Leakage problems in dam abutment of Tuokou hydropower station and its solutions

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Abstract. The leakage problems in dam abutment of Tuokou Hydropower Station are first revealed by geological analysis. The complexity of the special geological conditions of the dam abutment is mainly due to the widely distributed large fractures and karst caves. It’s hard to conduct grouting work in such type of geological condition. A new grouting method, upstage with paste slurry packer and pulsating pressure, was presented. Moreover, a series of new grouting materials (pasty clay-cement slurry and stable slurry) were developed to resist the high-speed water rushing in karst aquifers. The leakage problem was finally solved, and the effectiveness of the solution further verified by both monitoring analysis.

1. Introduction
Tuokou hydropower station is located in Hongjiang (Hunan Province, China), and its hydraulic engineering grade is Type (1), Grade 1. The distance from Tuokou to Huaihua is 74 km. The normal storage water level of the reservoir is 250 m. The normal reservoir storage is 1.25×10⁹ m³. The powerhouse with a width of 31.5 m, a length of 171.4 m, and a height of 58.8 m includes four units with an installed production capacity of 830 MW. Its main hydraulic structures include Dongyoushi main dam, Wangmaxi auxiliary dam and Hewan mountain [1]. The layout of the dam and its main hydraulic structures are shown in Figure 1. Hewan mountain has a peculiar geological conditions and serious geological defects. It is covered with deep cretaceous red strata whose thickness is 80m on average. The stratum has strong mechanical and chemical weathering. Mechanical weathering generally that precedes chemical weathering renders the rock mass more permeable and facilitates access for groundwater to large surface areas of rock substance [2]. Furthermore, a large proportion of adglutinates are eroded or there grows dense tiny fracture. Because of active groundwater, rock and soil masses, which are at the bottom of cretaceous red strata, around the boundary of soluble and non-soluble rocks and in the place groundwater changes, are incompact and have a large porosity. What's more, the most major problem is widely distributed corrosion phenomena. The karst caves and fractures also distribute widely so that there are large-scale leakage passages. The above mentioned phenomena will reduce the benefits of hydropower station and be a serious threat to the safety of the dam [3]. Therefore, to guarantee the normal operation of hydropower station, it is necessary to take urgent measures to minimize the leakage in Huwan mountain.
Among the anti-seepage treatments, grouting is an effective and well-known procedure to control underground leakage behaviors [4-6]. Grouting is designed to create a narrow barrier (or curtain) through an area of high permeability. It usually consists of a single row of grout holes which are drilled and grouted to the base of the permeable rock, or to such depths that acceptable hydraulic gradients are achieved [7]. One or more lines of holes is drilled from the cutoff level of the dam into the dam foundation. The cement slurries or chemicals are under pressure and forced into the rock defects, that is joints, fractures, bedding partings and faults [8]. There are many different grouting methods nowadays, such as downstage without packer, downstage with packer, upstage, full depth, full depth circuit. Downstage without packer is one of the preferred methods for high standard grouting, since each stage is drilled and grouted before the next, lower stage, allowing progressive assessment whether the hole has reached the desired closure requirement [9-10]. However, it necessitates a separate set up of the drill for each stage and separate hook-ups of the grout lines. It is, therefore, relatively expensive. Downstage with packer allows use of increased grout pressures for lower stages, since these pressures are not applied from the surface [11]. However, there may be problems with seating and leakage past the packer. Upstage is cheaper in principle than downstage methods since the drill rig is only set up once, but these savings may be offset by the need for more conservative total depths. Full depth does not allow proper assessment of where grout take is occurring or proper monitoring of reduction in Lugeon values with grouting. It is not an acceptable method except for consolidation grout holes. Full depth circuit has the same limitations as full depth grouting, but by injecting the grout into the base of the hole, the possibility of settled grout is lowered [12, 13]. As a consequence, it is urgent need to develop complete sets of grouting technique for the geological conditions of Huwan mountain of Tuokou hydropower station including grouting technology, material, etc.

