplitude deformation has an obvious influence on the dam deformation, the dam deformation still shows a strong regularity in each incremental impoundment process itself. As shown in Figure 4, taking the fifth loading and fifth unloading process as an example, during the loading and unloading of the reservoir water level, the measured radial displacement of different measuring points of the dam decreases gradually to both sides with the dam section as the center, and the values of the left and right banks are close, and the dam body shows deformation coordination.



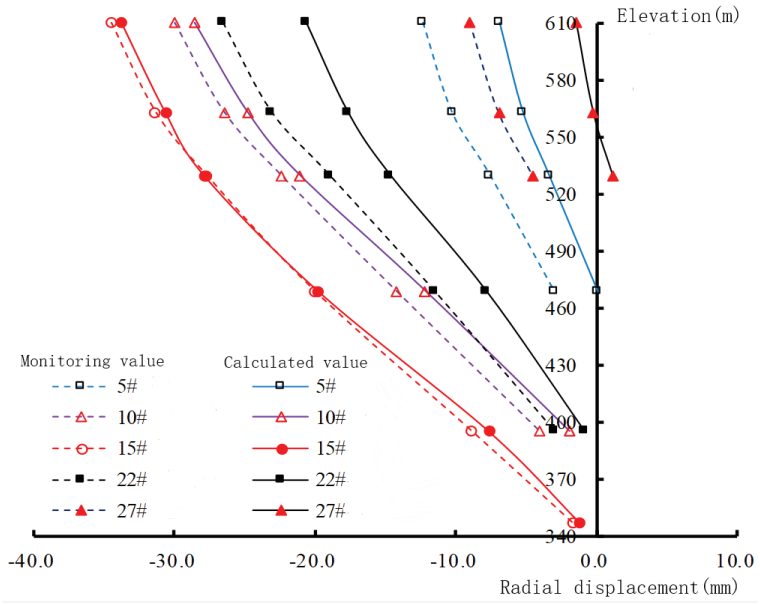
(a) Fifth loading



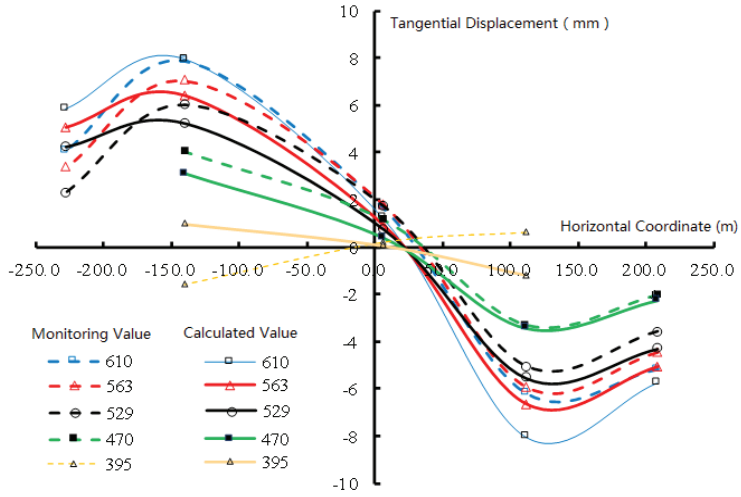
(b) Fifth unloading

Figure 4 :. Distribution of dam radial displacement variables during loading-unloading

In addition, all kinds of monitoring feedback analysis show that as long as the inversion of the mechanical parameters of the arch dam foundation system is correct, the predicted incremental deformation of the dam is in good agreement with the measured incremental deformation in each loading and unloading process of the power station. The comparison between the predicted and measured values of deformation of Xiluodu arch dam is given in Figure 5 during the fifth unloading period of arch dam, the monitoring value is close to the calculated value, and the law is consistent.



(a) Radial displacement



(b) Tangential displacement

Figure 5 : Incremental comparison of deformation of arch dam during the fifth unloading

2.4 The deformation of dam structure and the annual periodic variation of water level have synchronous periodicity.

The fluctuation-impoundment period of the reservoir is longer. In such a long period of water storage and fluctuation, the structural deformation of the dam shown by the monitoring data has obvious synchronous periodicity with the change of the regulation period of the reservoir water level. The specific manifestations are as follows:

(1) The deformation is basically synchronized: although the influence of foundation deformation and the response speed of dam structure lag relative to the variation of water level, the phase difference is almost negligible before the long period of reservoir regulation and storage period. therefore, it can be considered that there is synchronization between the two;

(2) The periodic reciprocating law is the same: the deformation of the dam and the regulation and storage of the reservoir show obvious periodicity. Although the starting point of the period will change due to the stable convergence described in 2.2, the law of periodic reciprocation will not be changed.

