Rapid Construction Method of High Gravel-soil Core Wall Rockfill Dam of Changheba Power Station

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1. General

Changheba Power Station is located in Kangding County, Ganzi Tibetan Autonomous Prefecture, Sichuan Province, China. It is the 10th project in the hydropower cascade development of Dadu River basin. It’s a super-huge hydraulic & hydroelectric project with additional performance such as flood control, etc. The barrage is located 2.5km downstream from Jintang River. Main works include gravel-soil core rockfill dam, underground diversion system, and flood discharge system. The project is a large (1) engineering work. The maximum height of gravel-soil core rockfill dam is 240m. The total reservoir capacity is 1,075,000,000m$^3$. The catchment area is 55,880km$^2$. The total installed capacity is $4 \times 265(2600)$ mw and the annual generation capacity is 1.083 billion kwh.

The slopes at both banks of dam are very steep, forming to a V-type valley. The slope next to the river is around 700m high. Angles of left bank slope below EL.1590m and right bank below EL.1660m are both between 60° and 65°. The rock at dam site is Jinning-Chenjiang Period granite and (quartz) diorite. The geologic structure is characterized with minor fault and long joint. From bottom to the top, the overburden of river bed is respectively over-size gravel layer, over-size sand gravel layer with silt (with silt and medium to fine sand in the middle course), and over-size gravel layer. It has multiple layers with partial porosity. The overburden has a great permeability with a thickness of 79.3m. The dam is located at the north of intersection among Xianshui River fracture, Qianning-Kangding fracture, Zheduotang fracture, Shimian fracture, and Longmenshan fracture. The regional basic seismic intensity is 8 degree, while the anti-seismic intensity of the dam is designed to be 9 degree.

The gravel soil fill quantity of Changheba Power Station is around 4.28million m$^3$, and the rock fill quantity is 33million m$^3$. The project is commenced on December 1st, 2010, and is proposed to be ready for generation of the first Unit in May, 2017. The completion date is proposed to be April 30th, 2018. The project embodies four difficulties, i.e. super-high core rockfill dam, deep river bed overburden, high seismic intensity, and steep & narrow valley. There is no completed project of the same size regarding to anti-seepage treatment of dam body and foundation, sedimentation deformation, and anti-seismic safety, which brings challenges to design, construction and operation.

2. Work Design

2.1 Dam Body Structure
The gravel-soil core rockfill dam of Changheba Power Station has a crest elevation of 1697.00m. The max. dam height is 240.0m, and the dam crest length is 502.85m, with its width of 16.0m. Both the grades of upstream and downstream dam slopes are 1:2. The elevation of core wall bottom is 1457.00m, and its bottom width is 125.70m. The elevation of core wall crest is 1696.40m, and the crest width is 6.0m. Both the grades of upstream and downstream wall slopes are 1:0.25. Filter materials is placed at upstream and downstream of core wall. The filter layer at upstream is 8.0m thick. There are totally two filter layers at downstream, with each thickness of 6.0m (total 12.0m). Transition layer is arranged between U/s & D/s filter materials and rockfill materials. The thickness of U/s & D/s transition layers is respectively 20.0m. Please see dam structure in Fig.1, and the typical profile in Fig.2.

![Fig.1 Dam Structure (Unit: m)](image1)

![Fig.2 Typical Dam Profile (Unit: m)](image2)

2.2 Foundation Treatment

Two concrete cut-off walls with 14.0m interval are set in the overburden of river bed at
the bottom of core wall. The U/s cut-off wall is 1.4m thick, while the D/s cut-off wall is 1.2m thick. The max. depth of cut-off wall is around 53.8m. The U/s cut-off wall is connected to core wall with an integrated grouting gallery. The lowest elevation of curtain grouting of cut-off wall is 1290.00m, and the max. depth is around 117.00m. The D/s cut-off wall is connected to core wall with concrete key wall inserting into the core wall for a depth of 15.00m. The lowest elevation of curtain grouting of cut-off wall is 1397.00m, and the max. depth is around 10.00m. Consolidation grouting shall be carried out for overburden layer with thickness less than 5m. High-plastic clay with thickness not less than 3m shall be placed between the foundation grouting gallery and concrete key wall. 3m-thick high-plastic clay shall be placed at the contact surface between core wall and base rocks above EL.1597m at left bank and above EL.1610m at right bank. For the contact surface below those elevations, the placing thickness of high-plastic clay shall be 4m. The sand prism of U/s dam foundation shall be jet grouted with high pressure for around 3000m² in area.

