KEY CONSTRUCTION TECHNOLOGY OF 300M HIGH CORE WALL ROCK-FILL DAM

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ABSTRACT

As the high rock-fill dam being constructed to 300m, the dam anti-seepage safety attracts much more attention. For the high rock-fill dam constructed at the place where the overburden is thick and the river valley is steep and narrow, the construction quality of foundation processing, ant-seepage system and dam body filling becomes particularly important. The dam of Changheba Power Station is a gravel soil core-wall rock-filling dam, which is construction on the thick overburden, with the dam height of 240m. The height of overburden and dam is 293m in total. The seismic intensity reaches 9 degree. For the above reasons, the control of dam deformation stability and seepage stability is very difficult and it requires high design index and construction quality standard. The deep scientific research was carried out for this project and it made plentiful achievements. This article briefly introduces the engineering characteristics and construction difficulties of Changheba Power Station dam and describes the key technology adopted during the dam filling works, which has a reference value on the construction of similar projects.

***Key words** : core wall rock-fill dam; construction; key technology; new process*

1. General

Changheba Power Station is located at the upstream of Dadu River and it is the 10th grade power station of Three Reservoir and 22 Grades Dadu River Hydropower Plan. The structures for this project include gravel-soil vertical core wall rock-fill dam, diversion generation system at left bank and discharging tunnel system at right bank. The total reservoir volume is 1.075 billion m³and available reservoir volume 0.415 billion m³. The total installed capacity is 2600MW.

The barrage is gravel-soil vertical core wall rock-fill dam with dam crest elevation 1697m, maximum dam height 240.0m, core wall bottom elevation 1457.00m, dam crest width 16.0m and upstream and downstream dam slope 1:2.0. The total filling volume is 34.17 million m³. Two concrete diaphragm walls are constructed in the dam foundation overburden. The upstream auxiliary wall is 1.2m thick and the main wall is 1.4m thick.

2. PROJECT CHARACTERISTICS AND CONSTRUCTION DIFFICULTIES

2.1 Project Characteristics

The Changheba Power Station dam construction condition is complicated with the features of “Two High, One Large, One Deep and One Narrow”. Two High means the dam height is 240m and the bottom overburden is 60-70m thick (the total height is around 300m). For the seismic intensity is very high and the dam is located in the 8-grade seismic region, the earthquake fortification grade is 9. One Large means the filling scale is large. The total dam filling volume is 34.17 million m³. One Deep means the dam foundation overburden is 60-70m deep and it reaches 79.3m locally. One Narrow means the river valley is so narrow that the width and height ratio is only 2.09 and the slope is greater than 70 degree. The valley arch effect and stored water elevation steep rising effect is significant and the reservoir has no storage controlling capacity during the initial impounding period, which leads the upstream water level rapidly rises by 72m in 2 days after the initial diversion tunnel gate is closed. Changheba Power Station is the highest core wall rock-fill dam built on the thick overburden in the world at present, the construction of which is very challenging.

2.2 Construction Difficulties

(1) High design index and construction quality standard.The dam of this project is beyond the current design and construction code and standard (It specifies in the current design and construction code that the special research and demonstration shall be carried out for the dams higher than 200m.), and it requires high quality. For this reason, the compaction degree of gravel soil core wall material shall be controlled by complete aggregate compaction degree and fine aggregate compaction degree, in which the compaction degree of complete aggregate shall be no less than 0.97

(compaction power efficiency 2688KJ/m³) and that of fine aggregate shall be no less than 1.00 (compaction power efficiency 592KJ/m³). The core wall soil material parameter obtained from the compaction tests is as follows, 2 times of static compaction and 12 times vibrating compaction with 26t pad-foot roller. It also requires high filtering technology. 4 sorts of filter materials are designed for dam filling with different design indexes and requirements. The controlling accuracy of traditional mixing process is so low that the mixing quality is hard to be guaranteed.