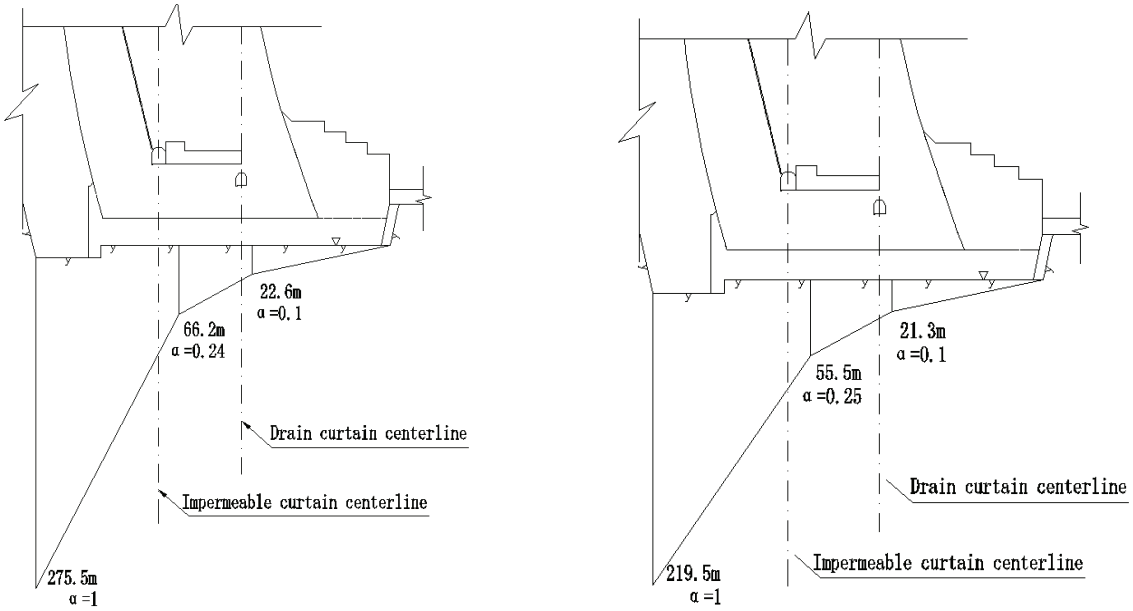
3. SEEPAGE PRESSURE

3.1 Seepage pressure of dam foundation

The distribution of the seepage pressure reduction coefficient of the dam foundation of the arch crown dam section is shown in Figure 6, and the seepage pressure reduction coefficient behind the curtain of each characteristic water level is shown in Figrue 7.

On June 15, 2019, when the reservoir water level is 544m, the seepage pressure head behind the dam curtain of each dam section is between 0.00m~55.51m, and the reduction coefficient is between 0.005 and 0.22, which is less than the design allowable value. There is a good correlation between dam foundation seepage pressure and reservoir water level in riverbed dam section, and the correlation coefficient is between 0.80 and 0.99.

Since the impoundment, the change of the reduction coefficient of each seepage pressure measuring point behind the curtain is generally small, and the reduction coefficient of each measuring point is less than the design allowable value.



(a) Water level reached 600m for the fifth time (b) Water level falls to 544m for the fifth time

Figure 6 : Distribution of seepage reduction coefficient of dam foundation for arch crown 15 # dam section