Five curtain grouting adits shall be set respectively at both banks of abutment at elevation 1697.00m, 1640.00m, 1580.00m, 1520.00m, and 1460.00m. The adit axis at each elevation shall be in the same plane. The grouting adit of left bank abutment shall be integrated with the grouting adit of underground power house. The axis of grouting adit of right bank abutment shall be the same as dam axis.

2.3 Aseismic Strengthening

The aseismic design of dam is Grade A. For a 100 years design reference period, the seismic peak acceleration of bedrock beyond 2% probability is 0.359g. For a 100 years calibration reference period, the seismic peak acceleration of bedrock beyond 1% probability is 0.430g. Aseismic strengthening measures include removing sand layers of dam foundation; high-pressure jet to the dam foundation prism; reinforcing the dam slope within 6-50m below dam crest with geogrid; widening dam body, dam slope grade elimination; widening and heightening U/s and D/s dam toe ballast; improving compaction standard of each kind of materials; and reserve additional seismic settlement, etc.

2.4 Material Resources

(1) Borrow Areas

High-plastic clay shall be exploited from Haiziping borrow area at downstream of dam site with 60km distance away. The total exploitation volume is 221,000m³. After exploitation, all materials are stocked at the temporary stockpiles and then transported to the workface.

Materials used for gravel-soil core wall below EL.1585m are exploited from Tangba borrow area at the left bank with 22km distance away from the dam. Materials used for gravel-soil core wall above that elevation is exploited from Xinliantu borrow area with 23km distance away. The total exploitation volume is 4,280,000m³.

(2) Filter Materials Producing Plant
Upstream filter material No.3, downstream filter material No.1 and No.2, core wall foundation filter material (including filter material No.1 and No.2), and downstream dam foundation filter material No.4 are all mixed and produced through the aggregate processing system which is located at Mozigou of Dadu River, around 6km away from downstream of dam site. The aggregate processing system is mainly used for producing dam filter materials and concrete aggregate, with a processing capacity of 1000t/hour. The raw materials are come from Jiangzui quarrt and Mozigou borrow area. The total quantity of filter material is 1,660,000 m³.

(3) Quarry

The rockfill materials, transition materials, and ballast are all exploited from Xiangshuigou quarry at upstream of dam site with 3.5km distance away, and Jiangzui quarry at downstream of dam with 6km distance away. The Jintang Hekou quarry is used for spare. The total exploitation quantity is 33,000,000 m³, in which 2,880,000 m³ is used as transition materials.

2.5 Fill Materials Standard

(1) High-plastic Clay and Gravel Soil

High-plastic clay is come from Yeba stockpiles exploited from Haiziping borrow area. The gravel materials exploited from Tangba borrow area is screened without any over-size gravel, and then mixed and adjusted with moisture content. Then it is transported to the workface. Please see the control standard of high-plastic clay and gravel in Table-1.

