Engineering properties and slope failure mode of Karst Breccia

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Abstract. Karst Breccia is the secondary action product of carbonate rocks on surface or near surface. In addition to the properties of soil, the Karst Breccia slope material also form sedimentary structure or inherit the original rock structure during diagenesis. The Karst Breccia is widely distributed in the dam site of a power station in Wujiang River, which is produced in the upper part of Member 4 of the Lower Triassic Jialingjiang Formation (T1j4-2), and the maximum height of the slope is about 180m after excavating. By studying the basic characteristics and engineering characteristics of Karst Breccia, the failure modes of the Karst Breccia slope can be summed up as three basic failure modes: plane sliding failure, collapse failure, and circular arc sliding failure. Moreover, the Karst Breccia has both the engineering characteristics and structural characteristics of soil and rockmass. The failure mode of the Karst Breccia slope is also more complicated, and there is a combined failure mode: circular arc - plane failure mixed-mode.

1. Introduction
Karst Breccia is the product of secondary action of carbonate rocks on the surface or near the surface. When the carbonate rocks are exposed to the surface or near the surface, these rocks will be dissolved and leached by the surface water or ground water, then the top and bottom of karst caves collapse, disintegrate, and break up because of the loss of support, and the collapsed materials form the Karst Breccia after re cementing. Therefore, the breccia formed by the collapse of the top wall of karst cave can often be seen in the carbonate rocks area where the groundwater is active[1].

The Karst Breccia rocks have developed and widely distributed in different geologic historical periods. The most developed era of the Karst Breccia is Ordovician, Triassic, Cambrian and Tertiary, followed by Jurassic, Cretaceous. Because of the difference of the material composition, weathering state and structural characteristics of the Karst Breccia to the common karst rocks, the engineering geological problems in engineering construction can not be considered as general karst geological problems[2].

From mechanical strength, the Karst Breccia belongs to extremely soft rock series, it is a kind of soft rock - hard soil [3]. This kind of special soft rock and hard soil has extremely special engineering and mechanical properties. If improper treatment, it will bring extremely serious harm to the project[4, 5].

From the data collected at present, the research on the engineering characteristics of the Karst Breccia is very few [5]. In order to ensure the construction and structure safety, the engineering characteristics of the Karst Breccia in the dam site area are deep studied in the feasibility study stage of a hydropower station in Wujiang River, and the failure mode of the Karst Breccia slope is analyzed to provide the basis for the slope design.
2. Basic characteristics of Karst Breccia slopes

The dam site of a hydropower station is located in Wujiang River, which is one of the primary tributaries of the Yangtze River, the largest rivers in China. The left bank slope of this hydropower station is mainly composed of Karst Breccia. The lower part of the original topography is slow, with the lower dip is 25°~30°, and the upper terrain dip is 33°~37°.

The surface vegetation is better, and the natural slope is in equilibrium and stable, there is no sign of damage. According to the layout of the hydropower station, it is necessary to excavate the slope of the left bank, the maximum building slope is as high as 180 m, the slope direction is NE56°, and the slope surface tends to NW.

3. Basic properties of Karst Breccia

3.1. Lithologic characteristics of Karst Breccia

The Karst Breccia strata in the dam site of this hydropower station is the upper part of member 4 of the Jialingjiang Formation in the Lower Triassic(T1j4-2), and the output horizon is stable. Karst Breccia can be divided into two layers according to lithology difference:

A. The upper layer is gray-yellow, brown-yellow, pinch a small amount of light gray, gray, mainly argillaceous cementation. The breccia diameter is relatively different, the grinding roundness is poor;
B. The lower layer is dark-gray, gray-black, and the bottom part contains gypsum lensing, with calcium or calcium-argillaceous cementation mainly, a small amount of cementation is semi diagenetic, and the grain size of breccia is relatively homogeneous, with relatively good grinding roundness.

The thickness and distribution of the upper and lower layer of Karst Breccia in T1j4-2 strata are unstable, the total thickness is generally about 52m, the local thickness varies greatly, the top and bottom interface fluctuates.