(2) Complex cause of natural gravel soil borrow area formation and lack of homogeneity, The natural moisture content of the materials in the borrow area is between 1.7% and 19.3%, 9.8% in average; variation range of P5 content is between 7% and 90%, 49.1% in average; variation range of aggregate with diameter less than 0.075mm is between 8% and 64%, 30.4% in average; variation range of aggregate with diameter less than 0.005mm is between 1.6% and 26.3%, 10.3% in average; the average content of oversize aggregates(diameter larger than 150mm) is high, about 5.6%. The large variation of each test index and lack of spatial distribution homogeneity of the materials causes that the grading indexes of the natural materials hardly meet the design requirement and cannot directly meet the needs of core wall filling quality and scale construction. Therefore, multiple preparation processes shall be carried out, such as oversize aggregates removal, inhomogeneous mixing and moisture content adjustment, etc., which creates great difficulty of material exploitation and requires much more construction quality control processes.

(3) The rock materials in the quarry are hard and difficult to exploit.Two quarries are planned for this project, Xiangshuigou quarry at upstream side of the dam for upstream rock-fill and transition material filling and Jiangju quarry at downstream side for downstream rock-fill, transition material filling and filter material processing system aggregates supply. The rocks in quarry are primarily granite and diorite, the rock saturation compressive strength of which reaches 190MPa and the strength of rock is great. A mass of transition material blasting tests were carried out at the early stage of project and it showed that the stable transition material can still not be obtained even when the unit explosive consumption reaches 2.5kg/m³.

3. KEY CONSTRUCTION TECHNOLOGY

Combining the actual characteristics and construction difficulties of Changheba Power Station dam engineering, plenty of site tests, theoretical analysis and experience application research are carried out, as well as new technology and new equipment research and development. Furthermore, the research of key technologies, including core wall material modification preparation processes under complicated conditions, new systematical equipment for earth-rock dam refinement construction, new quality inspection and control methods based on information technology and environmental-protection green construction methods, etc. are also conducted, in order to improve the super-high rock fill dam construction technical capacity.

3.1 New Complete Construction Process for Core Wall Material Modification

Based on the traditional borrow area inspection method, for the problem of inhomogeneous spatial distribution of gravel soil in the borrow area in Changheba Power Station project, the borrow area inspection method based on the P5 content isoline is applied for P5 content partition and classification for those materials with the same geological origin in this area, which also helps to find out the distribution characteristics and partition volumes of coarse material, qualified material and fine material, and provides useful basis of rational exploitation of borrow area.

In order to guarantee the quality of dam filling materials, through processes comparison and selection and tests, the bar-type vibrating feeding machine to be used for mine and aggregates production system is adopted to remove the oversize aggregates (with diameter larger than 150mm) after modifying the length and spacing of grate bars. 5 sets of reinforcement concrete structure screening towers are also built according to the engineering intensity. The box-type receiving hopper, screening equipment erection layer and discharging layer that meets the need of material loading and discharging with loaders are all set in the screening tower. The average proportion of available material in the remaining screening material form system is only 0.2% with high leaking screen rate. The unit capacity can reach 670t/h.

For the coarse and fine aggregates, P5 is applied as the controlling index to improve the material utilization ratio. As the stable mixing system for road project to be used as the mechanical preparation system for material mixing, the production techniques of automatic material proportioning and homogeneous mixing are realized by means of material rationing, measuring feeding and forced mixing. Based on the equipment selection, combining with the characteristics of large aggregate size, high viscosity and high moisture content, the equipment has been improved that the space between mixing blade and the slope of proportioning bin wall have been both adjusted and certain number of tests have been completed, which shows good mixing homogeneity and can efficiently solve the problems of bad mixing homogeneity and clay caking that exist in the traditional production techniques. And the actual production capacity can reach 700t/h.

For the soil material with high moisture content existing in the Changheba project, the layered tedding technique is adopted to adjust the moisture content and the rapid tedding facility, which is appropriate for bulldozer is also designed

In the Changheba project, with comprehensive utilization of 69.5m³ coarse and fine materials and 31.6m³ high moisture content soil materials, the ratio between borrow area exploitation dam filling quantity is 1.41, which is much less than

the ratio between borrow area planning and dam material filling quantity (2.00-2.50) recommended in the relevant standard. The soil material exploitation ratio is improved greatly and the Xinlian borrow area is canceled, which helps that the area of occupied cultivated land is reduced by 510000m^2 and guarantee the consistent physical and mechanical performance of the core wall material.