In this case study, leakage problems in dam abutment of Tuokou hydropower station is first revealed by geological analysis. The complexity of the special geological conditions of the dam abutment is mainly due to the widely distributed large fractures and karst caves. It’s hard to conduct grouting work in such type of geological condition. A new grouting method, upstage with paste slurry packer and pulsating pressure, was presented. Moreover, a series of new grouting materials are developed to resist the high-speed water rushing in karst aquifers.

2. Site Characterization

2.1. Project description
Tuokou hydropower station is located in the middle reach of Yuan River in Western Hunan. The main dam contains water retaining structure and water release structure. It is divided into left bank roller compacted concrete gravity dam, roller compacted concrete overflow dam in riverbed and right bank rockfill dam with clay core. The length of dam is 648.5m. The dam is at an elevation of 253 m, and its height is 82 m. There are nine operable overflow weirs which use flip trajectory bucket in the overflow dam section. The auxiliary dam mainly consists of diversion canal, concrete gravity dam, power house, navigation structure, tailrace system. The length of dam is 344.6 m. The dam is at an elevation of 253 m, and its height is 52 m.
A river bend which has a length of 18 km is located between Hamawan and Tuanyuwan. There is a long and narrow Hewan mountain whose length is 9 km. At the base of water, the width between Hamawan and Tuanyuwan is 3.8 km, the width around Dongyousi dam is 2.0 km, and the width round Liuyuan is 1.5 km. The length of Hewan mountain between main dam and auxiliary dam is 4.5 km.

2.2. Engineering geological characteristics

The Huwan mountain is located in Yuanma basin. Yuanma basin which is formed in the cretaceous period has deposited a set of clastics with thickness more than 2 km. In the late Cretaceous, the earth's crust rises slowly, and the Yuanma basin are eroded. It declines and receives deposits in the early Tertiary period. Nevertheless, in the end of Tertiary period, the earth's crust rises again, rises by 200-270 m. The Yuanma basin turns into land, and is eroded once more. Subsequently, the earth's crust is stable and rises alternately. Six orders terrace appears gradually. The ascensional range weakens by time and becomes hodiernal Yuan river.

The Huwan mountain is structurally located in Tuokou syncline spreading in the north-eastern direction. The stratum is based on dissolvable clasolite forming in Nantuo tillite group of sinian system. Its top is covered with the cretaceous red beds which has huge bedding-thickness mud rock, argillaceous siltstone in the upper and huge bedding-thickness calcareous boulder bed, straticulate mud rock, argillicaceous siltstone in the lower. Carboniferous system and dyas carbonatite are between the two stratum. The stratum near reservoir along the river inclines the dip slope. The level is slow wave. The stratum inclination of Wangjiaoo puerto is North North West (NNW). The angle of dip becomes slow from 65° to 15° when the stratum turns from old stratum to new stratum. The rock stratum included angle in syncline both flanks is 50°~70°. Its synclinal shaft distributes along Hama bay and Yanggu brook. The synclinal shaft rock stratum whose length is 200 to 300m is strongly crumpled in Hama bay. The strata sequence is also destroyed.