### Table-1 Control Standard of High-plastic Clay and Gravel

<table>
<thead>
<tr>
<th>Soil Control Index</th>
<th>High-plastic Clay</th>
<th>Gravel Soil</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-soluble salt content</td>
<td>≤1.5%</td>
<td>&lt;3</td>
<td></td>
</tr>
<tr>
<td>Organic matter content</td>
<td>≤1.0%</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>Max. particle (mm)</td>
<td>&lt;5</td>
<td>≤150 and 2/3 h</td>
<td>h=placing thickness</td>
</tr>
<tr>
<td>Over-size particle content (%)</td>
<td>≤5</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Particle content (%)</td>
<td>&gt;5mm</td>
<td>&lt;50</td>
<td>continuously graded</td>
</tr>
<tr>
<td>(&lt;0.075mm)</td>
<td>--</td>
<td>&gt;8</td>
<td></td>
</tr>
<tr>
<td>Clay content (%)</td>
<td>&lt;0.005mm</td>
<td>&gt;25</td>
<td>--</td>
</tr>
<tr>
<td>Plasticity index</td>
<td>&gt;15</td>
<td>10~20</td>
<td></td>
</tr>
<tr>
<td>Permeability coefficient (10⁻⁶cm/s)</td>
<td>1.0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Seepage gradient</td>
<td>&gt;12</td>
<td>&gt;5</td>
<td></td>
</tr>
<tr>
<td>Max. dry density (g/cm³)</td>
<td>around 1.69</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Compaction dry density (g/cm³)</td>
<td>&lt; 5mm fine material</td>
<td>--</td>
<td>&gt;1.82</td>
</tr>
<tr>
<td>P₅ content 30%</td>
<td>--</td>
<td>&gt;2.07</td>
<td></td>
</tr>
<tr>
<td>P₅ content 40%</td>
<td>--</td>
<td>&gt;2.10</td>
<td></td>
</tr>
<tr>
<td>Control Index</td>
<td>Filter No.1</td>
<td>Filter No.2</td>
<td>Filter No.3</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Saturated compressive strength (mpa)</td>
<td>&gt;45</td>
<td>&gt;45</td>
<td>&gt;45</td>
</tr>
<tr>
<td>Max. grain size (mm)</td>
<td>≤20</td>
<td>≤80</td>
<td>≤40</td>
</tr>
<tr>
<td>Characteristic grain size (mm) D15</td>
<td>0.15 0.50</td>
<td>1.40 5.00</td>
<td>0.25 0.75</td>
</tr>
<tr>
<td>Characteristic grain size (mm) D85</td>
<td>2.80 7.80</td>
<td>15.00 46.00</td>
<td>8.00 19.00</td>
</tr>
<tr>
<td>Particle content (%)</td>
<td>&lt;5mm</td>
<td>&lt;5mm</td>
<td>&lt;5mm</td>
</tr>
<tr>
<td>&lt;0.075mm</td>
<td>&lt;5</td>
<td>&lt;2</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Permeability coefficient (10⁻³cm/s)</td>
<td>≥1.0</td>
<td>≥10.0</td>
<td>≥2.0</td>
</tr>
<tr>
<td>Compaction dry density (g/cm³)</td>
<td>≥2.08</td>
<td>≥2.14</td>
<td>≥2.20</td>
</tr>
<tr>
<td>Relative compaction density</td>
<td>≥0.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(3) Transition Materials and Rockfill Materials

Transition materials shall be exploited from quarries. Weak, sheet, needle-shaped rocks shall be avoided. Rocks shall be weather resistant and hardly dissolve in water. The rockfill materials shall be continuously graded. The maximum and minimum side ratio shall be not more than 4. Please see the control standard in Table-3.

Table-3 Control Standard of Transition and Rockfill Materials
Control Index | Transition Materials | Rockfill Materials | Note
---|---|---|---
Saturated compressive strength ($\sigma_{cu}$)  | $>45$ | $>45$ |  
Softening coefficient | $>8$ |  
Frost thawing loss ratio (%) | $<1$ |  
Max. grain size (mm) | $\leq 400$ | $\leq 900$ |  
Max. and min. side ratio | $\leq 4$ |  
Characteristic particle size (mm) | 200 | 29 |  
0.075mm particle content (%) | $\leq 3$ | $\leq 3$ |  
5mm particle content (%) | $4~17$, $\geq 10$ | $\leq 20\%$ |  
Permeability coefficient after compaction ($10^{-2}$ cm/s) | 5 | 10 |  
Relative density | $\geq 0.9$ |  
Porosity % | $\leq 20$ | $\leq 21$ |  
Compaction dry density ($g/cm^3$) | $\geq 2.33$ | $\geq 2.22$ |  

2.6 Fill Parameters

Based upon rolling test on all fill materials, the decided fill parameters are as following table.

<table>
<thead>
<tr>
<th>Material</th>
<th>Placing Thickness (cm)</th>
<th>Placing Method</th>
<th>Rolling Machine (self – propelled)</th>
<th>Rolling Speed (km/h)</th>
<th>Rolling Passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfill materials</td>
<td>100</td>
<td>Advancing Method</td>
<td>26t smooth wheel roller</td>
<td>2.7±0.2</td>
<td>Static 2 + Vibration 8</td>
</tr>
<tr>
<td>Gravel soil</td>
<td>30</td>
<td>Advancing Method</td>
<td>26t padfoot roller</td>
<td>2.5±0.2</td>
<td>Static 2 + Vibration 12</td>
</tr>
<tr>
<td>Filter materials</td>
<td>30</td>
<td>Backward Method</td>
<td>26t smooth wheel roller</td>
<td>2.7±0.2</td>
<td>Static 2 + Vibration 8</td>
</tr>
<tr>
<td>Transition material</td>
<td>50</td>
<td>Backward Method</td>
<td>26t smooth wheel roller</td>
<td>2.7±0.2</td>
<td>Static 2 + Vibration 8</td>
</tr>
<tr>
<td>High-plastic clay</td>
<td>100</td>
<td>Advancing Method</td>
<td>26t smooth wheel roller</td>
<td>2.5±0.2</td>
<td>Static 2 + Vibration 8</td>
</tr>
</tbody>
</table>