3.2 Research on Filter Material Accurate Mixing Technique

For the aggregate processing system, the accurate filter material mixing technique is confirmed by means of plenty of filter material mixing technique tests, basic technical data collection and automatic controlling system programming. The technical principle is as follows, that the sands, small-size stones, middle-size stones and large-size stones are discharged and spread on the belt conveying machine successively. The discharging volume of each sort of aggregates for mixing shall be determined according to the design grading of filter materials and the volume shall be controlled by adjusting the opening of electrical gate and accurately controlling the frequency charging vibrating feeding machine through center control chamber remote operation. And the filter material automatic mixing is finally realized through automatic data programming based on the volume feedback from the belt scale under the conveying machine and data collected through technical tests.

The filter material discharging speed stability test is carried out under the condition of assigned frequency with electrical belt scale, which shows that the feeding frequency conversion accuracy can be controlled in 1% to 3% and it is 3% to 5% higher than the traditional technical controlling accuracy.

3.3 High Standard Transition Material Mechanical Crushing Technique

The mechanical crushing technique is one kind of transition material preparation process that is carried out through secondary crushing of blasting material with rational unit explosive consumption, maximum size controlling in coarse crushing and grading adjustment in secondary crushing. Comparing with blasting, the grading of transition material produced by this technique is more stable and it can also solve the problems such as low utilization of the transition material and great difficulties of being directly produced from hard rocks blasting.

Although the rocks with high strength obtained from the quarry in Changheba project, after the secondary crushing for the rocks obtained from blasting through transition material mechanical crushing technique and coarse crushing of jaw crusher, the maximum aggregate size can be efficiently controlled and the transition material with stable quality can be finally obtained after secondary crushing of 50% coarse crushed materials with gyratory crusher and mixed with belt conveying machine.

3.4 New Equipment and New Technology for Refined Earth-rock Dam Construction

(1) Development of High and Steep Slope Slab Concrete Reversal-rail Hydraulic Climbing Formwork

For the construction difficulties of high and steep and thin concrete slab, the reversal-rail hydraulic climbing formwork and automatic controlling system for slope concreting works are developed. The force and supporting of hydraulic formwork climbing is applied with the special rail through reversal roller controlling the uplift pressure of concrete, and the side formwork automatic lifting and adjustment of formwork length and direction can also be carried out. The self-climbing reversal rail hydraulic climbing formwork was applied in the slope slab concrete construction of Changheba project and the automatic climbing speed could reach 80cm/h. The reversal rail system could completely overcome the concrete uplifting pressure and the concreting quality was good. The evenness of concreting block could be controlled within ±5mm.

(2) Slab Concrete Surface High-plastic Clay Mechanical Spraying Technique

In order to ensure the combination of high-plastic clay and concrete pressing plate, 3-5mm grout shall be sprayed on the surface of pressure plate. In the similar projects, the grout is usually sprayed by hand with low construction efficiency and bad homogeneity and the thickness cannot be guaranteed.

In order to improve the insufficiency in traditional technologies, the mechanical spraying technique is developed. Under the influence of compressed air, the grout is transported to the spray-head after filtration to form the pressure flow and to reach the coating cohesion. As the Wagner PC spraying machine made in Germany used as spraying equipment and combining with plenty of site tests, the grout mix and proportion are determined. The spraying process is as follows, grout preparation → tube moistening → grout injecting → test spraying → spraying to design thickness.

The slab grout spraying technique is the innovation of concrete slab surface traditional grout painting technique in the earth-rock dam high-plastic clay filling. The construction equipment for grout spraying is simple and convenient for installation and operation with high construction efficiency and quality. The mechanical spraying thickness is between 3.7mm and 4.0mm and the average thickness is 3.87mm. The coefficient of dispersion is only 0.01. The mechanical spraying performance can reach 1 m^2/min, which is twice that of spraying by hand.