Karst mineralization formation is widely distributed in Huwan mountain. It main includes carbonate rock formation of carboniferous system and dyas, dissolvable fragmental rock of cretaceous system. The karst of carbonate rock formation mainly distributed in P2m or upper part of P2q [14]. From the point of the plane, it distributes in the fault distribution zone of F14~F1 and F15~F16 between right bank of Zaohechong and left bank of power house. According to the drilling core sample analysis, there are buried karst caves in the bottom of ZK132, K1-1 and bare karst caves in the Sheguchong. The imestone of maokou formation exposes as a skylight [15], so does the contact zone of K1-1/P2m. Underground water flows along stratum contact surface of maokou formation and cretaceous. Conglomerate layer adglutinates of cretaceous are corroded. The stratum will form solution cave when residual debrises are washed away by intensive underground water. Its distribution height is 250.66m. On the both sides of K2-1 conglomerate layer, it can form karst caves when the layer is cut by valleys and exposed surface. Although its extension is not long, the scale is quite large [16]. The distribution of gouting stratum, fault occurrences, full weathered zone, intensely weathered zone, moderate weathered zone and karst cave in river-bending block is showed in Figure 2. Under the natural state, there are two aquifers in Huwan mountain. One is carbonate reservoir of carboniferous system, the other is mudstone and argillaceous siltstone of cretaceous system. After the reservoir impoundment, the hydraulic gradient is formed between the formation closed the reservoir and back to the reservoirs. Because the groundwater level of the formation closed the reservoir is higher than back to the reservoirs, the rock and soil mass in fault zone of F1~F14, and F15~F16 has a strong permeability. In the one hand, reservoir water outflows reservoir through pore and fracture of stratum. On the other hand, since there are many half-filled karst caves, the reservoir water gradually permeates to the half-filled karst cave. As a continuation of the leakage, filling is taken away step by step and then a larger pipe leakage formed [17].
Figure 2. Cross-section of Huwan mountain.

Through a stereometry and exploration, there are numerous karst caves in layer F1~F14 and F15~F16 of Huwan mountain. However, there has not been found relatively concentrated karst pipe flow. Karst cave is generally in a state of filled and half filled. There is no entrance that free flow turns into undercurrent except the two covered ponor in integration brook near the reservoir. On the side back to the reservoir, it also does not find the export of karst fracture water. Therefore, after the reservoir impoundment, it is hybrid leakage including fracture seepage and tiny pipe seepage in the early days. But as time goes on, some cave filler will be taken away by groundwater, and then the tiny pipe seepage will gradually become bigger. The pore and fracture seepage can be calculated sectionally based on the differences of hydrogeological condition. The rock and soil mass of each segment is assumed homogeneous [18]. The calculation results as shown in the Table 1.

Table 1. Calculation of pores and fracture leakage of Huwan mountain.

| Calculation section | Stratum between right bank of main dam and F14 | Stratum between F14 and right bank of Zaohechong | Stratum between right bank of Zaohechong and baituchong | Stratum between baituchong and left bank of power house |
|---------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------------|-------------------------------------------------------|
| Calculation models  | Confined water—no pressure flow in horizontal homogeneous aquifer | Confined flow in aquifer with varying thickness | Phreatic flow in layered strata of Huwan mountain | Phreatic flow in layered strata of Huwan mountain |
| Average leakage per unit width (m³/d·m) | 2.95 | 0.19 | 0.64~1.85 | 1.66~3.00 |
| Leakage width (m)   | 1045 | 2775 | 880 | 890 |
| Section leakage (m³/d) | 3083 | 520 | 1093 | 1792 |
| Total leakage (m³/d) | 6488 (not include possible pipe seepage) |

The total fracture leakage is 6488 m³/d or 0.075 m³/s. The stratum between right bank of main dam and F14 has the maximum leakage of 3083 m³/d. The stratum between F14 and right bank of Zaohechong has the minimum leakage of 520 m³/d. The stratum between right bank of Zaohechong and left bank of power house has a biggish leakage of 2885 m³/d. Look from the average leakage per unit width, the stratum between right bank of main dam and F14 has the maximum leakage of 2.95 m³/d·m, and the stratum between right bank of Zaohechong and left bank of power house has the leakage from 0.64 to 3.0 m³/d·m. It is equivalent to 0.09% of the Yuan river runoff in drought period. But as time goes on, some cave filler will be taken away by groundwater, and then the tiny pipe seepage will gradually become bigger. The main problem is the problem of seepage stability in initial period, but the amount
of leakage will be the biggest problem latterly. It is a serious threat to the reservoir safety and normal operation. Therefore, there must be seepage prevention.