3 Construction Technologies

3.1 Construction of Anti-seepage Coating and Deformation Transition Zone for Foundation Gallery and key-wall Concrete

Two concrete anti-seepage walls with 14.0m intervals shall be deployed at the deep overburden layer of lower riverbed of Changheba core wall. The thickness of the U/S wall is 1.4m. Concrete foundation gallery shall be used to connect the U/S wall and core wall. The thickness of the D/S wall is 1.2m. Concrete key-wall plug-in connection structure shall be used to connect the D/S wall and core wall. The thickness of
key-wall which plugs into the core wall shall be 15m. The high plastic clay with the thickness not less than 3m shall be placed around the concrete foundation grouting gallery and concrete key-wall. Due to the gallery on the overburden layer foundation and key-wall is at the bottom of dam foundation. The force situations of structure are very complex. Three-dimensional nonlinear finite element calculation indicates that because the transverse joint is not deployed along the dam axis of the riverbed section, and the normal stress values of the gallery is vertical to the river which appears at a quarter of full cross location on the left and right bank is big, the tensile stress of the gallery floor along the river is big which will easily cause the longitudinal crack of the floor (during recent years, the crack in different degree exists in building high core wall foundation gallery concrete during the dam filling process and water storage operation period). In order to avoid the cracks may appear in gallery, key-wall under the overburden layer foundation differential settlement, temperature changes during construction period, load changes during construction period, the stress changes of operation condition and the seismic stress condition, these cracks may result in water course which will damage the core wall. Therefore, the cracks need to be sealed by chemical grouting treatment method. Integral structure without open seam shall be adopted for dam foundation gallery. The construction shall be carried out by continuous placement method. The concrete strength and grade is high. Concrete by pumping method shall consume a large amount of cement. The hydration heat is big. Shallow crack is found in gallery during construction, interpenetrate cracks appeared in newly-cast concrete during Lushan earthquake on 20th April. After detailed survey analysis, surface seal and chemical grouting treatment shall be adopted for interpenetrate cracks. For the choice of sealing material, the requirement is that the cracks of the gallery under adverse conditions can suffer 230 m water head positive pressure, and the slurry can be stopped during chemical grouting processing. Method such as outsourcing modified asphalt waterproofing materials, the Perth waterproof base material is normally used for sealing in other similar gallery treatment works. Although the waterproof roll material can meet the high water head seepage control requirements, the adhesion stress on concrete face is not strong which could not ensure the quality of the connection part and the chemical grouting confining pressure requirement. The Perth waterproof base material is a brittle material which can't meet the dam deformation requirements of the deep overburden layer. Finally, the Spray Polyurea Elastomer is selected to be sprayed on the surface of the gallery, and the special asphalt impervious membrane is selected to be deployed on the surface of the key-wall to eliminate possible potential safety hazard in the future.

Spray Polyurea Elastomer is a newly coating structure waterproof technology with high strength, high permeability, ageing resistance, corrosion resistance, good thermal stability, flexible, impact resistance, strong adhesion with concrete, jointless, insoluble, pollution-free, green coating merits etc. Spray Polyurea Elastomer can effectively simplify the structure of waterproof layers and reduce the thickness, with simple process, convenient construction, a high construction efficiency merit, which shows incomparable superiority of the traditional waterproof protection technology. Polyurea CW730 anti-seepage coating with 4mm thickness shall be used for high
water head water tightness test and contact permeability test, when the crack width is 5mm, non-leakage appears under 300m water head. The coefficient of permeability of high plasticity clay contact area shall be not more than $3 \times 10^{-7}$ cm/s, and the contact surface seepage failure grade shall be not less than 13. The main physical properties is: solid content 100%; hardness A30~D50 (Hardness JIS); breaking elongation 400%. The 28d tensile strength, tear strength, and bond strength is 10 mpa, 30 mpa, 3.5mpa respectively. Gelation time is 5s~30s. Concrete base surface polishing treatment, epoxy mortar defect repair, prime paint spraying and spray polyurea coatings process shall be used for construction. The spraying thickness is 4mm. The spraying area is 3150 m². The seepage control method is a great innovation in the domestic hydropower station construction.