3.2. Material composition characteristics of Karst Breccia

The angular gravel of the Karst Breccia in the dam site area is the same as that of the surrounding rock, which is mainly gray-light grey limestone, muddy limestone, dolomite, dolomite limestone and so on. The breccia is distinct in shape and large in size; the size of the breccia is different from a few centimeters to a number of meters, and the size of gravel is mixed, no separation, and a local angle. The original sedimentary characteristics are also maintained in the local angular gravel. Some gravel has smaller angular gravel, which reflects the multiple nature of the Karst Breccia formation.

Gypsum lens is included in the bottom of the Karst Breccia strata. The existence forms of gypsum in rock mass are scattered in the form of star spots, irregular clumps, textured, very thin layers to thin layers, fissures, veins, and cemented matter. Gypsum, formed by cementation of CaCO3 and CaSO4 brought by later groundwater, is well cemented and relatively strong.

Due to the influence of the cements composition on the whole character of the Karst Breccia strata, the chemical composition analysis and the rock mineral composition were carried out during the feasibility study on the Karst Breccia cemented, also known as the cementing material between the gravel, that is, the filling material between the gravel. The test results are shown in Table 1 and Table 2.

| Sample number | SiO2 (%) | Al2O3 (%) | TiO2 (%) | MgO (%) | CaO (%) | Na2O (%) | K2O (%) | TiO2 (%) | P2O5 (%) | MnO (%) | Loss of PD (%) |
|---------------|----------|-----------|----------|---------|---------|----------|---------|----------|----------|---------|----------------|
| PD1-Y1        | 25.14    | 4.51      | 1.71     | 11.11   | 27.36   | 0.058    | 1.06    | 0.27     | 0.046    | 0.016   | 28.28          |
| PD1-Y2        | 21.55    | 4.57      | 1.78     | 6.38    | 33.72   | 0.038    | 0.63    | 0.25     | 0.039    | 0.016   | 30.60          |
| PD1-Y3        | 20.43    | 2.33      | 1.19     | 8.29    | 35.60   | 0.042    | 0.58    | 0.13     | 0.025    | 0.008   | 30.96          |
| PD1-Y4        | 27.53    | 14.36     | 8.45     | 1.74    | 21.06   | 0.046    | 1.68    | 1.02     | 0.12     | 0.018   | 23.68          |
Table 2. Results of rock mineral composition analysis (Diffraction Method) for the Karst Breccia (cements)

| Sample number | Analysis items and results |
|---------------|---------------------------|
|               | Montmorillonite /% | Chlorite /% | Illite /% | Talcum /% | Quartz /% | Calcite /% | Dolomite /% |
| PD1-Y1        | 27              | -            | 8         | 3         | 7        | 40         | 15          |
| PD1-Y2        | 23              | 2            | 6         | -         | 14       | 55         | -           |
| PD1-Y3        | 38              | -            | 7         | -         | 5        | 50         | -           |
| PD1-Y4        | 50              | 5            | 5         | 5         | -        | 35         | -           |

It shows that the burning loss of gray and gray-black Karst Breccia cements is high, reaching 28.28% to 30.96%, indicating that the content of H2O, CO2 or organic matter in the chemical composition is higher. The identification results of rock and mineral composition indicate that the cementation of the Karst Breccia mainly consists of clay minerals (montmorillonite, illite, etc.) and calcite.

Based on the analysis of geological surveying, exploration results and test results, the Karst Breccia of the dam site is mainly 80%~95% with muddy cementation and poor cementation, and the Karst Breccia with calcareous cementation and relatively good cementation is 5% to 20%.

4. Engineering characteristics of Karst Breccia

4.1. Weathering characteristics of Karst Breccia
According to the difference of weathering degree, the Karst Breccia in the dam site can be divided into three types: completely weathered, heavily weathered, and non weathered.

The completely weathered Karst Breccia, which original rock structure has all been completely destroyed, mainly composes of clay, and contains a small amount of minor fragments of dissolved residual of primary carbonate breccia. The physical and mechanical properties of the completely weathered Karst Breccia are similar to that of gravel clay, and can be evaluated the engineering properties according to the ordinary clay.

The heavily weathered Karst Breccia, which original rock structure has all been basically destroyed, mainly composes of clay and residual angular gravel. When the water content is large, the heavily weathering Karst Breccia is a mud-stone mixed structure, which can be evaluated the engineering performance by reference to gravel soil.