(3) Technique of Two - Material Spreading

In order to solve the problems existing in the normal earth-rock dam soil – sand interface sand first and soil second construction method, such as mutual contamination, nonstandard filling size and low construction efficiency. The core

wall interface two-material spreading machine is developed for one-time accurate shaping of interface spreading between core wall material and filter material and between different filter materials. This machine with the advantages of rational structures, simple operation system, adjustable interface slope ratio, efficiently improves the construction efficiency and spreading quality. The spreading machine is manufactured with structural steel and steel plate, in bottomless box type. The splitter steel plate is set in the middle of the spreading machine and the dip of the plate below the discharge hole is the same with core wall design slope ratio. The height of discharge hole, that is the spreading thickness of two kinds of materials, is decided according to the material sedimentation rate in compaction test. The two – material spreading technique can efficiently solve the problems existing in the normal earth-rock dam soil – sand interface *sand first and soil second* construction method, including mutual contamination, nonstandard filling size and low construction efficiency, avoids the materials separation at the interface in traditional techniques and improves the interface joint quality.

(4) Vibrating Roller Self-driving Technology

In Changheba hydropower station dam project, through the deep systematic research on compaction machinery operation technology, the vibrating roller self-driving technology is developed, including the vibrating roller electric and hydraulic controlling system, integrated application satellite navigation, condition monitoring and feedback controlling, and ultrasonic environmental perception, which realizes the compaction roller self-driving operation for the first time and accurately controls the compaction works to improve the compaction quality and efficiency.

The electric and hydraulic controlling system of vibrating compaction, with the parameter setup by electric master controller, controls the states of walking, turning and vibrating, etc. and helps to realize the automatic controlling of vibrating roller operation. The location, direction and route are controlled with satellite navigation technology and the compaction route automatic setup and differential adjustment are carried out according to the instructed construction area planning.

The vibrating roller driving states and poses are inspected by angle encoder and inclination sensor and the compensation control of automatic controlling system is realizes to improve the operation accuracy. The vibrating roller display controller is also developed to setup the compaction parameter and realize the real-time display of working area, environment, construction parameter and driving states. The automatic barrier avoidance is realized with ultrasonic environmental perception system. And the low-frequency wireless remote control emergency device is also developed to further improve the reliability of vibrating roller emergency brake.

The first batch of 5 self-driving vibrating rollers has been successfully applied in Changheba dam construction. The total operation time is more than 5000h. In quality controlling, it avoids compaction missing and lack of compaction, the line deviation within ±10cm and speed deviation 0.1km/h. and it efficiently control over-compaction to ensure the compaction qualified at one time (average value about 97.1%). In construction efficiency, the efficiency is about 10.6% higher than manned operation construction, the intermittent time is shortened and the working time is lengthened about 20%. In safety risk controlling, the anthropogenic influence and night construction safety risk are decreased. In labor protection, the damage of vibrating environment to the human body can be efficiently reduced, as well as the waste of human resources.

(5) Automatic Dam Filling Material Watering System

The intelligent watering system attained the national patent is applied for material watering in the transportation trucks with the dam filling material weighing system. It can efficiently guarantee the watering volume and realize automatic controlling. This system is simple to be operated, safe and reliable, and economic. Through the inspection on on-board wireless radio frequency card auto-identifying pump system, the dam filling material weight can be measured and the suitable watering volume can be calculated. The water switch is controlled through liquid flow sensor and electromagnetic valve, so as to realize the intelligent watering. The quantity of vehicle monitored at the peak in Changeheba project reaches 272, however, the system can still efficiently guarantee the watering volume and the automatic controlling.

3.5 New Quality Inspection and Controlling Method Based on Information Technology

(1) On-board Mobile Laboratory and Gravel Soil Moisture Content Rapid Detection Technology

The large-scale infrared microwave equipment is developed to rapidly dry the gravel soil under the condition that the structure of soil are not damaged, which greatly shortens the moisture content inspection time. The on-board mobile laboratory made up of infrared microwave equipment, high-accuracy flow meter and other measuring and calculating devices is also developed, to shorten the dry density inspection time by about 7h and to improve the test accuracy.