Special asphalt impervious membrane (CF - 16 hydraulic modified asphalt impervious coils) is with anti-aging, flow resistance, convenient construction, and fast speed advantages, which is usually used for concrete face crack repairing. Specifications performance is: thickness 5mm, width 1.05m, length 15m. The density is greater than 1.3g/cm³. The elongation percentage is greater than 20%. The permeability coefficient is less than $1 \times 10^{-9}$. For tensile strength, the longitudinal strength is greater than 500N/mm, and transverse strength is greater than 400N/mm. The environmental temperature is 90℃ and non-flow appears under grade 1:0. No blisters, flowing, crack and wrinkling phenomena appears under 200 times freezing and thawing cycles. The material is flexible, curved without brittle below -5℃. The method as FIRST ASPHALT CEMENT, THEN IMPERMEABLE MEMBRANE shall be improved during paving period. The paving of asphalt cement shall be carried out together with the paving of impermeable membrane, that is to say, the seepage control coiled material shall be cut by sizing. The melting asphalt cement shall be paved by fix quantify. Concrete surface shall be cleaned and grinded, and cold primer oil shall be brushed. Impermeable membrane shall be paved at fixed location to ensure the quality of the paved asphalt membrane. Mobile trolley and movable scaffolding can be used when the wall is high and long.

In order to improve the work condition of the cut-off wall and reduce the major principal stress, high plastic clay filling transition zone shall be used around the concrete gallery and key-wall. The paving thickness shall be 14m. In order to prevent contact scouring between high plastic clay and dam foundation, the geomembrane shall be paved within 30m at the U/S of the key-wall. Gap shall be reserved for feedstock at the key-wall concrete. Advance method shall be used for high plastic clay material paving. The paving thickness shall be 30cm, and 18t smooth drum vibratory roller shall be used to vibrate 2 times in static rolling method and 6 times in vibration grinding method. Series of test and research shall be carried out on filling compaction degree and moisture content of the high plastic clay, critical compaction degree concept is promoted, and the suggested compaction degree shall be controlled in 98% or more. Principle of wet without dry shall be used for core wall contact clay filling in order to increase the plasticity and viscosity of contact clay of the core wall, so as to reduce the permeability and dam settlement after reservoir impoundment, and
improve the contact erosion resistance.

3.2 Gravel Soil Mix Adjustment Technology

The material for Changheba Core wall is mainly from Tangba borrow area. The Tangba borrow area is formed by glacial, diluvial and clinosol terrains. The slope range is between 20° and 30° and the elevation range is between 2050m-2260m. The total area is 575000 m².

After the re-investigation, the borrow area can be divided into glacial area and diluvial area. Refer to the following table-4 for the physical-mechanical index of the materials in different areas.

Table-4 Physical-mechanical Index of Materials in different areas

<table>
<thead>
<tr>
<th>Physical-mechanical index</th>
<th>Glacial area</th>
<th>Diluvial area</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural density (g/cm³)</td>
<td>2.06</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>Dry density (g/cm³)</td>
<td>1.86</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>Natural moisture content (%)</td>
<td>10.7</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Void ratio</td>
<td>0.45</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Plasticity index</td>
<td>14.3</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Clay content (%)</td>
<td>Range 4~18</td>
<td>2~12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 9.86</td>
<td>6.31</td>
<td></td>
</tr>
<tr>
<td>&lt;5mm Particle content (%)</td>
<td>Range 35.0~74.0</td>
<td>25~55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 53.17</td>
<td>37.15</td>
<td></td>
</tr>
<tr>
<td>0.075mm Particle content (%)</td>
<td>Range 19.0~45.0</td>
<td>6~33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 28.6</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>Non-uniform coefficient</td>
<td>1800</td>
<td>2473</td>
<td></td>
</tr>
<tr>
<td>Curvature coefficient</td>
<td>0.2</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Maximum compaction dry density (g/cm³)</td>
<td>2.194</td>
<td>2000kJ/m³ Compaction</td>
<td></td>
</tr>
<tr>
<td>Optimum moisture content (%)</td>
<td>7.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeability coefficient</td>
<td>0.86~1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness of available layer (m)</td>
<td>Range 7~16</td>
<td>2~7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average 10.7</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>Area (m²)</td>
<td>45.7</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>Reserves (m³)</td>
<td>450</td>
<td>64.4</td>
<td></td>
</tr>
</tbody>
</table>

Diluvial area is located at the downstream side of borrow area. For the big change of physical and mechanical characteristics, large content of $P_5$, coarse grain size and less available materials in this area, it goes against concentrated material excavation and it is not worth exploitation.