2.3. Analysis of general grouting
To ensure the normal operation of the Tuokou hydropower station, it is necessary to take urgent measures to deal with the leakage in Huwan mountain. Grouting can create a narrow barrier (or curtain) through an area of high permeability. It also can reduce leakage through the dam foundation, i.e. through the defects and reduce uplift pressures (under concrete gravity dams when used in conjunction with drain holes). It is an effective and well-known procedure to control underground leakage behaviors [19].

In Huwan mountain, soften and loose soil and soil-rock mixture with large porosity, which are easily softened by water, widely distribute in or around covering layer, thick discontinuities, soft clay and Karst caves, etc. The traditional technologies grouting in this stratum can encounter several problems.

2.3.1. Grout take of grouting in red bed is very large. Engineering investment is difficult to control.

The cement grouting experiments conducted in feasibility study stage indicated that the grout take of stages is up to 700 kg/m on average, and individual stages are over 1200 kg/m.

2.3.2. Many technical issues appeares in red bed. Firstly, grouting holes can be collapse and grouting drills are buried easily. Secondly, grouting should be closed sectionally. Thirdly, grouting pressure cannot go up. Finally, the grouting of the power station will have a long construction period.

2.3.3. Anticipative grouting effects can’t be reached. In the cement grouting experiments, grouts ran 100 meters away the earth's surface in a few holes. Even grouted repeatedly, the permeability tested by rate pump-in test didn’t improve obviously. Therefore, the traditional grouting technologies can’t form effective anti-seepage curtain.

3. Concept of new grouting technology
Deep-thickness overburden layer, gravel bed, large fracture and carst cave are widely distributed in Huwan mountain of Tuokou hydropower station. It is essential to improve the efficiency of grouting, control diffusion range effectively, avoid grout leaking and mud spillover and achieve an equable perfusion in full hole in this kind of special formation. Massive aboratory simulation test, prototype test, production test and construction research were carried out. Eventually, a new grouting method, upstage with paste slurry packer and pulsating pressure was presented. It can considerably improve project benefit, reduce construction cost. Moreover, an independent research and development of corresponding new grouting material (clay-cement slurry and stable slurry) was carried out. This series of new grouts can be adjustable, controllable and groutable according to the change of formation. It can be made quickly and have a strong ability to adapt.

The schematic diagram of new grouting technology is showed in Figure 3. Main technical key points are as follows.

3.1. Upstage with paste slurry packer
Grouts are grouted into grouting holes in sequence from lower stage to higher stage. Paste slurry packer is grouted between grout pipe and drill hole wall as a packer to block grouting stages. Paste slurry packer has an important effect that it can block stock outlet three-dimensionally when grouting and ascending grout tubes. Ultimately, the goal of control grouting in situ perfusion is achieved and the uniform in every grouting stage is ensured.

3.2. Pulsating grouting mechanism
Pulsating grouting pump is used to conduct pulse grouting. It can basically eliminate differences of stratal three-dimensional stress. Probabilistic and controllable homogeneous filling, permeation and compacting splitting grouting of full hole comes true [20, 21]. What’s more, it also can avoid invalid perfusion and reduce waste material.
3.3. A series of modified clay-cement slurry

Clay-cement paste slurry and stable slurry were developed technically for anti-seepage grouting of watery rock and soil strata in Huwan mountain of Tuokou hydropower station. Comparing with the ordinary cement slurry, the new material owns many advantages, such as a larger initial viscosity, an adjustable thixotropy and setting time, a strong anti-scouring capability and a controllable diffusion range. Those remarkable grouting performance can overcome grouting problem in watery rock and soil strata, such as large grout consumption and unilaminar grouting veins [22].

![Figure 3. Illustration of the new grouting method.](image)

The grouting method of upstage with paste slurry packer and pulsating pressure is suitable for the highly permeable formation with geological defects, such as large fracture, carst cave, etc. The new grouting method effectively solves the technology problems (large grout take, grouting hole collapse, weak anti-seepage curtain) when grouting in the highly permeable formation.