The non weathered Karst Breccia is a hard breccia. The engineering properties of the Karst Breccia rock mass are similar to calcareous cemented breccia limestone or breccia dolomite, which can be evaluated the engineering properties by reference to breccia limestone and breccia dolomite.

4.2. Structural characteristics of Karst Breccia
The Karst Breccia is gravelly soil on the surface, but also develops weak structural planes. These structural planes can be either the primary sedimentary formations or the superficial ones. They are characterized by macroscopically connected weak planes, revealing structural planes or subtle structural planes.

The Karst Breccia has different forms of cementation and also has different structural types. The Karst Breccia with muddy cementation is mainly composed of fragment structure, partly clastic structure, which is a rock block or muddy substance, the rock mass is broken and the chimerism is relaxed. The rock masses mainly composed of calcareous cementation and strong cementation are mostly fragmented-mosaic structures. At the same time, due to the action of water flow during deposition, the rock mass also has bedding structure locally.

Overall, the Karst Breccia in the dam site is more granular after weathering near the surface; It can form of steep cliffs at the top of the mountain or the anticline core etc., and has mosaic structure. With long-term immersion by karst groundwater in certain depth underground, dissolution and consolidation diagenesis, the Karst Breccia has bedding structure, and forms of gypsum layer lens body in the local deep underground.
4.3. Physical and mechanical properties of Karst Breccia

According to the seismic wave test results, the wave velocity of the Karst Breccia distributed in the dam site is obviously low, generally less than 2000 m/s, which is basically similar to the gravel soil of Quaternary.

According to the field shear test and rock mass deformation test etc., the saturated uniaxial compressive strength of the Karst Breccia is 0.14~2.2 MPa, belongs to the extremely soft rock; the shear strength, c=0.02~0.30 MPa, f=0.30~0.55. The shear strength parameter can be taken great value in natural state, and the strength will be reduced sharply under the condition of saturation, then the strength parameter need to be taken the lower value in saturated state.

Under different cementation types, the Karst Breccia has obvious differences in strength. For example, the calcareous cemented Karst Breccia has relatively great strength, while the strength of the muddy cementation or calcareous muddy cemented breccia is relatively low. In addition, influenced by karst corrosion and weathering, the strength and engineering geological characteristics of the Karst Breccia are also very different. For example, the Karst Breccia with strong erosion and strong weathering in the shallow surface is looked as the gravel soil with bad character; the Karst Breccia with local semi diagenesis in a certain depth of the surface has a certain cementation, and the engineering geological characteristics is relatively good.

5. Failure mode of Karst Breccia slope

5.1. Basic mode of slope failure

Through analyzing the engineering characteristics of the Karst Breccia, the failure modes of the Karst Breccia slope can be summed up as three basic failure modes: plane failure, collapse failure, and circular arc failure.

(a) Plane Sliding

This kind of failure mode is mainly controlled by the remaining or hidden structural planes in the slope, such as the local residual level and the joint surface control (Figure 1, a). It is not directly related to the height of the slope, mainly depends on the spatial combination of the surface and the structural plane of the slope and the shear strength of the weak surface. This kind of slope failure occurs mostly in the rainy season. The rainfall makes the structural surface soften further. The original cracks of the slope rock mass expand or produce new cracks, gradually disintegrating and sliding out along the structural plane.

(b) Collapse Destruction

It means the wedge body (block) collapse by the combination of fault, fissure, rock layer and other structural planes and cutting excavation. When the structure of the Karst Breccia slope is inclined to the free face with a large angle and close to vertical, the excavation of the slope can easily cause collapse and destruction. When the slope is excavated, the upper part of the steep structure is opened.
because of the unloading effect (Figure 1, b). The upper part of the slope is filled with water when it rains. Because of the action of dynamic and static water pressure, the soil of the weak surface overturns to the free face, resulting in collapse and destruction. In addition, rainfall will also lead to a sharp decrease in strength of rock mass, which will lead to disintegration and collapse of slope surface rock mass.