The glacial area is located at upstream side of borrow area, where the soil material has good anti-seepage and anti-permeability performance and high physical strength,
and the quality meets the standard requirements. However, for the different formation causes of the borrow area, inhomogeneous distribution of the soil material, mix of available and unusable materials, physical-mechanical characteristic differences, large variation range of material grading, inhomogeneous content of oversize rocks, inhomogeneous distribution of $P_5$ (26%-65%) and 70% moisture content (higher than the optimum moisture content), it presents the features of randomness and dispersion of the materials distributed at upper and lower layers as well as at the horizontal and vertical direction. The material source for gravel-earth core wall is uneven distributed, which is the key factor to affect the high gravel-earth core wall construction quality and differential settlement.

As per the designed $P_5$ (30%-50%) index, the borrow areas can be divided into the following types, coarse material area ($P_5 > 50$%), qualified material area ($P_5$ 30%-50%), fine material area ($P_5 < 30$%) and spoil material area. According to the contour of $P_5$ content, the exploratory points on the borrow area plan and profile plan shall be connected into the smooth lines to form the contour map of different $P_5$ indexes. The grade of material in the area divided by the same contour or by the contour and boundary line shall be the same. By the detailed division of the borrow area, Tangba borrow areas can be divided into 4 areas (Area I, II, III, IV), which can be also divided into sub-regions as per the depth (ground, 0-6m underground, below 6m underground), including 4 coarse material concentrated areas and 3 fine material concentrated areas. The qualified material can be directly transported to the dam and the coarse and fine materials shall be mixed before transportation, so as to meet the design standard of high rock-fill dam. Refer to the Fig. – 3 for Tangba borrow area geological plan. Refer to the Fig. – 4 for Tangba borrow area different $P_5$ content regions.

Fig.3 – Tangba Borrow Area Geological Plan
The stick-type vibration sieving machine shall be used to screen out the oversize rock and the gravel in a certain grade. 5 2500ton/h screening systems shall be installed to screen out the oversize rocks with diameter more than 150mm. The coarse and fine materials shall be mixed and based on the detected P₅ content in coarse and fine materials, content of particles with diameter less than 5mm and the content of 0.075mm diameter particle content, the mix proportion shall be dynamically calculated and converted into volume ratio. The paving layer thickness control method shall be adopted to carry out the material paving in the order of coarse material first and then fine ones. When it is paved 3-4 layers, the materials shall be turned over for 4 times with excavator or bulldozer and loaded after the material is mixed evenly.

For the problem of natural moisture content of most gravel-earth is higher than the optimum moisture content, the tests, such as conventional drying, tedding with four-share mounted plow, and tedding with scarifier, are carried out and finally it is decided to adopt tedding with improved bulldozer scarifier (five-tooth-hook inclined moldboard) to adjust the moisture content.

The distribution of gravel-earth in Tangba borrow area is much complicated and the materials of different particle grades are unevenly distributed with only 1/3 qualified materials. By effective material preparation technology, the different materials are fully used and the quality is also guaranteed.

3.3 Accurate Mixing and Fine Construction of Filter Materials

Filter material layer is the most direct and efficient way to prevent soil stratum seepage failure. Whether the seepage failure of the seepage proof material will happen under the high water head or not to a large extent depends on the protection of the filter material behind the seepage proof material. Except meeting the
requirements of filtering soil, drainage and self-healing of the protected soil after cracking, it shall also be able to adapt the large shear deformation to play an important role of deformation transition.

The aggregate processing system is utilized to produce the filter material of Changheba Power Station. The methods of controlling the opening size of vertical crusher and reducing the stone powder content shall be adopted to adjust the particle size of filter material’s grading, ensure the continuous grading and reduce the content of stone powder, etc. The automatic mixing computer system will be used for making the semi-finished materials to qualified fill materials. The traditional mixing process is changed, which makes the production and mixing of filter materials even uniform, accurate and high efficiency, and which reduces the occupied area. During the stockpiling of filter material, the measures including separately stockpiling, slowing down, mixing & loading, etc are used for ensuring the quality of filter materials.

During the fill construction at filter materials area, the automatic vehicle identification system for different kinds of filter materials and accurate spread process of boundary line between two kinds of filter materials are used for avoiding the mixed loading & unloading of filter materials, approaching the boundary line and cross contamination. And the advantages are accurate spread size of each filter material, saving the levelling equipment, reducing the materials separation, less construction disturbance and high fill efficiency.