4. Foundation curtain grouting methodology

Upstage with paste slurry packer and pulsating pressure is a fire-new grouting technology. The holes are drilled to their full depth in one stage. Clay-cement paste slurry with low strength and short setting time is used as a packer of grout hole before grouting. Grouts are grouted into grouting holes in sequence from lower stage to higher stage by a specialized full hydraulic continuously viable pulsating grouting pump. The grouting pump can make grout through one-way grouting device enter into stratum at a continuous and even flow rate by high instantaneous pressure pulse. Therefore, it also can avoid invalid perfusion and reduce waste material.

4.1. Drill holes

Layout of grouting holes is single row in the grouting project of Huwan mountain of Tuokou hydropower station. The grouting holes are in two order construction in accordance with the principle of points sequence encryption. Grouting was executed via fan holes spaced 2 m apart. Grouting holes are straight hole and with a minimum diameter of 56 mm. Geological drilling rig of XY-2 with diamond head is used to drill holes. It is difficult to drill holes in Huwan mountain because of its bad geological conditions. In addition, the problem of hole collapsing and chip off-falling occur frequently. In order to solve those problems, mud takes the place of water when drilling since mud can have the effect of retaining wall. At the same time, it is necessary to excavate a settling basin near drilling holes.
for recycling mud. Mud is reused and emissions of mud are reduced. The holes are drilled to their full depth in one stage. Every stage is about 10m to 30m. Grouting hole maximum depth is 160 m. Confined water head is over 60 m.

4.2. Grouting pressures
Grouting pressure is determined according to circannual grouting test results. Design requirements, formation condition and capacity of machines and equipment are the gist of determining drilling hole stage length. Every 10m to 30m is as a grouting period from bottom to top. The drilling hole stage length can adjust on the basis of geological flaw when encountering faultages, karst caves and other special geological section. The detailed grouting pressure of every stage is showed in table 2. Grouting pressure is controlled according to maximum pulsatile pressure in the porthole.

4.3. Grout mixes
Two types of grout mixture (clay-cement paste slurry and stable slurry) were used for the grouting operation. They were developed technically for anti-seepage grouting in Huwan mountain of Tuokou hydropower station. Comparing with the ordinary cement slurry, the new material owns many excellent performances, such as a larger initial viscosity, an adjustable thixotropy and setting time, a strong anti-scouring capability and a controllable diffusion range. Those remarkable grouting performance can overcome grouting problem in watery rock and soil strata, such as large grout consumption and unilaminar grouting veins.

The mix proportions of clay-cement paste slurry and stable slurry are shown in Table 3 and Table 4, respectively. The function of the paste slurry is to replace the traditional grouting plug to plug the grouting hole. The paste slurry should not be extruded out of the hole under the designed maximum grouting pressure. At the same time, it should ensure that the drill pipe can be successfully lifted without being locked. Therefore, the initial and final setting time of the paste slurry can be adjusted in 8-30min and 20min-7h respectively according to the site conditions. Moreover, the paste slurry must be flexible and the strength of the final setting should not be too high, in order to pull and lift the grouting pipe.

The clay-cement paste slurry is used to grout in red-bed primary grout holes, contact zone of red-bed and limestone, carst cave of limestone. The stable slurry is used in secondary grout holes and whole limestone primary grout holes. The cement-soil of clay-cement slurry grouted in red-bed is 1:1. 5, while grouted in limestone is 1:1.