(c) Circular Arc Sliding

The Circular Arc Sliding mode is the basic failure mode of homogeneous cohesive soil slope. When the structural plane of the Karst Breccia slope is tilted against, it doesn't control the failure of the slope, the slope will be destroyed with circular arc sliding. The other case is that the Karst Breccia is further weathered into soil like slopes under various geological conditions without obvious structural planes (Figure 1, c).

5.2. Combined failure mode of Karst Breccia slope

The Karst Breccia has both the engineering and structural characteristics of soil and rock mass, and the failure mode of the Karst Breccia slope is also more complex. In addition to the 3 basic failure modes, there are more complex combination failure modes. Most of these slope failure planes are the combination of plane (structure plane) and circular arc (Figure 2).

The structure planes of the slope have a considerable control effect on the slope stability, so that the form of the failure of the Karst Breccia slope is distinctly different from the circular arc failure of the homogeneous soil slope. The slope stability and failure mode are mainly controlled by the outward structural plane when there is an outward camber structure and a good extensibility in the slope.

Figure 2. Schematic diagram of combined failure mode

On the section, the upper part of the sliding plane is a circular failure section, and the lower part is a straight sliding section (Figure 2, a). The lower plane failure section is usually less than 30°, and it is easy to become the shear outlet of sliding soil on the slope surface. The closer to the lower side of the slope, the weathering degree of the original rock is relatively low, and the control of the structure is more obvious, and the weathering interface of different degrees can also form a part of the sliding surface. In the upper part of the slope, the weathering degree of the soil is deep, and the mechanical control characteristics of the structure surface are weak, and the structure surface is gently inclined, the sliding force along the structural plane is weak, so the shape of the middle upper part of the slide surface is more easy to form the circular arc of the homogeneous soil, thus forming a straight slip form under the upper circle.

When the slope develops structural plane gently inclined to the slope, such as faults and long crevice, may also form a shear exit at the bottom plane sliding (see Figure 2, b). When a group of extroverted structural planes are developed in the slope, the structural planes is joined by the circular arc failure of the rock mass to form a through slip failure plane (Figure 2, c).

Influenced by weathering and karst erosion, the development of the structural planes such as faults and long cracks in the Karst Breccia is more complex, and it is not easy to find by exploration means. When the slope is destroyed by combined type, the scale is often larger and the harm degree is greater.
6. Conclusions

(1) In addition to the soil properties, the Karst Breccia slope media also forms new structures or inherit the structural characteristics of the original rock during diagenesis.

(2) According to the difference of weathering degree, the Karst Breccia in the dam site can be divided into three types: completely weathered, heavily weathered, and non weathered.

(3) The failure mode of the Karst Breccia slope is mainly controlled by the cementation composition and cementation degree of the Karst Breccia.

(4) According to the engineering characteristics of the Karst Breccia slope, the failure modes of the Karst Breccia slope can be summed up as three basic failure modes: Plane Failure, Collapse Failure, and Circular Arc Failure.

(5) The Karst Breccia has both the engineering and structural characteristics of the soil and rockmass, The failure mode of the Karst Breccia slope is also more complicated, and there is a combined failure mode: Circular Arc - Plane Failure mixed-mode.

References

[1] Hu Wenshou, Yu Junqing 2003 Engineering characteristic study of Gypsum Breccia J. Chang’ an University (Earth Science Edition), 25(1) pp 37-41
[2] Wei Dongyan 1991 On the characteristics and classification of evaporite-solution breccia in China ACTA Petrologica Sinica 1991(3) pp 73-79
[3] Wang Liwei, Li Wenjiang, Zhu Yongquan 2007 Monitoring and analysis of construction in Gypsum Breccia region of Taihang Mountain Tunnel J. Shijiazhuang Railway Institute (Natural Science) 20(3) pp 10-14
[4] Zhu Zhengguo, Zhu Yongquan, Cao Huiqin, etc. 2015 Comprehensive reinforcement effect and foundation base stability of water-rich breccia karst tunnel J. China Railway Science 36(4) pp 60-66
[5] Cao Huaping 2004 Dentification and geological characteristics of salt solution breccia in Moxi to Baitao section of Chongqing-Huaihua Railway J. Railway Investigation and Surveying, 2004(03) pp 58-60