3.4 Blasting & Mechanical Crushing Process of Transition Materials

For the transition materials of gavel-earth core rockfill dam at Changheba, the quantity of fine materials with less than 5mm is generally larger. So the research works about directly exploiting the transition materials through the blasting method have been carried out. By means of adjusting the blasting parameters, such as hole diameter, hole depth, hole spacing, explosive quantity, detonation method, etc., the unit explosive consumption is increased from 0.75kg/m$^3$ to 2.5 kg/m$^3$, the drilling diameter is reduced from 120mm to 90mm, the bench height is reduced from 15m to 10m, and the hole mesh area is reduced from 11.7m$^2$ to 1.3 m$^2$. The comparison tests of explosive type have been made to the 2# rock, emulsion explosive and ANFO. The tests result shows that for directly exploiting the transition materials through the blasting method at granite quarry, the quantity of fine materials is generally lower; one of the coarse materials is generally larger, the indicators and grading curve cannot meet the design requirements. Therefore, the combined filter materials production process of blasting and mixing has been adopted. The unit explosive consumption of 1.85 kg/m$^3$ is used for the blasting of coarse materials and some fine materials from aggregate production are mixed into the coarse materials. After the fine materials and coarse materials being staggered spread, the mixed materials are vertically excavated and transported to the dam.

After the dam being filled to El.1536m, the grading design of core wall’s transition materials will be adjusted. According to the results of many blasting tests, when the unit explosive consumption is 2.2 kg/m$^3$, the transition materials can meet the grading
requirements after the removal of over-size rock and graded discontinuity materials. Besides the utilization ratio is 73.5% and the economic performance is poor. At present, the research works about the deficiency of fine materials from the production of overall mobile crushing system are being carried out.

3.5 Intelligent Water-adding System and Transportation Across Core Wall

Rolling with water is the key measure to improve the compaction effect of rockfill materials. By adding water, masonry will be soaked; fine material will be softened; compressive strength will be decreased; frictional force and apparent cohesion of particle will be decreased; meanwhile, angular and weak part of particle will be softened and broke to improve compaction density and efficiency and reduce the afterward settlement which happened after completion of works. The watering of rockfill materials shall be carried out on the workface and outside of it. Intelligent adding water system shall be adopted to add water before rockfill material entering the filling surface, the weight of dam materials shall be recognized by detecting on-board RFID of transportation vehicles, the adding water quantity shall be calculated as preset proportion, and liquid flow sensor and solenoid-controlled valve shall be adopted to control add water flow and time to realize intelligent adding water.

In order to guarantee the quality of high gavel-earth core rockfill dam core wall, heavy trucks shall not be allowed to pass through the core wall as requirements of design. During construction, the unbalanced strength of up and down stream rockfill quarry, the economical of different load distance, obstructed ventilation exhaust of truck in long tunnel and transportation technology for heavy truck passing through core wall shall be resolved immediately. The stress and strain effect of three measures of passing through core wall such as paving gavel-earth padding singly, padding with paved steel plate, and paving land box pier shall be researched and compared. The paving land box pier principal shall be adopted to design and manufacture articulated trestle to resolve the transportation technical problems of heavy trucks passing through core wall. It guarantees that balance of material source; rockfill material transporting to dam; general environment benefit, economy benefit improvement; and construction progress acceleration. After adjusting the plan, Xiangshuigou quarry which is 6.3km distance away will provide 64% of the total (45% in original plan) rockfill material, and Jiangju quarry will provide 36% (55% in original plan) of the total rockfill material.

3.6 Digital Control of Dam and Digital Construction

In order to guarantee filling quality of high gavel-earth core rockfill dam, 3S technology (GPS, GIS, and RS), high-volume database management technology, network technology, multi-media and virtual reality (VR) technology etc. shall be adopted to establish integrated digital information platform and 3D virtual model to dynamically collect and digitally process the information that is involved in construction quality and progress during design, construction and operation of Changheba Power Station. Sharing all kinds of project information and data, and dynamic update and maintenance of integrated information will be realized in the whole product life cycle of
project, which provides information application and support platform for project
decision making and management, dam safety operation and health diagnosis. Online
real time monitoring and feedback control for construction quality (material excavation
and transportation, core wall material mixing, material placing, adding water for rockfill
material, dam surface construction, foundation grouting operation) and progress of
core rockfill dam will be realized. Integration management for construction parameter,
quality test and progress information etc. will be realized, which provides information
application and support platform to construction quality and progress control, and dam
safety operation and health diagnosis. It also has the function that employer and
consultant could participate in construction quality, progress and precision
management of project. Through system automatic monitoring, construction quality
and progress shall be controlled effectively, and the fast response on dam
construction quality and progress will be realized. The management level of
Changheba Power Station will be improved and the innovative management of project
construction will be realized to provide the strong technical guarantee for building an
excellent project. It also provides data information platform for the completion
acceptance, safety appraisal and future operation management.