| Project | Hore depth 1~15m | Hore depth 15~30m | Hore depth >30m |
|---------|-----------------|------------------|-----------------|
|         | \( P_{\text{max}} \) /MPa | \( V_{\text{max}} \) /L·m\(^{-1}\) | \( V_{\text{min}} \) /L·m\(^{-1}\) | \( P_{\text{max}} \) /MPa | \( V_{\text{max}} \) /L·m\(^{-1}\) | \( V_{\text{min}} \) /L·m\(^{-1}\) | \( P_{\text{max}} \) /MPa | \( V_{\text{max}} \) /L·m\(^{-1}\) | \( V_{\text{min}} \) /L·m\(^{-1}\) |
| Red section Primary grout holes | 2.0 | 500 | 4.0 | 300 | 2.5 | 450 | 4.5 | 250 | 3.0 | 400 | 5.0 | 200 |
| Red section Secondary grout holes | 3.0 | 400 | 5.0 | 200 | 3.5 | 350 | 5.5 | 150 | 4.0 | 300 | 6.0 | 100 |
| Limestone section Primary grout holes | 2.0 | 200 | 4.0 | 100 | 2.5 | 200 | 4.5 | 100 | 3.0 | 200 | 5.0 | 100 |
| Limestone section Secondary grout holes | 3.0 | 100 | 5.0 | 50 | 3.5 | 100 | 5.5 | 50 | 4.0 | 100 | 6.0 | 50 |

| Material | Cement | Clay | Water-solid radio | Modifier % |
|----------|--------|------|-------------------|------------|
| Paste slurry | 0.4~0.5 | 0.6~0.5 | 0.7~0.8 | 1~2 |
Table 4. Grout proportion of (The mix design of) the stable slurry

| Material              | Cement  | Clay   | Water-solid ratio | Standard funnel viscosity (s) |
|-----------------------|---------|--------|-------------------|------------------------------|
| Stable slurry         | 0.4~0.5 | 0.6~0.5| 0.7~0.8           | 20~30                        |

4.4. Grouting operation

The paste slurry packer is as a packer to block grouting stages in this new grouting technology [23]. It is the key technique of this method. Paste slurry packer is similar to the sleeve body material of sleeve-valve pipe grouting method [24]. Its role is to block space between grout pipe and hole wall in grouting stage. It has many fine properties, such as convenient perfusion, rapid hardening, stable performance after consolidation and reliable blocking effect. The detailed performance parameters are shown in Table 5. The closed process is shown in Figure 4. Firstly, the moderate paste slurry is grouted as packer according to the length of grouted stage. Secondly, the grouted holes are filled with paste slurry packer above the grouting section. Finally, grout and ascend grout tubes after paste slurry packer reach initial setting time.

![Grouting process](image)

Figure 4. Process of closing drill hole.

Table 5. The detailed performance parameters of Paste Slurry Packer material

| The mix design of grout (weight ratio) | Slurry and stone properties |
|---------------------------------------|----------------------------|
| Cement | Clay | Water-solid radio | Funnel viscosity(s) | Stone compressive strength(MPa) |
|---------|------|-------------------|--------------------|---------------------------------|
| 0.4~0.5 | 0.6~0.51 | 1.5~2 | 40~50 | 30 min<0.3 | 2 h<1 | 3 d<2 |

4.4.1. Grouting in soft layer. The grouting process is shown in Figure 5. The pulsatile high pressure is used to grout and compact the paste slurry after the paste slurry packer reaching initial setting time. Compare with traditional slurry, the paste slurry has a bigger cohesion and viscosity, a smaller fluidity, so it needs a higher grouting pressure. The pulsatile grouting frequency is about 10 to 20 times every minute. In the process of grouting, paste slurry can be stone quickly under pressure. It also can generate self-sealing effect and assist enhancing the sealing effect of paste slurry packer. After completion of the current stage, then lift grouting pipe and grout the next stage. Every stage’s length should be 0.5 m.

4.4.2. Grouting in conglomerate layer. The grouting process is shown in Figure 6. Continue to drill in conglomerate layer after accomplishing grouting in soft layer. When the paste slurry packer reaches initial setting time, conduct splitting grouting with stable slurry. The bleeding rate of stable slurry at 2 hours is less than 5%. At the same time, it has a fine mobility and stability. The pulsatile grouting frequency is about 50 to 70 times every minute. After completion of the current stage, then lift grouting pipe and grout the next stage. Every stage’s length should be 0.1m.
4.5. Refusal criteria
There are two refusal criteria in the process of grouting: i) the grout take exceeds the maximum volume and grouting pressure exceeds the minimum pressure; ii) the grout take is less than the minimum volume and grouting pressure exceeds the maximum pressure [25, 26]. When any refusal criteria appear, the grouting operation for the stage is considered to be complete. The minimum and maximum grouting pressures, the minimum and maximum volumes of grout take are shown in table 2. As shown in Figure 7, conduct hole sealing when all stages complete grouting. Grout stone and rock and soil mass constitute the new anti-seepage system after grouting.