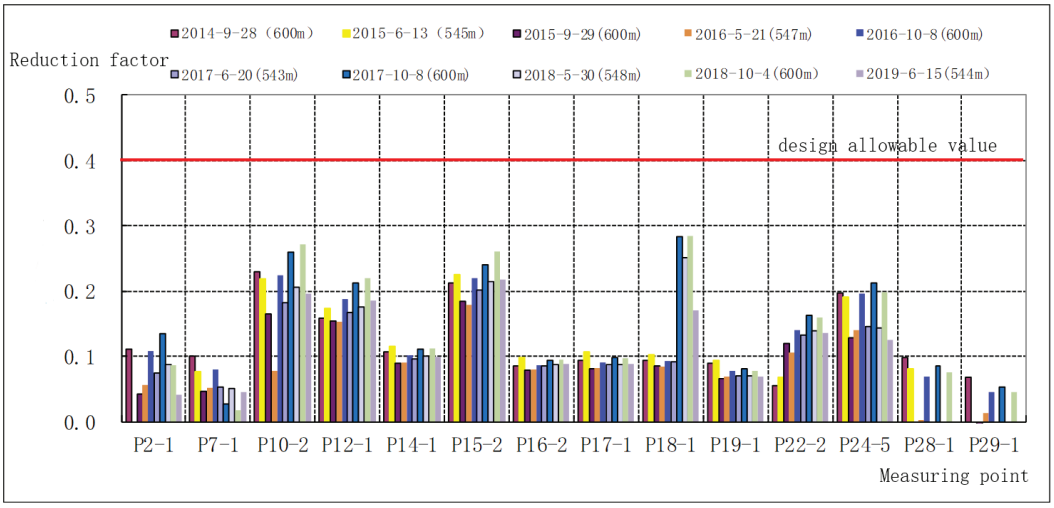


Figure 7 : Histogram of reduction coefficients of osmometer measurement points behind the curtain of the dam foundation for each characteristic water level

3.2 Dam foundation seepage

The seepage process line of dam foundation is shown in Figrue8. There is a good correlation between the seepage of the irrigation and drainage corridor of the dam and the water level of the reservoir, the seepage of the rising water level increases, the seepage of the water level decreases, and the seepage decreases as a whole.

When the water level reaches 544m, the total seepage of the irrigation and drainage corridor of the dam is 186.17L / min, which is less 72.76L/min than that at the water level of 548.46m (258.93L/min) in 2018. There is a positive correlation between the total seepage of the dam foundation and the reservoir water level, and the correlation coefficient is 0.71.

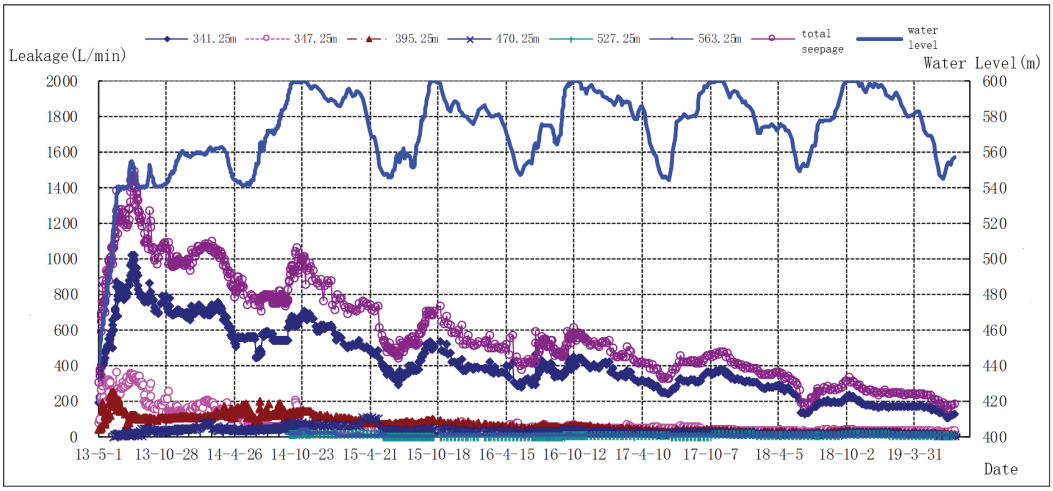


Figure 8: Seepage process line of dam foundation

4. CONCLUSION

According to the deformation monitoring data of Xiluodu arch dam during operation and the results of finite element calculation and analysis of working behavior, the working behavior of arch dam meets the "four characteristics" evaluation criterion of elastic working state of high arch dam. in addition, the seepage pressure behind the curtain of the arch dam is less than the design value, the foundation seepage decreases year by year, and the working behavior of the arch dam is normal.

Since the first impoundment of Xiluodu Project, more comprehensive and systematic research work on dam safety monitoring has been carried out in each water storage period and each loading and unloading cycle. Special studies on characteristic water level monitoring at 440m, 540m, 560m, 580m and 600m were carried out at the initial stage of impoundment. After that, the existing models and results are used to predict the deformation of the arch dam, put forward the dispatching strategy, and constantly use the new monitoring data to carry out the real-time evaluation of the working behavior of the arch dam in the process of water level loading and unloading. it provides a strong technical guarantee for the reservoir operation process. Engineering practice has proved that the method, model and technical route of such analysis and evaluation are scientific and feasible.

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