Based on a plenty of test data, it is confirmed that the gravel saturated surface moisture content of dry weight is relatively fixed. The alternative method for measurement of the moisture content is hereby presented. It is that the moisture content of gravel soil core wall material can be rapidly obtained through the measurement of fine material moisture content and weighted calculation. And the inspection time is shortened by 6-8h than the traditional method and the efficiency is quadrupled than before.

(2) Rock Fill Dam Filling Compaction Density Quality Inspection Technology Based on Three-dimensional Laser Scan

The principle of rock fill dam filling density inspection based on three-dimensional laser scan is to solve the point cloud registration problem with the improved ICP iteration method, which improves the accuracy of ICP iteration and iteration efficiency. The accuracy is increased by 10%-20% and the time is shortened to 10min. The ground Delaunay triangulation irregular net is applied for modeling and the grid is closest to the real surface relief situation. The raster test within compaction area can help to carry out the quality inspection on any filling area, to mark the unqualified area and feed back to monitoring center for timely supplementary compaction.

(3) Image Screening Grading Inspection Technology

For the great difficulty in rock fill dam material grading inspection, low efficiency and big error, based on the advanced nondestructive testing theory, by means of integrating the digital image processing technology into dam filling material grading inspection and combining with artificial intelligence and big data, a whole set of convenient, rapid and accurate dam filling material grading inspection technology is developed. Based on the characteristics of particle fractal scale, by the standard of operation feasibility, efficiency and accuracy of image processing technology, the dam filling material digital image processing technology, on the platform of MATLAB and combing with wavelet de-noising, contrast enhancement and Ostu threshold segmentation, is explored. The grading distribution characteristics of dam filling material is described through particle size distribution mathematical model and reflected by characteristic parameter in the model, which realizes the multi-dimensional description of material grading. Based on the big data statistics, the large scale inspection is carried out by means of stacking numerous unit small scales. Meanwhile, the dam filling material micron-scale particle inspection is also implemented indirectly. The workload is reduced and the technical operability is improved. Based on a series of artificial intelligent algorithm, the error is avoided *Roundaboutly* and the inspection accuracy is guaranteed. In addition, based on the certain software platform, the particle intelligent identification system is developed, which further simplifies the operation and realizes the routinization and automation of grading inspection.

(4) On-board Compaction Quality Test Method Based on Foundation Counterforce Test

Based on the completely researching on available international index system and the principle and mechanism of foundation counterforce test, combining with the signal analysis method, the real time test index is determined. And also the availability of expressing rock fill dam coarse aggregate normal compaction test parameters (dry density, relative density, porosity, etc.) by peak factor CF value is verified. The multiple regression model of CF to coarse aggregate and compaction parameter has also been built. With comparison of regression model accuracy, it is found that prediction model error of CF index is small and it is more scientific and rational.

(5) Application of GPS Real-time Compaction Monitoring System

The digital dam monitoring system is applied in Changheba dam construction. By means of installing the high accuracy GPS mobile terminal installed on compaction equipment and handling and transferring compaction information through base station, the compaction process can be real-time monitored through site control room. GPS digital monitoring system can completely real-time monitor each item of compaction parameter (including compaction frequency, speed, exciting force, compaction thickness, etc.), which can efficiently avoid compaction missing and lack of compaction. The compaction thickness can be strictly controlled and the process can be controlled.

(6) Development of Information Management Platform Based on Wireless Microwave Transmission

Through the wireless transmission network via wireless microwave technique as data transmission link, the comprehensive digital information management center is established. Based on the related monitoring information from each working face, transportation, flood prevention and dangerous mountains real-time collected by wireless microwave transmission technique, the systems for dam filling material weighing measuring monitoring, on-board refueling information monitoring, real-time compaction monitoring, mixing information monitoring, side slope dangerous rock monitoring and flood monitoring can be centralized managed at the management center. The construction information management platform with mobile tablet and PC terminal to adapt to the fast pace of construction is established, including the construction schedule management system with progress curve and survey charts real-time counter-counting filling volume with truck scale weighing data, quality management system for test and inspection data statistics, curve reflecting data fluctuation, acceptance evaluation of filling thickness and quality, material management system for fuel consumption and equipment quantity statistics, safety management system for speeding vehicle catching, flood protection and dangerous rock monitoring, and the mobile tablet office management system for basic data recording, such as construction log, site photos, measures and tests, etc., and it completely realizes the dynamic intelligent management of quality, safety, schedule, material, documents and measurement, greatly shortens the management route and improves the management efficiency.