5. Grouting analysis
5.1. Effect of the grouting project
The anti-seepage project of Huwan mountain of Tuokou hydropower station is examined by water pressure test in boreholes. The water pressure test was conducted 2369 stages in total. There are 2311 stages whose lugeon values are less than 5 Lu, and the percent of pass is up to 97.55%. According to technical specification for cement grouting of hydraulic structures (SL 62-2014), construction quality
can meet the engineering requirements when construction team have grouted again in stages with lugeon values exceeding 5 Lu. Furthermore, on the basis of grouting construction quality inspection, typical parts in weathered red bed are chosen to conduct fatigue pressure water test for 24～72 hours. The result shows that the permeability rate has a small undulation, and the maximum permeability rate is less than 5 Lu when the pressure is 1.2 times of design pressure. It indicates that the curtain body carrying capacity is stronger and its durability can meet the requirements.

There are 2231 grouting holes in the anti-seepage project of Huwan mountain of Tuokou hydropower station. The accumulated grouting depths of the anti-seepage project are up to 169650.53 m. Comparing with traditional grouting technologies, the new grouting technology (upstage with paste slurry packer and pulsating pressure) used in the anti-seepage project of Huwan mountain can save hundreds of millions of dollars.

5.2. The problems and treatments in the new technology of grouting construction
The new grouting technology encountered the following problems in the construction process of Huwan mountain of Tuokou hydropower station, and the corresponding treatment measure were conducted after finding out the reason.

5.2.1. Losing efficacy of the paste slurry packer. The strength of the paste slurry packer is under capacity when encountering the grounds suffering from water soaking or scouring. It cannot meet the effect of blocking the grouting stages. Its treatment is adjusting the material prescription of the paste slurry packer. The air hardening cementitious materials was replaced by a hydraulic binding material.

5.2.2. Grout pipe plugging by grouts. Pipe plugging appears several times at the beginning of the grouting construction, and brings about hindering of the next stage grouting. The main reason is that laborers didn’t grasp setting and hardening characteristics of grouts adequately. After directing of specialists on the spot, the setting time of grouts is mastered. The grout constituents whose effect is to make grout rapid hardening and early strength is joined the blender when they are about to grouting.

5.2.3. Pipe-holding. At the beginning of the grouting construction, the grouting pipe always cannot be lifted because they was gotten stuck by hardened grouts. On the one hand, adjust the material prescription of the paste slurry packer, and make rapid hardening and early strength constituents in an appropriate proportion; on the other hand, rotate grouting pipe constantly in the process of grouting construction.

5.2.4. Large grout taking. The grout take is up to 10 m$^3$ per metre; however, it still cannot meet the refusal criteria when encountering carst caves or big voids. The treatment is that clay-cement paste slurry takes the place of stable slurry.

6. Conclusions
Karst mineralization formation is widely distributed in Huwan mountain of the Tuokou hydropower station. The traditional technologies grouting in this stratum can encounter several problems that grout take of grouting in red bed is very large, and the anticipative grouting effects can’t be reached in red bed.

A new grouting method, upstage with paste slurry packer and pulsating pressure was presented. A new grouting material (clay-cement slurry) which can be adjustable, controllable and groutable according to the change of formation was carried out. The permeability rate has a small undulation, and the maximum permeability rate is less than 5 Lu when the pressure is 1.2 times of design pressure. It indicates that the curtain body carrying capacity is stronger and its durability can meet the requirements.

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