Integrated dam digital information system consists of real time monitoring & analyzing
system for quarry exploitation, core wall material mixing and transporting to dam;
automatic monitoring and feedback control system of rockfill dam compaction quality;
and rockfill dam construction information collection and analysis system based on
PDA etc. The pavement equipment, compaction equipment and dam material
transportation vehicles shall be positioned precisely (precision reaches cm, m,
respectively) by using GPS, wireless network transmission technology and computer
real-time analysis technology, and establishing digital control station, network relay
station, random GPS terminal network. The compaction parameters such as
compaction thickness, compaction track, times, driving speed, excitation force
condition and the information of offloading material that is transported to dam by
vehicles shall be online real time monitored and analyzed. When the compaction
condition is over the preset alert limits, or transportation vehicles occurring offloading
mistakes, the monitoring system will report to site Engineer and construction
personnel to handle with the situation timely.

Digital construction will be realized by engineering machine combined with earth
moving machinery control products and dam surface mechanical control products
which is integrated with laser aiming, sonar control, angle transducer, GNSS, total
station etc. Traditional machinery construction will be changed through digital
construction to reach the effect that machine guides the operators to construct. The
functions of machinery control products consist of slope trimming, trench excavation,
and complex modeling which is carried out by excavator during excavation; layer
thickness, elevation control, slope control works which is carried out by bulldozer
during pavement; layer thickness, elevation control, slope control works which is
carried out by grader during leveling; track monitoring, times monitoring, compaction
thickness quality inspection which is carried out by vibration compaction equipment
Unmanned driving technology of vibration compaction equipment and remote control technology of pavement and leveling equipment is another innovation on digital construction, which will make great progress for construction technology.

### 3.7 Rapid Quality Test Technology

Since requirements on deformation and anti-seepage of super-high core wall is very strict, and the constitution and distribution of gravel soil particles is quite uneven, special experimental study shall be done for gavel-soil core wall material inspection method and evaluation criterion. It is proposed that water content of gravel should be replaced by saturated surface dry water content of gravel which will be used for calculating the weight of gravel in dry density of earth material. This accelerates test speed. It is also proposed that double control method (fine aggregate dominates first and fully-graded aggregate supplements) will be adopted for core wall compaction site inspection and control. Three points compacted method is adopted in site rapid test, and software of three points compacted method has been developed to facilitate the site rapid test. The 800 mm diameter ultra-large electric compaction apparatus which is the largest in China has been developed to review the compaction degree of fully-graded aggregate. Large microwave drying equipment which could dry 50kg material once has been developed. Movable laboratory equipped with large microwave drying equipment, vehicle-mounted controller, high precision metering tank used for water-filling method, and work platform equipped with sufficient experiment and office instruments is invented to reduce test time and facilitate the rapid test. Based on lots of indoor experiment and site compaction test for gravel soil from Tangba quarry of Changheba Power Station, the site quality testing methods and evaluation standards of gave soil materials has been put forward.

### 3.8 Other Construction Technologies

Lots of practical and innovative technical studies such as quick construction of deep cut-off wall high earth-rock cofferdam, concrete tracked hydraulic sliding mode system of high steep slope, support suspension shelving system of high steep slope without berm, copper water stop molding machine, copper water hot melt welding technology, mud mechanical spraying construction technology etc. have been researched and applied in the engineering construction. At present, deformation compatibility study of 300m level gavel-earth core wall dam, production scheduling assistant decision system, damming machinery optimization allocation system, LNG environment friendly vehicle transportation system study etc. are under researching and developing, which brings higher technological content to the 300m level earth-rock dam. Modernization of earth rock dam will be realized through industrialization and informatization.

Changheba gavel-earth core wall dam has been constructed to the elevation of 1557, which has risen 100m (exceeds 1/3 of total dam height) accumulatively. 2060 thousand m³gavel-earth and 1.247 million rockfill have been placed accumulatively.
The schedule, quality and safety of dam are under control. And project department strides forward towards the goal of first unit generating on May, 2017.