3.6 Green Construction Technique

(1) Technique of Dam Filling Material Exploitation Blasting with Mix-load Explosives

For the large-scaled quarry exploitation, the application of mix-load explosives blasting technique has the advantages of complete coupling charging, high utilization of blast-holes, well grading controlling and high efficient charging, etc. The reliable parameters meeting the requirement of dam filling material grading and anti-seepage measures are obtained and

made based on a plenty of blasting tests. The comparison analysis of two kinds of blasting is as follows, the proportion of oversize rocks reduced by 0.5%, utilization ratio of semi-finished transition materials increased by 8%-10%, charging efficiency reaching 240kg/min and increased by 40%, and the labor saved by 50%.

(2) Application of LNG Environmental Protection Vehicle

The liquefied natural gas is the putative cleanest fuel on the earth. In order to reduce the security risk caused by the smoke and dust produced in Changheba project long tunnel transportation, to decrease the difficulties of long tunnel ventilation and smoke discharging, to save energy and secure the energy supply, and to avoid the effect of diesel shortage on construction transportation schedule, dozens of LNG dump trucks are introduced in this project as the Jiangju rock transportation vehicles and the corresponding refueling system is also completed, which helps to save about 20% fuel cost and brings significant economic and social benefits.

(3) Box-type Bearing Plate Cross-Core Wall Technique

Based on the core wall soil material static and dynamic nonlinear characteristics, elastic-plastic theory and finite element method, the core wall stress deformation distribution regularities and range of influence of different cross-core wall roads under the force of traffic vehicle are revealed. The core wall shearing strength analysis is also carried out, which provides the theoretical basis for cross-core wall road types. By means of systematical theoretical analysis and site tests, the effect mode of vehicle load to the soil mass in the course of driving is found out, the rational cross-core wall road scheme and operation parameters are determined and dismountable box-type bearing plate crow-core wall technology is developed, which homogenizes the vehicle load and efficiently controls the impact on core wall soil material. Under the condition of 60t loading vehicle passing, the maximum additional pressure on the surface in pressure reduction scheme is 69.2kPa, 9.5% of wheel pressure value. The application of cross-core wall technology greatly promotes the material source balance and optimization, avoid long distance transportation and has gained a good effect on energy conservation and emission reduction.

Meanwhile, through soil material modification research, the borrow area is rationally arranged and exploited and the second borrow area is canceled, which helps to save 765mu cultivated land and to reduce the migration relocation. The self-driving vibrating roller is adopted to avoid the harm of strong vibration on operators. The application of complete mechanical equipment and high efficient construction technology also helps to reduce 330000 liter oil consumption, 831t CO_2 discharging, 1.32t SO_2 discharging, 6.7t NOX discharging and 3t CO discharging. The effect of energy conservation and emission reduction is significant and it efficiently protects the environment and realizes the green construction.

4. CONCLUSION

The application of the new technologies and new techniques in Changheba dam project efficiently guarantees the construction quality. The dam was filled to the crest on 10th September, 2016, which is 4 months ahead of the contract construction period. After 13 times quality inspection carried out by quality monitoring station, it shows that the dam filling is totally under control and the quality is well received by experts. The Changheba dam filling work has been awarded as Excellent Working Face and Quality Demonstration Area for many times. At present the dam seepage controlling and deformation both meet the design requirement and the dam is in good operation condition.

The systematical construction and quality controlling technology developed from the research on Changheba dam construction key technology and engineering practices, the engineering problems in 300m high core wall rock fill dam constructed on thick overburden have been solved and the engineering quality and anti-seepage safety have also been guaranteed. 3 industrial standards are formed, more than 50 national patents are obtained and many national and provincial-level construction methods are also formed. The relevant technologies have been applied in some large-scaled hydropower projects, such as Lianghekou project and Shuangjiangkou project. It brings remarkable economic and social and environmental benefits and has wide application prospect.